CHAPTER-1

ADVANCED CONSTRUCTION MATERIALS

Technology is evolving at a very fast rate and keeping pace with the advancement of research and invention, the conventional materials of construction are increasingly being replaced by more advanced and modern materials of construction having better or desirable engineering properties. The pertinent characteristics may be durability, resistance, aesthetic or economic as the case may be, sometimes with assured or guaranteed performance. Of the modern materials of construction, the most widely used ones are fibres, plastics, artificial timber and a lot of miscellaneous materials.

1.1 Fibres

Fibres are thin philaments of materials of varying strength and physical properties used in different engineering applications. These may be of natural origin or artificially manufactured with desirable properties or required characteristics. Steel, carbon, glass fibres and synthetic fibres such as polypropylene fibres, fibre composites are in common use now-a-days. They can be used in isolation as well as for reinforcement or in composites as per requirement. Some of the artificial fibres are disused here.

1.1.1 Steel fibres

Steel fibres are short, discrete lengths of steel with an aspect ratio from about 20 to 100 and with any one of several cross sections. Some steel fibres have hooked ends to improve resistance to pull out from a cement-based matrix. Various types of steel fibres like Hooker end steel fibres, Round steel fibres and Flat crimped steel fibres etc. are available as shown in the Fig.1,2 & 3.

Manufacture of steel fibres

Generally steel fibre is cold down steel wire crafted from high quality low carbon steel or it could be manufactured by other methods such as a by product during processing of steel. Thus, steel fibres can be divided into four groups depending upon the manufacturing process viz. cut wire (cold down), slit sheet, melt extract and mill cut.

Various properties of steel fibres

Some important properties of steel fibres are given in the following table.

Table-1

Properties of steel fibre

Properties	**Value**
Relative densit y	7.80
Diameter, μ	100-1000
Tensile strength, MPa	500-2600
Modulus of elasticity, MPa	210,000
Strain at failure, %	0.5 to 3.5

Advantages of steel fibre

The following are the advantages of steel fibre as a construction material.

a) It is user-friendly for handling and faster in application.

b) There is considerable saving of material when used as fibre compared to its use as rebar.

c) It results in excellent ductility and durability.

d) Use of fibre leads to less rebound and voids.

e) It gives rise to safer working environment through the use of short creting robots.

f) It is amenable to easy mixing and easy guniting.

g) It induces ideal fibre bond as well as excellent refractory characteristics with increased life span.

h) Its use results in superior resistance to high temperature corrosion.

i) It exhibits consistent strength at all temperatures.

j) It leads to indirect cost saving by means of increased life.

Disadvantages of steel fibre

a) The presence of steel fibre on the surface may affect the optics.

b) When cutting the slip joints, the isolated fibres are torn.

Use of steel fibres as a construction material

The area of application of steel fibres is vast. It's primary use is as a reinforcing material in steel fibre reinforced concrete (SFRC) and steel fibre reinforced shortcrete (SFRS) i.e. spray concrete with added steel fibres. Now-a-days, even stainless steel fibres designated as SS304 and SS310 having non-magnetic properties are in demand for use in refractory linings, bricks and walls. Besides, the steel fibres are used in tunnel linings, retaining walls, piles, road concrete or roller compacted concrete, pre-cast concrete and machine foundations.

Steel fibres when mixed with concrete increases the flexural strength of the composite appreciably depending upon the proportion of fibre added and the mix design. Although the workability of concrete is affected due to addition of fibres, the risks of cataclysmic failure of concrete effectively lowers down because of the fibres which continue to support the load even if any crack occurs. It exhibits higher post crack flexural strength, better crack resistance, higher resistance to spalling and improved fatigue strength.

Use of steel fibres in concrete can improve its various properties and result in a number of benefits as given below.

i) Uniform distribution of steel fibres are possible throughout a given cross section where as the reinforcement rebars or wires can be placed at a particular location / depth.

ii) Steel fibres, even in low volume dosages (often less than 1%) have been shown to be effective in reducing plastic shrinkage cracking.

iii) It increases crack, impact and fatigue resistance and improves toughness by preventing / delaying crack propogation from micro-cracks to macro-cracks.

iv) It helps in reducing localized stresses, reduce in maintenance and repair cost, provide tough and durable surfaces etc.

v) It acts as a crack arrestor, reduces surface permeability, dusting, wear and tear in SFRC.

vi) It indirectly results in cost saving owing to increased tensile strength, resistance to impact, freezing and thawing etc.

The steel fibre reinforced short crete (SFRS) has higher tensile strength than unreinforced shortcrete and is quicker to apply than weld mesh reinforcement and that is why it is often used in tunnels. Addition of randomly distributed steel fibres improves the ductility capacity in all possible directions and thus is one of the reasons why steel fibre reinforced (shortcrete form) concrete successfully replaced weld mesh in lining tunnels. It saves in terms of labour requirement and construction time. SRFS has various applications depending upon situations. However, short steel fibres are used in tunnels whereas long steel fibres are used in industrial floorings.

1.1.2. <u>Carbon fibre</u>

Carbon fibres are a type of high performance artificial fibre available for engineering application. It is also called graphite fibre or carbon graphite. Carbon fibres are organic polymers, characterized by long strings of molecules bound together by carbon atoms in the form of crystals that are more or less aligned parallel to the long axis of the fibre as the crystal alignment gives the fibre high strength to volume ratio. Carbon filaments are typically between 5 and 8 micron in diameter and are combined into tows containing between 3000 to 12000 filaments. The tows are twisted into yarns and woven into fabrics.

Carbon fibres have high tensile strength and are very strong for their size. In fact, carbon fibre might be the strongest material having very high elastic modulus and fatigue strength compared to other artificial fibres. Carbon fibres are twice as stiff as steel and five times as strong as steel (per unit weight). The most important factors determining the physical properties of carbon fibres are the degree of carbonization (carbon content, usually more than 92% by weight) and the orientation of the layered carbon planes (the ribbons). Considering service life, studies reveal that carbon fibre reinforced polymers have more potential than agamid and glass fibres. They are also highly chemical resistant and have high temperature tolerance with low thermal expansion and corrosion resistance.

Manufacture of carbon fibres:-

Carbon fibres are manufactured by controlled pyrolysis and cyclisation of certain organic fibre precursors (the raw materials used to make carbon fibre). Depending upon the precursor to make the fibre, carbon fibre may be turbo static or graphitic or have a hybrid structure with both graphitic and turbo static parts present. In turbo-static carbon fibre, the sheets of carbon atoms are haphazardly folded, or crumpled together. Carbon fibres derived form polyacrylonitride (PAN) are turbo static, whereas carbon fibres derived from mesophase pitch are graphitic after heat treatment at temperatures exceeding 2200^0C. Turbo static carbon fibres tend to have high tensile strength, whereas the heat-treated mesophase-pitch-derived carbon fibres have high Young's Modulus (i.e. high stiffness or resistance to extension under load) and high thermal conductivity.

Carbon fibres are usually combined with other materials to form a composite. When combined with a plastic resin and wound or molded it forms carbon fibre-reinforced polymer (often referred to as carbon fibre) which has a very high strength-to-weight ratio, and is extremely rigid although some what brittle. However, carbon fibres are also composited with other materials, such as with graphite to form carbon-carbon composites, which have a very high heat tolerance.

Various properties of steel fibres:-

Some important physical properties of carbon fibres are given in the following table.

Table-2

Properties of carbon fibre

Properties	Value
Diameter	5 to 8 μ
Tensile strength, MPa	3500-5200
Modulus of elasticity, GPa	260-450
Ultimate strain, %	0.78 to 1.93
Specific strength, KN.m/Kg	2450
Relative density	1.6 to 1.8

Advantages of carbon fibre:-

The properties of carbon fibres, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion make them very suitable for engineering, military and sports use. The following are the main advantages of carbon fibres as a construction material.

i) It has high specific strength i.e. strength to weight ratio that makes it possible to build higher components.

ii) It has high value of rigidity or stiffness. Carbon fibre reinforced plastic is over 4 times stiffer than glass reinforced plastic.

iii) Carbon fibre is corrosion resistant and chemically stable.

iv) It is electrically conductive and this feature can be useful where it has to be taken into account just as aluminium conductivity comes into play.

v) Resistance to fatigue in carbon-fibre composites is good and failure is unlikely to be a problem when cyclic stresses coincide with the fibre orientation.

vi) Carbon fibre has good tensile strength or high ultimate strength.

vii) It is fire resistant and chemically inert so that it is often integrated into protective clothing for fire fighting where there is fire combined with corrosive agents.

viii) Low coefficient of thermal expansion of carbon fibres makes it suitable for applications where small movements can be critical such as telescope and other optical machinery.

Disadvantages of carbon fibre:-

i) Carbon fibres are relatively expensive compared to similar fibres such as glass or plastic fibres.

ii) Electrical conductivity of carbon fibre may facilitate galvanic corrosion in fittings and cause short circuits.

iii) Carbon fibre being brittle fails catastrophically without much warning.

Use of carbon fibre as a construction material:-

Carbon fibres have revolutionized the technology of a wide array of construction materials in Civil Engineering, military, sporting goods, medical instruments and automobile industry. Also carbon fibre plates are thin, strong and flexible so that they can be designed and installed to provide a cost effective solution which does not detract visually from the original design of the structure. So use of carbon fibre in the field of construction is always effective and provide high strength to the structure.

Following are the major application of carbon fibres.

a) **Civil Engineering:-** Several structural engineering applications make use of carbon fibre reinforced polymer because of its potential construction benefits and cost effectiveness. The usual applications include strengthening structures made up of concrete, steel, timber, masonry and cast iron; retrofitting to increase the load capacity of old structures like buildings or bridges; to enhance the shear strength and flexural resistance of reinforced concrete members. Other applications include replacement for steel, prestressing materials and strengthening cast-iron elements.

b) **Aerospace industry:-** Carbon fibre has found its use on spacecraft but is widely used in aircraft components and structures where its superior strength to weight ratio far exceeds that of any metal. From helicopters to gliders, fighter jets to micro-lights, carbon fibre is playing its part, increasing range and simplifying maintenance.

c) **Sporting goods:-** Its application in sports goods ranges from the stiffening of running shoes to ice hockey sticks, tennis racquets to golf clubs. Shells (hulls for rowing) are built from it and in motor racing circuits by its strength and damage tolerance in body structures. It is also used in crash helmets for rock climbers, horse riders and motor cyclists; in fact in any sports where there is danger of fatal injury.

d) **Military:-** The application of carbon fibres in military ranges from planes and missiles to protective helmets, providing strengthening and weight reduction of equipments. Perhaps the latest and most exotic military application is for small flapping wings on miniaturized flying drones used for surveillance missions.

e) **Household articles:-** The uses of carbon fibres in household articles are both for living styles or practical applications. Shiny black bath tubs, coffee tables, i Phone cases, pens and even bow ties can be made from it.

f) **Medical appliances:-** Carbon fibre offers marked advantages over other materials in the field of medical science despite being radiolucent (transparent to

X-rays). It is used widely in imaging equipment to support the limbs being x-rayed or treated with radiation. But the most well known medical use of carbon fibre is that of prosthetics i.e artificial limbs.

g) **Automobile industry:-** Now-a-days, with reduction in cost, carbon fibres are increasingly being used in automobile sector, starting from super car bodies to internal components such as instrument housing and seat frames.

Besides the above, carbon fibr finds its application in textiles (carbon fibre filament fabric), fabrication of micro-electrodes, for catalysis, synthesis and delivering infrared heating.

1.1.3. Glass fibres:-

Glass fibre is also other wisely known as fibre-glass. It is a material made from extreamly fine fibre of glass. Fibre glass is a light-weight, extremely strong and robust material. Although, its strength properties are somewhat lower than carbon fibre; being less stiff and typically far less brittle, the raw materials are much less expensive too. As compared to metals, its bulk strength and weight properties are also very favourable and it can be easily formed using moulding processes. Of courses, glass fibre is the oldest and most familiar performance fibre.

Manufacture of glass fibre:-

Glass fibres are manufactured by drawing molten glass from an electric furnace through plantinum brushings at high speed. The filaments cool from the liquid state at about $1200^{0}C$ to room temperature in 10^{-5} seconds. Then it is treated with a lubricant to reduce the abrasive effects of the filaments against one another and to minimize the damage to the fibres during mechanical handling. About 200 filaments are bundled together to form a strand and the strands of glass fibre are combined together to form thicker parallel bundles called rovings which when twisted form several types of yarn, which can be used individually or in the form of woven fabric. These can be used in a number of different forms and manner to achieve desired engineering properties.

Use of fibre glass as a construction material

The following types of glass fibre are the major ones used in construction.

i) **A-glass fibre:-** It has high alkali content and used in the aircraft industry and for special manufactured articles in Civil Engineering. With regard to its composition, it is close to window glass and extensively used in the manufacture of process equipments. (Fig.)

ii) **E- glass fibre:-** It is of low alkali content and is the commonest glass fibre in the market being the major one used in the composites in the construction industry. It is used with polyster resin in the manufacture of radoms-a structural weather roof enclosure that protects radar equipment. Also it is now being widely used with vinyl ester and epoxy resin. This kind of glass combines the characteristics of C-glass with very good insulation for electricity. (Fig.)

iii) **C-**glass:- This kind of glass shows better resistance to chemical attack. (Fig..)

iv) **AE-glass or Z-glass (Zircona glass):-** These are alkali resistant glass. They were developed for reinforcing cement, mortar and concrete products because of their high resistance to alkali attack.(Fig.)

v) **S2-glass fibre:-** It is used in extra-high strength and high modulus applications especially in aerospace and on occasions in Civil Engineering.

Of course the area of application of glass fibres is vast that encompasses air craft and aerospace industry, equipment manufacture, civil constructions, resistant pipes, marine accessories, protective gears, industrial tools and what not.

Various physical properties of different glass fibres:-

Table

Properties of glass fibres

Properties /particulars	E-glass	AE-glass	S-glass
Tensile strength (GPa)	3.5	3.5	4.6
Modulus of elasticity (GPa)	73.5	175	86.8
Elongation (%)	4.8	2	5.4
Density (g/cc)	2.57	2.68	2.46
Refractive index	1.547	1.561	-
Coefficient of thermal expansion ($10^7/^oC$)	50-52	75	23-27
Dielectric constant RT, 10^{10}Hz	6.1-6.3	-	5.0-5.1

Advantages of glass fibre

i) Its high strength and light weight property render a favourable strength to weight ratio.

ii) It is corrosion resistant and chemically inert resulting in increased life span.

iii) Both electrical and magnetic non-conductive characteristic makes it amenable for use in measuring instruments.

iv) It can be easily assembled and its low maintenance cost makes it economical.

v) It is fire resistant and so used in fire fighting jackets and protective barriers or partitions / covers.

vi) It being transparent finds its use in optical and construction field.

vii) It dimensional stability characteristic makes it suitable for use in precision equipments.

Disadvantages of glass fibres

i) It has low modulus of elasticity compared to other reinforcing fibres.

ii) Fatigue resistance of glass fibres is low relative to carbon fibres.

iii) It is susceptible to stress corrosion.

iv) When machined, it exhibits high abrasive character.

v) In comparison to other reinforcing fibres,it possesses higher weight.

Polypropylene fibre:-

Of the synthetic fibres, the important ones for upgrading cements and mortars or for use in reinforced earth situations are polypropylene, polyethylene, polyester and polyamide. The first two are utilized in the manufacture of cement / mortar composites; but all are used in geosynthetics, especially to form geotextiles and geogrids. Synthetic fibres are the only ones that can be engineered chemically physically and mechanically to suit particular geotechnical engineering applications.

Polypropylene is the first stereo regular polymer to have achieved industrial importance. Initially the polypropylene fibres were introduced in the textile areana and have become an important member of the rapidly growing family of synthetic fibres. Today, polypropylene enjoys the fourth spot behind the big three fibre classes i.e. polyester, nylon and acrylic. However, as opposed to other commodity fibres, its use as apparel and household textiles has been rather limited; the bulk of the fibre produced is used for industrial applications.

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Manufacture of synthetic fibres

The manufacture of synthetic fibres commences with the transformation of the raw polymer from solid to liquid either by dissolving or by melting. Then a spinneret consisting of many holes is used to extend the liquid polymer, which is then solidified into continuous filaments. The filaments undergo further extension in their longitudinal axes, thus further increasing the orientation of molecular chain within the filament structure, with a consequent improvement in the stress-strain characteristics. Thus, different types of synthetic fibre or yarn may be produced including mono filament fibres, hetero filament fibres, multi filament yarns, staple fibres, staple yarns, split film tapes and fibrillated yarns.

Various properties of polypropylene fibre

Table

Properties of polypropylene fibre

Properties / characteristics	**Value**
Elongation (%)	40 to 100
Abrasion resistance	Good
Moisture absorption (%)	0 to 0.05
Softening point (^{0}C)	140
Melting point (^{0}C)	165
Chemical resistance	Excellent
Relative density	0.91
Thermal conductivity	6.0
Electrical insulation	Excellent
Resistance to insects (mildew, moth)	Excellent

Advantages of polypropylene fibre:-

i) **High specific strength** It is a light fibre, its density $0.91 gm/cm^3$ is the lowest of all synthetic fibres which is responsible for high specific strength.

ii) **Non absorption of moisture** It does not absorb moisture, which means the wet and dry properties of the fibre are identical. Its low moisture regain helps in quick transport of moisture as is required in some special applications.

iii) **High chemical resistance** It has excellent chemical resistance being resistant to most acids and alkalies.

iv) **Low thermal conductivity** The thermal conductivity of polypropylene fibres is lower than that of other fibres and may be used in applications as thermal wear.

Disadvantages of polypropylene fibre:-

i) **Low melting point:-** Its low melting temperature prevents it from any kind of heat treatment.

ii) **Poor adhesive property:-** Its adhesion is very poor to glues and latex.

iii) **Poor resilience:-** Its resilience is poor compared to other synthetic fibres.

iv) **Poor thermal stability:-** Due to poor thermal stability, it requires additions of expensive stabilizers to overcome this problem.

Use of polypropylene (PP) fibre as a construction material:-

Polypropylene fibre finds wide application in the diverse field of engineering. When added to cement mortar, it can be advantageously used in a variety of applications like cement rendering, stucco work, texture coating, machinery base bedding, tunnel lining, low cost housing, water tank and reservoir construction, mould filling(blocks, panels, architectural profiles etc.), slab jacketing (sunken floors, roads etc.), swimming pool finishing, creation of artificial park / theme part etc. as well as fire proofing. Pre-mixed polypropylene fibre reinforced ready-to-use cement based mortar can be effectively used for crack free external as well as internal plaster. The use of cement compatible polypropylene fibre reinforcement reduces drying shrinkage and other cracks in concrete also. Thus, PP ensures waterproof, reduced crack-free structures of consistent quality. Also, it can effect economy by enhanced labour productivity and less rebound wastage in plastering and concreting.

1.2 Plastics :

Plastic is the generic name for a family of synthetic materials derived from petrochemicals and often is a product of two or more compounds. Plastics are typically organic polymers of high molecular mass, but they often contain other substances. Though they are usually synthetic but many are partially natural. Thus plastic is a material consisting of any of a wide range of synthetic or semi-synthetic organics that are malleable and can be moulded into solid objects of diverse shapes through industrial process involving heat and pressure.

Due to their relatively low cost, ease of manufacture, versatility and imperviousness to water, plastics are used in an enormous and expanding range of products, from paper clips to space crafts. They have already displaced many traditional materials such as wood, stone, horn and bone, leather, paper, metal, glass and ceramic, in most of their former uses. In developed countries, about a third of plastics is used in packaging and another third in buildings such as piping used in plumbing or vinyl siding. Other uses include automobiles, furnitures and toys. Plastics have many uses in the medical field as well, to include polymer implants.

Manufacture of plastics

Plastic is manufactured by the process of polymerization from raw materials like catalysts, solvents, pigments, blowing agents, lubricants, filters, plasticizer and resin. The properties such as strength, rigidity and elasticity are considerably improved by the polymerization method. There are mainly three methods of polymerization as given below.

i) Condensation polymerization : In this method, low-molecular substances are removed from high-molecular substances formed from a large number of identical or different molecules.

ii) Addition polymerization : Here, similar or different molecules join together due to opening of double bonds and there is no loss of any substance in the process.

iii) Co-polymerization – it is the addition polymerization of two or more different monomers.

Classification of Plastics

Plastics can be classified based on their thermal behavior, structure or physical and mechanical properties..

a) Thermal behavior : According to behavior with respect to heating, the plastics are divided into two groups.

i) Thermo plastic ii) Thermosetting.

The thermoplastic or heat non-convertible group is the general term applied to the plastics which become soft when heated and hard when cooled. The process of softening and hardening may be repeated as long as heat is not so high as to cause chemical decomposition. It is thus possible to shape and reshape these plastics by means of heat and pressure and the scrap obtained from old and worm out articles can be effectively used again.

But the thermosetting or heat convertible group are the plastics which become rigid when moulded at suitable pressure and temperature. Although this type of plastic passes originally through thermo-plastic stage, when they are heated in temperature range of 127^0C to 177^0C, they set permanently and further application of heat does not alter their form or soften them. The thermo-setting plastics are durable, strong and hard being available in a variety of colours. They are mainly used in engineering application of plastics.

b) Structure : According to this classification, the plastics are devided into two groups.

i) Homogenous plastics ii) Heterogeneous plastics

Homogeneous plastic is composed of carbon chain i.e. plastics of this group are composed only of carbon atoms and they exhibit homogenous structure. Heterogeneous plastic is composed of the chain containing carbon and oxygen, the nitrogen and other chemicals and they exhibit heterogeneous structure.

c) Physical and Mechanical properties : According to this classification, the plastics are divided into four groups.

i) Soft plastics
ii) Elastometers
iii) Rigid plastics
iv) Semi-rigid plastics

Soft plastics have low modulus of elasticity and their elongation under pressure completely disappears when stress is removed Elasto-meters are plastics that are soft and elastic with low modulus of elasticity. The can deform considerably under load at room temperature. Rigid plastics have high modulus of elasticity and they retain their shape under exterior stresses applied at normal or moderately increased temperature. The semi rigid plastics have medium elasticity and the elongation under pressure completely disappears when pressure is removed.

Advantages of plastics:

Some of the important advantages of plastics are listed below:

i) High strength to weight ratio – Plastics are strong yet light weight and so they are easy to transport and manoeuvre.
ii) Durable and tough – They are durable, knock – and scratch resistant.
iii) Excellent weatherability – They have high resistance to adverse weathering conditions.
iv) Rotting and corrosion free – They do not rot or corrode.
v) Immunity to insect and fungal attack – They are not attacked by insects and fungi.
vi) Easy workability – Easy to work upon as it can be sawn, drilled, punched and welded easily.

vii) Easy mouldability – Can be moulded to any desired shape and size.

viii) Maintenance free – It requires little or no-maintenance.

ix) Easy installation – Plastics are easy to install, many having a snap-fit kind of joining procedure.

x) Flexibility of design – Plastics offer limitless possibilities in design achieved by extrusion, bending, moulding etc.

xi) Shock absorption – It is a good shock – absorbing material.

xii) Good insulation – Plastics are good electrical insulators.

xiii) Low thermal conductivity- They are poor conductor of heat and can be used as insulating material in green building concept.

xiv) Easy removal and recyclability – They can be easily removed and recycled.

xv) Colourful – They can be given any range of colours by adding pigments. So available in desired colour and texture.

xvi) Decorative surface effect – Painting or polishing of the surface not required.

xvii) Leak free and moisture proof – The plastic products can achieve tight seals and can withstand moisture, oil and greese well.

xvii) Economical – It has low manufacturing cost and hence cheap.

Disadvantages:

i) Susceptible to direct sun light – It deteriorates under prolonged exposure to sun's ultraviolet rays.

ii) High coefficient of thermal expansion- It has high thermal expansion and hence adequate thermal movement has to be allowed in detailing.

iii) Inflammable- Many plastics are flammable unless treated.

iv) Low melting point- They soften when exposed to moderate temperature.

v) Low modulus of elasticity- Makes them un-suitable for load-bearing applications.

vi) High creep- Thermo plastics are subject to creep.

<u>Use of plastics as a construction material-</u>

There are many families of plastics and polymers used in construction industry. Examples of plastics used in buildings are acrylic, composites, expanded polystyrene, polycarbonate, polyethylene, polyvinyl chloride. Generally, the construction professionals select plastic materials based on the criteria of durability, cost effectiveness, recycling, safety and ease of installation.

It goes without saying that plastics form an index of the progress of modern society. This is all due to the fact that plastics offer some definite advantages over all the other materials both in cost and quality in the competitive market. Most significant fields of application of plastics are as follows:

a) Aerospace engineering:- In the manufacture of control and navigational instruments, pipe lines and fuselage. As the reinforced fibre glass plastics, these have found use in the aerospace engineering.

b) Automotive engineering:- Plastics are widely used for making wind-shield, instrument panels, tail-light lenses, and other such accessories. Fibre glass reinforced plastic (FRP) has become a popular material for motor car bodies.

c) Electrical Engineering – Plastic is widely used in electrical engineering insulation, power transmission and communication equipment. Also, it is used in parts of generators, motors, switch boards, condensers, fluorescent light fixures and cabinets of most of the engineering gadgets.

d) Industrial Engineering – For making pipe lines, tanks, towers, conveyors etc.

e) Civil Engineering – The inherent qualities of plastics such as their capacity to be moulded in any shape, design, colour and appearance, ornamental finishing coupled with resistance to corrosion and insulation against thermal and electrical shocks, water proof quality have made them popular as a building material. Some of the important uses are as follows.

i) Floor and wall tiles :

Polyvinyl chloride synthetic resins being non-absorbent, resistant to abrasion and many types of chemicals, resistant to wear and tear, capable of keeping original beautiful appearance till end, easy to clean and maintain, light in weight and easily replaceable and after all less prone to sound pollution, are widely used for floors of residential and industrial buildings. Again, polystyrene tiles have excellent water proofing properties and are used in bathrooms, kitchens, lavatories, swimming pools and facing tiles.

ii) Roofing sheets – Laminated plastics are light weight and can be used for roofing purposes. To protect the outer surface of roof from damage, two layer of different plastic layers are employed. The upper part is made of coloured thermo-plastic olefin or vinyl while the lower part consists of polyurethane foam which consumes less energy and keeps the interior of a house cooler. Corrugated plastic roofing sheets with or without fiber reinforcement are used for covering open spaces for buildings. These admit sunlight and at the same time provide shelter from the rain water.

iii) Flooring / cladding sheets – Mastics, prepared from synthetic resins such as polyvinyl acetate with suitable plasticizers form decorative Linoleum floor coverings Similarly, resins impregnated with the craft paper, glass or cloth or any other type of fibre form good cladding material.

iv) Doors and windows - Polycarbonate is used to manufacture building windows. This plastic material is strong, clear and very light in weight. Poly carbonate windows are considered more bulgar-proof than regular glass windows. Two plastic materials, vinyl and fiberglass are used commonly in the production of window frames. Fiberglas is extremely strong while vinyl in quite durable and also inexpensive. Some construction agencies use doors made from a stiff polyurethane foam core with a fibre reinforced plastic (FRP) coating. The sandwich structure of these doors makes them incredibly strong. Also, steel reinforced thermo-vinyl polymer sections as a substitute of wood, steel and aluminum are used in buildings. They find their application in coastal areas. Besides, door window fittings such as handles, grips, knobs and other accessories earlier made from metals are now easily available in plastics and find extensive application as there require no further surface treatment.

v) Water storage conduits and sanitary appliances- Plastic tanks, cisterns, tubing and connections are fast replacing cast iron, steel and concrete materials in dwelling units because of their better adaptability and appealing looks as also due to their low cost. Plastics pipes, commonly made up of polyvinyl chloride (PVC), CPVC, acrylonitrile butadiene styrene (ABS) or polyethylene are flexible and very light in weight, making them easy to install. Also polythene, polypropylene and PVC are used for making sanitary wares and fittings. All of these plastic materials are also highly chemical and water resistant making them suitable for many extreme environments. Roof top water tanks are made from polyethylene compounded with 2.5 percent carbon black that makes the tank resistant to ultraviolet rays of sun. They are absolutely maintenance free and have become very popular.

vi) Wall panels- A structurally insulated panel (SIP) is a sandwich of expanded polystyrene amidst two slim layers of oriented strand board. This type of pre-fab, composite wall board can be transferred to work place easily for a particular task and provide good support to columns and other associated essentials during renovation.

vii) Insulation- Polyurethane spray is frequently used for insulation when constructing green or low energy buildings. Rigid polyurethane foam is known for its high thermal resistance which promotes temperature consistency. Polyurethane foam is also popular because it is light weight, chemical resistant and flame retardant. Due to closed cell nature, polyurethane insulation performs as an air barrier, resulting in significant energy savings.

viii) Water proofing membranes- Polyethene and polyvinyl resins with suitable fillers and plasticizers, oils and antipyrene compounds are used to make films which have high elastic strength, rupture value and acid resisting properties. These films are used for damp proofing courses, covering of concrete for curing, temporary protection from rain and wind.

ix) Soil reinforcement and permeable membranes- The geotextiles (in the form of fabrics) are used for ground stabilization, containment, separation, drainage and filteration purposes.

x) Plastic paints- The thermosetting plastics are soluble in alcohol and certain organic solvents, when they are in thermo plastic stage. This properly is utilized for making paints and varnishes from these plastics. Copal resins form an important constituent of paints, varnishes and lacquers.

xi) Reinforced plastic- Plastics can be reinforced with different types of fibre to stabilize, stiffen and to improve the physical properties. The examples are glass fibre reinforced plastics and carbon fibre reinforced plastics. The combination of a high-strength, high-modulus inorganic fibre with a polymeric matrix yields a very strong material. The polymer protects the fibre from mechanical damage and the adhesion between the matrix and fibre ensure stress transfer with the composite. Reinforced plastics are used for water proofing and damp-proofing of roofs and tanks, for making roofing sheets and strengthening of slabs.

Special Plastics

There are some plastics with special characteristics or properties manufactured for specific use or purpose. These include polyvinyl chloride (PVC), high density polyethylene (HDPE), rigid polyvinyl chloride (RPVC), fibre reinforced plastic (FRP), glass fibre reinforced plastic (GRP) etc. Besides coloured plastic sheets are also used now-a- days for various purposes. Such materials are dealt with in the following sections.

PVC (Polyvinyl chloride)

Polyvinyl chloride commonly abbreviated as PVC is a general purpose, strong but light weight plastic used in construction. Like all other plastics its features are determined by its chemical composition and the type of molecular structure. Generally PVC has an amorphous structure with polar chloride atoms in the molecular structure; both the features being inseparably related. Although plastics seem very similar in the context of daily use, PVC has completely different features in terms of performance and functions compared to olefin plastics which have only carbon and hydrogen atoms, in their molecular structures. Of course, chemical stability is a common feature among substances containing halogens such as chlorine and fluorine. This applies to PVC resins also, which further more possess fire retarding properties, durability and oil / chemical resistance.

PVC was accidentally discovered in 1872 by German chemist Eugen Baumann. The polymer appeared as a while solid inside a flask of vinyl chloride that had been left exposed to sun light. In the early 20th century, the scientists attempted to use it in commercial products, but difficulties in processing this rigid and sometimes brittle polymer thwarted their efforts. Waldo Seman and the B.F. Goodrich company developed a method in 1926 to plasticize PVC by blending it with various additives. The result was a more flexible and more easily processed material that soon achieved wide spread commercial use.

Production / Manufacture PVC is made from petroleum. Polyvinyl chloride is produced by polymerization of the vinyl chloride monomer (VCM), as shown in the fig.

About 80% of production involves suspension polymerization. Emulsion polymerization accounts for about 12% and bulk polymerization accounts for 8%. At the beginning, VCM and water are introduced into the reactor and the polymerization of VCM is started by compounds called initiators that are mixed into the drop lets. These compounds breakdown to start the radical chain reaction. The resulting polymers are linear and strong. The monomers are mainly arranged head-to-tail, meaning that there are chlorides on alternating carbon centres. PVC has mainly an atactic stereochemistry, which means that the relative stereochemistry of the chloride centres are random. However, some degree of syndiotacticity of the chain gives a few percentage of crystallinity that is influential on the properties of the material. Of course about 57% of the mass of PVC is chlorine. The presence of halide group (chloride) gives the polymer completely different attributes from the structurally related material polyethylene.

The product of polymerization process is unmodified PVC. Before PVC can be made into finished products, it always requires conversion into a compound by the incorporation of additives (but not necessarily all of the following) such as heat stabilizers, UV stabilizers, plasticizers, processing aids, impact modifiers, thermal modifiers, fillers, flame retardants, biocides, blowing agents and smoke suppressors and optionally, pigments. Moreover, the choice of additives used for the PVC finished products is controlled by the cost performance requirements of the end use specification e.g. underground pipe, window frames, intravenous tubing and flooring etc., all having very different ingredients to suite their performance requirements. Previously, polychlorinated biphenyls (PCBs) were added to certain PVC products as flame retardants and stabilizers.

Generally PVC comes in two basic forms-flexible or plasticized PVC (PVC-P) and unplasticized or rigid PVC (PVC-U) or sometimes abbreviated as uPVC or RPVC. The rigid form of PVC is generally used in the construction of pipes and in profile applications such as doors and windows. It is also used for bottles, other non-food packaging and cards (such as bank or membership cards). On the other hand, it can be made softer and more flexible by the addition of plasticizers, the most widely ones used being ph-thalates. In this form it is also used in plumbing, electrical cable insulation, imitation leather, signage, phonograph records, inflatable products and many more applications as a replacement of rubber.

Additional sub-categories of rigid and flexible PVC with desirable physical properties targeted to a specific application can be developed by altering additives to the base resin, for example, addition of UV stabilizers to enhance weather ability of rigid vinyl siding used in outdoor applications etc. Infact, PVC is available in a wide spectrum of colours as well as transparent variations.

PVC is manufactured into products by the injection molding process (e.g. pipe fittings), extrusion (e.g. pipes, shapes, siding etc.), blow molding (e.g. bottles etc.) and calendering (e.g. sheet). Of course, joining and fabrication of PVC is readily accomplished by the solvent cementing process, thermal hot air welding, machining, thermoforming and hot sheet welding. Thus PVC with wide range of formulations, processing characteristics, fabrication capabilities, durability and its relatively stable cost provide an economical material for a broad range of applications.

Properties

Pure polyvinyl chloride is a white brittle solid. It is insoluble in alcohol but slightly soluble in tetrahydrofuran. PVC is a thermoplastic polymer and the physical parameters of flexible PVC are as under:

Table

Physical Parameters of Flexible PVC

Property	Value / Magnitude
Density (gm/cm^3)	1.1-1.35
Thermal conductivity ($W/_{m-k}$)	0.14-0.17
Yield strength (psi)	1450-3600
Resistivity (Ωm)	10^{12}-10^{15}
Surface resistivity	10^{11}-10^{12}

Mechanical Properties

The mechanical properties enhance with the increasing molecular weight but decease with the increase in temperature. The elastic modulus of flexible PVC is 1.5 to 15Mpa.

Thermal and fire retarding properties

The heat stability of raw PVC is very poor and so the addition of heat stabilizer during the process is necessary in order to ensure the product's properties. PVC starts to decompose when the temperature reaches 140^0C with melting temperature starting around 160^0C. Also it has good flame retardancy, the limiting oxygen index (LOI) being upto 45 or more. The LOI is the minimum concentration of oxygen, expressed as a percentage, that supports combustion of a polymer and noting that air has 20% content of oxygen.

Electrical Properties:-

PVC is a polymer with good insulation properties but because of its higher polar nature, the electrical insulating property is inferior to non-polar polymers such as polyethylene and polypropylene. Again, since the dielectric constant, dielectric loss tangent value and the volume resistivity are high, the corona resistance is not very good and it is generally suitable for medium or low voltage and low frequency insulation materials.

Chemical properties:-

PVC is chemically resistant to acids, salts, bases, fats and alcohols; therefore, it is used in sewerage piping. PVC in general, is resistant to most solvents although plasticized PVC is less resistant compared to uPVC. For example, PVC is resistant to fuel and some paint thinners. Some solvents may only swell it or deform it but not dissolve it , whereas some of them, like tetrahydrofuran or acetone, may damage it.

Application of PVC:-

PVC's relatively low cost, biological and chemical resistance and workability have resulted in it being used for a wide variety of applications. It is used for pipe applications where the lost and vulnerability to corrosion limit the use of metals. With the addition of impact modifiers and stabilizers, PVC scrap has become a popular material for widows and doors, often costing 50% less than their wooden equivalents. By adding plasticizers, it is made flexible enough to be used in cabling applications as a wire insulator. It has found its use in a variety of applications so much to that at present more than 40 million tons of PVC is being consumed world wide.

In a nut shell the application of flexible PVC can be summerised to the following cases.

1) Flexible tubing
2) Food and beverage grade bottling
3) Electrical cable insulation
4) Containment membrane
5) Protective gloves and clothing
6) Fabrics
7) Automotive industry
8) Electrical insulating tapes
9) Toys and novelties

Advantages of PVC:-

There are several advantages of PVC as discussed below:

i) **Fire retarding property:-** PVC has inherently superior fire retarding properties owing to its chlorine content, even in the absence of fire retardants. For example, the ignition temperature of PVC is as high as 455^0C and is a material with less risk of fire incidents since it does not catch fire easily. Furthermore, the heat generated in burning is considerably low with PVC as compared to other plastic materials. PVC, therefore, contributes much less to the spreading of fire to nearby materials even while burning. Thus, PVC is very suitable in products close to people's daily lives for safety reasons.

ii) **Durability:-** Under normal conditions of use, the factor most strongly influencing the durability of a material is resistance to oxidation by atmospheric oxygen. PVC, having a molecular structure where the chlorine atom is bound to every other carbon chain, is highly resistant to oxidative reactions and maintains its performance for a long time. Other general purpose plastics with structures made up of only of carbon and hydrogen are more susceptible to deterioration by oxidation in extended use conditions (such as, for example, through repeated recycling).

However, the shortened time for thermal decomposition is due to the heat history in the re-converting process and can be brought back to that of the original products by adding stabilizers. Recovered products can infact be recycled into the same products through re-converting, regardless of whether they are pipes or automobile parts. The physical properties of these reconverted products are almost the same as with products made from virgin resin and there is no problem upon actual use.

iii) **Oil/Chemical resistance:-** PVC is resistance to acids, alkalies and almost all in-organic chemicals. Although PVC swells or disolves in aromatic hydrocarbons, ketones and cyclic ethers, PVC is hard to dissolve in other organic solvents. Taking advantages of this characteristics, PVC is used in exhaust gas ducts, sheets used in construction, bottles, tubes and hoses.

iv) **Mechanical stability:-** PVC is a chemically stable material which shows little change in the molecular structure and also exhibits little change in its mechanical strength. However, long chain polymers are visco-elastic material and can be deformed by continuous application of exterior force, even if the stress level is well below their yield point. This phenomenon is called creep deformation. Although PVC is a visco-elastic material, its creep deformation is very low compared to other plastics due to limited molecular motion at ordinary temperature.

v) **Processability & mouldability:-** The processibility of a thermo plastic material largely depends on its melt viscosity and so PVC is not suitable for injection molding of large sized products as it melt viscosity is comparatively high. On the other hand, the visco-elastic behavior of molten PVC is less dependent on temperature and is stable. Therefore, PVC is suitable for complex shaped extrusion profiling (e.g. housing materials) as well as calendaring of wide films and sheets (e.g. agricultural films and PVC leather).

The exterior surfaces of PVC leather are excellent and display superior embossing performance enabling a wide variety of surface treatments with textures ranging from enamel gloss to the completely de-lustured suede. Since PVC is an amorphous plastic with no phase transition, moulded PVC products have high dimensional accuracy. PVC also exhibits excellent secondary processability in bending fabrication, welding, high-frequency bonding and vacuum forming as well as on-site workability. Moreover, paste resin processing such as slush moulding, screen printing and coating are convenient processing techniques that are feasible only with PVC.

These processing methods are used in flooring, wall covering, automobile sealants and under coating.

vi) **Vesatility of design and application:-** PVC has polar groups (chlorine) and is amorphous; therefore mixes well with various other substances. The required physical properties of end products (e.g. flexibility, elasticity, impact resistance, anti-fouling, prevention of microbial growth, anti-mist, fire retarding) can be freely designed through formulation with plasticizers and various additives, modifiers and colouring agents. PVC is the only general purpose plastic that allows free, wide and seamless adjustment of the required physical properties of products such as flexibility, elasticity and impact resistance by adding plasticizers, additives and modifiers. Since the physical properties of the end products are adjustable through compounding with additives, only a few types of resin are required to cover all applications (fibre, rigid and flexible plastic, rubber, paint and adhesive). This controllability is also extremely beneficial for recycling.

The polar groups in the PVC contribute to ease of colouring, printing and adhesion. PVC products do not require pretreatment, which enables a wide variety of designs. PVC is used in various decorative applications taking full advantage of its superior printability, adhesion properties and weatherability. Patterns such as wood grain, marble and metallic tones are possible. Familiar examples include wall coverings and floorings, housing materials, furniture, home electric appliances or sign boards and advertisements on air planes, trains, buses and trams.

Disadvantages / Limitations:-

1) Co-efficient of linear expansion of flexible PVC is high giving it limited thermal capacity.

2) Elastic modulus of soft PVC (flexible PVC) is very low, for which strength is very less.

3) Susceptible to ultra violet (UV) rays which shortens its life span.

4) Thermal decomposition evolves HCL, that can pose health hazard.

5) Often stained by sulpher compounds.

Rigid Polyvinyl Chloride (RPVC)

Regular PVC (Polyvinyl Chloride) is a common, strong but light weight plastic used in construction. It can be made softer and flexible by addition of plasticizers. However, if no plasticizers are added, it is known as un-plasticized polyvinyl chloride (uPVC), rigid PVC (RPVC) or simply vinyl siding in some countries.

Rigid PVC or PVC-U is extensively used in the building industry as a low maintenance material. The material comes in a range of colours and finishes, including a photo effect wood finish and is used as a substitute for painted wood, mostly for window frames and sills when installing double glazing in new buildings or to replace older single glazed windows. Other uses include fascia and siding or weather boarding. This material has almost entirely replaced the use of cast iron for plumbing and drainage, being used for waste pipes, drain pipes, gutters and downspouts. $UPVC$ does not contain phthalates since those are only added to flexible PVC nor does it contain BPA. It is known as having strong resistance against chemicals, sunlight and oxidation from water.

Properties of RPVC:-

Pure polyvinyl chloride is a white, brittle solid. It is in soluble in alcohol but slightly soluble in tetrahydrofuran. The most common parameters of the rigid PVC is shown in the following table. **Table--**

General parameters / properties of RPVC

Property / Parameter	Value / Magnitude
Density	1.3 to 1.45 g/cm^3
Youngs modulus	2900-3300Mpa
Tensile strength	50-80Mpa
Elongation at break	20-40%
Impact strength	2-5 KJ/m^2
Glass temperature	87^{0}C
Melting point	176^{0}F (approx)
Vicat temperature	85^{0}C
Heat transfer coefficient	0.16W/m.K
Coefficient of thermal expansion (linear)	5x10^{-5} /^{0}C
Specific heat	0.9 kJ/kg-K
Resistivity	1016 Ω m
Surface resistivity	10^{13}-10^{14}Ω

Physical properties:-

PVC is a substantially amorphous thermo-plastic material which does not exhibit a sharp melting point with density of approximately 1.41gm/cm^3 due to high chloride content, the non-filled, non-plasticized material will sink in water. UPVC can be cut easily with a knife and the cuts have smooth edges. The addition of plasticizers will lower the density but addition of inorganic fillers will raise the density and the densities of commercial compounds may range from 1.15 to 1.49gm/cm^3.

The natural colour of the material is clear when it is unfilled and stabilized with appropriate stabilizers, for example, tin stabilizers. If the material is stabilized with lead stabilizers and / or-filled, then the natural colour is usually off-white. In other words, this means that a wide colour range is possible. Pure PVC in its natural state is very unstable to heat and is rapidly degraded at temperatures within its softening range. Without additives such as stabilizers and lubricants, it cannot be successfully processed. In addition to these there are many other additives used to modify the properties of PVC rather than stabilize it. These include impact modifiers based on thermo plastics such as ABS or MBS or elastometers, fillers such as china clay etc. UPVC has high impact strength but can be very notch sensitive. Impact modifiers are used to reduce this problem. UPVC has a vicat softening point (50N) of 75-90^{0}C and therefore not recommended for use above 60^{0}C.

Chemical Properties:-

PVC alone has good chemical resistance. Water, salt solutions, concentrated non-oxidizing acids, alkalies and dilute oxidizing agents have little effect at room temperatures although at higher temperatures some hydrolysis may occur.

PVC is attacked by concentrated oxidizing acids such as sulfuric, nitric and chromic acids which cause decomposition, the rate of attack may be accelerated in the presence of metals such as zinc and iron. It is attacked by bromine and fluorine even at room temperature.

It is resistant to aliphatic hydro-carbons but is unsuitable for use in contact with aromatic and chlorinated hydro carbons, ketones, nitro compounds, esters and cyclic ethers which penetrate the polymer and cause marked swelling. Some solvents such as cyclohexanone THF and MEK will dissolve the polymer easily and hence are the basis of PVC adhesives. Treatment with ethylene chloride is used to detect inadequately gelled polymer.

Because of the large amounts used, additives can have major effects on chemical and solvent resistance of PVC formulations. The effect of stabilizers, lubricants and pigments on the chemical is less marked than the effect of plasticizers and co-polymers but the type and amount of these additives will have some effect on the chemical resistance.

Use of co-polymers or addition of impact modifiers will generally reduce chemical and weathering resistance. But weathering resistance is improved by the use of UV stabilizers titanium oxide or carbon black.

When PVC is heated in a flame, it softens, burns and chars. It is not normally self extinguishing. A dirty yellow flame is seen together with a lot of smoke and a sweat, chemical smell from the plasticizer. If a piece of PVC compound is heated on a copper wire, then the flame will be coloured green. This test distinguishes PVC from other common polymers. If the plasticizer is removed by the solvent extraction, then it may be identified by its boiling point and / or infrared spectrum.

Advantages of RPVC:-

i) It can be conveniently processed by thermoplastic methods.

ii) Wide range of flexibility possible with RPVC using varying levels of plasticizer.

iii) RPVC is generally non-flammable.

iv) Its dimensional stability is good.

v) It is comparatively a low cost material.

vi) It has good resistance to weathering.

Disadvantages and limitations of RPVC:-

i) It is easily attacked by several solvent types.

ii) It has limited thermal capability.

iii) Thermal decomposition of RPVC evolves HCL fume which causes health hazard.

iv) It is easily strained by sulpher compounds.

v) It possesses a higher density than many plastics.

Applications or Use of RPVC:-

The major applications of UPVC or RPVC is in pipes for waste or drainage etc. Use of UPVC profiles for window frames have increased considerably because of the materials good weatherbility, good colour range, stiffness, toughness and relatively low cost. Other profile shapes include runners, venetian and other blinds, claddings, framing, fencing, easy assemblance room portioning and electrical conduits. Also, it is widely used in chemical plants because of its good chemical resistance, rigidity and non-inflamability.

Rain water down pipes and guttering are also extruded from UPVC compounds because of their rigidity, good ultraviolet (UV) resistance and chemical resistance.

In film and foil, UPVC is used in the thickness range from 80 to 160 gauge as a twist wrapping film while thicker gauges are used as material to be thermoformed into nestings for cookies, cakes etc.

Application of rigid PVC can be summarized as given below:

i) Industrial piping applications (pipes, valves, fittings, sheet)

   a) Chemical processing

   b) High purity applications

   c) Water and waste water treatment

   d) Irrigation

   e) Agriculture

   f) Corrosive fume handling (duct)

   g) Food contact applications

   h) DWV / plumbing

ii) Sheet, Rod and Tube

   a) Corrosion resistant tanks and vessels

   b) Corrosion resistant work stations and equipments

   c) Nuts, bolts and fasteners

   d) Pump and valve components

   e) Spacers, hangers, stiffeners, hubs and other mechanical components.

iii) Other applications

a) Vinyl siding

b) Credit cards

c) Decorative applications

Installation and maintenance of RPVC:-

For finishing of UPVC, inks are available for printing onto PVC which because of its polar nature readily accepts the ink. When drilling or sawing, UPVC lubricants should not be used.

Hot plate welding can be used to join RPVC components and has become widely used in the window frame industry. Surfaces to be joined are brought into contact with a PTFE fabric covered hot plate which is at a temperature of 210 to 230^{0}C. Surfaces are held against the hot plate for 30-35 seconds after which they are pulled away from the plate which is removed so that the surfaces can be immediately pushed together. After being held together for upto a minute while the weld cools, the welded component is trimmed to remove weld flash. About 2 to 3mm is lost off the extrudate during hot plate welding.

Solvent welding is another widely used method. The initial set up is quick but joints need 24 hours to develop their full strength. Again, these joints require finishing after welding to give polished surface. Of course, the process of grinding and polishing can be very time consuming.

Chlorinated Polyvinyl Chloride (CPVC)

Chlorinated polyvinyl chloride (CPVC) is a thermoplastic produced by chlorination of polyvinyl chloride (PVC) resin. It is significantly more flexible and can withstand higher temperatures than standard PVC. It's primary uses include hot and cold water pipes and industrial liquid handling. When using CPVC, little waste is generated, especially when compared to materials used in disposable product applications.

CPVC is a light weight yet strong material based on the relatively low petroleum content, and is produced using a very energy efficient process. Therefore, the need for non renewable energy sources (such as oil and coal) is low compared to the need when using traditional materials such as polyethylene (PE), polypropylene (PP), polybutylene (PB), copper and steel etc. Of course, it is slightly more expansive and therefore it is found only in riche applications such as certain water heaters and certain specialized clothing. An extensive market for chlorinated PVC is there for use in office building, apartment and condominium fire protection.

Production & manufacture of CPVC:-

Chlorinated polyvinyl chloride or CPVC, as it is called is produced by chlorination of aqueous solution of suspension PVC particles via a free radical chlorination reaction. This reaction is typically initiated by the application of thermal or UV energy utilizing various approaches. In the process, chlorine gas is decomposed into free radical chlorine which is then reacted with PVC in a post-production step, essentially replacing a portion of the hydrogen atoms in the PVC with chlorine atoms.

Depending on the method, a varying amount of chlorine is introduced into the polymer allowing for a measured way to fine tune the final properties. The chlorine content may vary from manufacturer to manufacturer; the base can be as low as PVC 56.7% to as high as 74% by mass, although most commercial resins have chlorine content from 63% to 69%. As the chlorine content in CPVC is increased, its glass transition temperature (Tg) increases significantly. Under normal operating conditions, CPVC becomes unstable at above 70% mass of chlorine.

Various additives (such as heat stabilizers, impact modifiers, pigments, processing aids and lubricants) are also introduced into the resin in order to make the material procesible. Similar to PVC processing, CPVC is manufactured into various products by extrusion, injection moulding and calendaring. Joining and fabrication is also accomplished by solvent cementing, hot air welding, thermoforming, machining and hot sheet welding.

Properties:-

CPVC shares most of the features and properties of PVC. It is also readily workable including machining, welding and forming. Because of its excellent corrosion resistance at elevated temperatures, CPVC is ideally suited for self supporting constructions where temperature upto 200^0F (90^0C) are present. Due to its specific composition, dealing with CPVC requires specialized solvent content. The ability to bend, shape and weld CPVC enables its use in a wide variety of processes and applications. It exhibits five-retardant properties.

Some of the basic physical properties of commercially available CPVC resins are shown in Table----. However, these physical properties of CPVC can be further modified by compounding with optimum heat stabilizers, impact modifiers, lubricants, processing aids etc.

Table-1

Parameters / characteristics	Values / magnitudes
Density	1.55-1.56 g/cm^3
Water absorption	+ 0.03% (+ 0.55%)
Young's modulus	2.9-3.4 Gpa
Tensile strength	50-80Mpa
Elongation at break	20-40%
Linear coefficient of thermal expansion	8 x 10^{-5}/K
Thermal conductivity	0.16W/m/K
Heat distortion temperature	103^{0}C
Melting temperature (T_M)	150^{0}C
Glass transition temperature (Tg)	106-115^{0}C
Volume resistivity	3.4 x 10^{15} Ohm/cm
Limiting oxygen index (LOI)	60%

Advantages of CPVC:-

Being an advanced engineering material, CPVC has excellent chemical and mechanical strength. CPVC is also readily workable including machining, welding and forming.

Due to its extremely high corrosion resistance at elevated temperature, CPVC is ideally suited for self supporting constructions where temperatures of upto 93^{0}C are present. The ability to bend, shape and weld CPVC enables its successful use in a wide variety of long service-life process applications such as hot and cold water plumbing systems, fire sprinkler or piping systems, industrial piping and process equipment, sheets, tanks, scrubbers, ventilation systems, valves, pumps, profile extrusion and custom injection moulding products.

Moreover, CPVC is a very light weight material compared to most alternate materials, especially metals. This means energy saving when transporting both raw CPVC for processing and the finished CPVC based products. For example, because of its light weight, high mechanical strength and natural flame retardant properties, CPVC material has been successfully used for the internal cabin compartments of commericial air liners.

Further more, CPVC can be used in several ecological and safety related applications, such as air pollution control and residential fire sprinkler system, in a more practical and affordable way. Also, the total energy required to produce a given weight of CPVC pipe is much less than that needed to make an equivalent amount of copper pipe, ranging from 35% to 70% less energy, depending on the pipe diameters.

More over CPVC engineered polymer piping systems have been produced to the requirements of standard specification of different countries. CPVC has an upper working temperature limit of 200^0F or approximately 60^0F above that of PVC, which greatly increases the products application range and makes it of advantageous for many aggressive high temperature processing applications such as plating and chemical processing. It is used in a variety of engineering applications due to its high glass transition temperature, high strength to weight ratio, pressure bearing capacity, corrosion and chemical resistance and low friction loss characteristics. In addition to chemical inertness and mechanical strength, CPVC products have excellent flammability properties when compared to other plastics and many common building materials. It does not support combustion, is rated as self extinguishing and has very low flame and smoke characteristics. These unique fire resistant properties of CPVC enable product applications that are unacceptable for many other plastics, such as use in fire resistant construction and fire sprinkler piping systems.

Above all, CPVC pipes are the ideal choice because they provide several critical advantages being corrosion resistant, durable, smooth, friction free, resistant to bacterial growth and environmental friendly besides having a host of other user-friendly features as discussed below.

i) **Aesthetic, extremely easy, cost effective to handle and install:-** CPVC pipes are light weight, which implies low transportation cost along with faster, safer and easier handling, cutting and installation, reducing overall labour costs. Installation is easy due to fast cold welding, which is cost effective as no electric or heat source is required. Simple cutter, chamfering tool and CPVC solvent are the only requirements for 100% leak proof jointing.

ii) **Excellent resistance to chemicals, corrosion and abrasion:-** It does not break down even under harshest water conditions and aggressive service environment like low pH water, coastal salt air exposure and corrosive soils. It can even be buried directly in the concrete slabs with no chemical interaction with concrete.

iii) **Most suitable for carrying drinking water:-** CPVC retards bacterial growth, which keeps the water quality healthy and palatable. They are even suitable in aggressive water pH levels of less than 6.5. Vinyl chloride monomer levels in these pipes are so low as to be undectable.

iii) **Smooth internal surface:-** Absence of scaling, pitting and leaching in CPVC pipes leads to smooth and full bore flow and low water noise. Hence, it maintains full water carrying capacity because of no scale build up, avoiding water pressure loss.

iv) **Energy efficient, lower thermal conductivity and insulation cost:-** CPVC pipes are self insulating with lower thermal conductivity, which greatly reduces heat and therefore requires low insulation levels and cost.

v) **Excellent performance in tough conditions:-** These piping systems are tough, rigid and strong with higher pressure bearing capacity. It requires less hangers and supports with minimum off sets / looping.

vi) **High flexibility virtually eliminates water hammers:-** No water hammer arrestors are required under normal conditions as intensity of water hammer in CPVC is approximately one third that of copper or steel pipe.

vii) **Extremely fire resistant:-** It has integral flame retarding property with very high limiting oxygen index (LOI) of 60. Thus in air, these pipes cannot be the ignition source of fire or support or sustain combustion. It does not increase fire load, has low smoke generation and low flame spread without flaming drips.

viii) **Completely leak proof:-** The cold welding using CPVC solvent is fast and simple, ensuring leak free installation for the entire life span of the piping system.

ix) **Cost effective, durable with excellent long term reliability:-** CPVC pipes have high impact strength and durability. It has low initial cost and lower maintenance costs as against competitive materials.

x) **Ideal for home plumbing systems:-** The CPVC system is four times quiter than copper plumbing systems, reducing not only the sound of running water, but also the pounding noise of the water hammer. Its thermoplastic properties provide excellent insulation to virtually eliminate sweating and condensation. It keeps hot water hotter and cold water colder than copper plumbing. There is minimal energy loss through pipe walls, saving money on heating and cooling. Also it is less subjected to job site thefts as compared to copper or metal pipes.

Applications / Uses of CPVC:-

There is wide application of CPVC as a engineering material due to the combination of its many inherent excellent chemical and mechanical properties, especially in the following cases.

a) **High resistance to corrosion and chemical attack:-** In many a cases, products made from CPVC have often replaced metallic products to provide longer service life in handling corrosive materials and chemicals such as aggressive water, strong mineral acids, caustics and other corrosive aqueous solutions. As a result, CPVC improves the safety and performance of many process industry applications. Moreover, some materials may be adversely affected by the chlorine contained in the water supply which can cause break down of polymer chains and potential leaks. In this respect, CPVC piping system is unaffected by the chlorine present in potable water supply.

b) **High purity:-** CPVC materials have been world wide approved for potable hot and cold water applications by several reputed organizations. These approvals are based on extraction studies which have verified that ingredients such as heat stabilities do not migrate from CPVC at levels that would be unsafe.

c) **Flame resistance and low smoke generation in fires:-** Because of its low petroleum content, CPVC is self extinguishing and has a relatively low smoke generation. CPVC has a much higher limiting oxygen index (LOI) value than many other common materials of construction. Therefore, CPVC does not support combustion under normal atmospheric conditions and so find its application in all fire resistant construction.

d) **Good mechanical strength at high temperatures:-** Compared to many other thermoplastics, CPVC has excellent mechanical strength over a broad temperature range. This enables CPVC to be used in pressure piping applications for upto 50 years at temperatures as high as 95^0C.

e) **Low bacteria built up:-** Many studies have shown that biofilm and bacteria build up in CPVC piping system are far lower than with alternative piping materials such as copper, steel and other thermoplastics.

Thus CPVC is used in the manufacture of pipe, fittings, valves, machining shapes, sheet and duct etc. which can be summarized as follows.

Industrial piping applications (pipes, valves, fittings, sheets, rods, tubes)

- Chemical processing
- Plating
- Water and waste water treatment
- Corrosive fume handling (ducts)
- Hot and cold water plumbing
- Fire sprinkler piping
- High purity applications
- Condensate return lines
- Pulp and paper industries
- Food contact applications
- Corrosion resistant tanks and vessels.
- Corrosion resistant work stations and equipments
- Pump and valve components
- Spacers, hangers, stiffeners, hubs and other mechanical components
- Nuts, bolts and fasteners
- Fume scrubbers
- In areas of mining, aerospace, air pollution control, textile, food and beverage processing and municipal projects
- Use as high tension cable protection pipe for electric net improvement
- Solar heating, central heating and radiant floor heating applications.

Installation and maintenance of CPVC pipes:-

CPVC pipes and fittings for potable water applications are available in CTS (Copper Tube Size) ½ through 2 inches and in IPS (Iron Pipe Size) ¼ through 12 inches. CPVC pipes and fittings are joined by solvent cementing and CPVC pipe and other piping materials are connected by the use of adapter fittings. These CPVC pipes are available in different wall thickness and these pipes and fittings are pressure rated for continuous use at 100 psi at 180^0F and 400 psi at 73.4^0F.

These pipes are designed for a water flow rate between 5 and 12 feet /sec and while laying them it must be remembered that CPVC pipes expand and contract more than metallic pipes. Compensation must be provided for expansion and contraction, where they are installed in long, straight lengths by using off set piping arrangements like loops or bends. Adequate horizontal supports and vertical hangers at appropriate distances must be provided along the pipe line.

For cutting CPVC pipes fine tooth saws / simple hack-saws / rachet saws or a circular tubing cutter modified with a plastic cutting blade can be used. Care should be taken to avoid cracking of the pipe wall while cutting. For larger diameter pipes power tools are also used at major sites for cutting.

Fibre Reinforced Plastic (FRP)

Fibre reinforced plastic (FRP), also called fibre-reinforced polymer is a composite material made up of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, aramid or basalt, although other fibres such as paper, wood or asbestos etc. have been rarely used. This, FRP is a specific type of two component composite material consisting of high strength fibres embedded in a polymer matrix with or without fillers to produce a bulk material having properties better than those of individual base materials. The matrix can be thermoplastics (polypropylene, polyethylene, polystyrene, PVC etc.) or thermosetting (polyester, vinyl ester, epoxy resins etc.) The mechanical and physical properties are clearly controlled by their constituent properties and by the micro structural configuration. While the fibres are mainly responsible for strength and stiffness properties, the polymetric matrix contributes to load transfer and provides environmental protection. In addition, fillers are used to reduce the cost and sometimes to improve the performance, imparting benefits such as shrinkages control, surface smoothness and crack resistance. Other additives and modifiers can expand the usefulness of the polymeric matrix, enhance their process ability or extend composite durability.

Fibre reinforced plastics have found extensive use in aerospace automobile and marine industries during past few decades due to their excellent engineering properties such as high specific strength and stiffness, lower density, high fatigue endurance, high damping and low thermal expansion. Recently civil engineers, architects and construction industry have begun to realize potential of composites as strengthening materials for many problems associated with the deterioration of infrastructures. Of late, an increase in the application of FRPs has been seen in the construction industry because of their novel engineering properties. Further, these are being considered as a replacement to the conventional steel in reinforced concrete structures due to continuing drop in the cost of FRP materials. Use of FRP sheets for strengthening and rehabilitation of concrete structures has attracted considerable interest. First application of the composites were in the form of rebars and structural shapes. Later, FRP materials are being used for strengthening of concrete bridge girders by bonding them to the tension face of the girder as well as for the retrofitting of concrete columns. FRPs are available in the form of rods, grids, sheets and winding strands.

Fibres:-

Many different types of fibres are available for use and all have their respective advantages and disadvantages. In civil engineering applications, the three most commonly used fibres types are glass, carbon (graphite) and to a lessor extant, aramid (Kelvar). The suitability of various fibres for specific applications depends on a number of factors including the required strength, stiffness, durability considerations, cost constraints and availability of component materials.

Glass fibre:- Glass fibres are commonly produced by a process called direct melt, where in fibres with a diameter of 3 to 25 μ are formed by rapid and continuous drawing from a glass melt. Glass fibres are used for a majority of composite applications because they are comparatively cheaper than others. These are different forms known by names like E-glass (the most frequently used), S-glass (is a stringer and stiffer fibre with a greater corrosion resistance), R-glass (has a higher tensile strength and modulus and greater resistant to fatigue and aging) and AR-glass (an alkali-resistant glass used to reinforce concrete). The main characteristics of glass firbres are their high tensile strength and moderate elastic modulus. Glass fibres also have excellent thermal and electrical resistance. However, glass fibres are particularly sensitive to moisture especially in presence of salts and elevated alkalinity and need to the well protected by the resin systems used in the FRP. Glass fibres are also susceptible to creep rupture and loosed strength under sustained stresses.

Carbon fibres:- Carbon fibres are produced by a process called controlled pyrolysis, where in one of the three potential precursor fibre is subjected to a complex series of heat treatments (stabilization, carbonization, graphitization and surface treatment) to produce carbon filaments with diameters in the range of 5-8 μ. The resulting fibres can have properties that vary widely and so several classes of carbon fibres are available differentiated based on their elastic moduli:

Standard	:	250-300Gpa
Intermediate	:	300-350Gpa
High	:	350-550Gpa
Ulta High	:	550-1000Gpa

Although, considerably more expensive than glass fibres, cabon fibres are beginning to see wide spread use in structural engineering applications such as pre-stressing tendons for concrete and structural FRP wraps for repair and strengthening of reinforced concrete beams, columns and slabs. Their steadily increasing use can be attributed to their steadily decreasing cost, high elastic modulus and available strengths, low density (weight) and their outstanding resistance to thermal chemical and environmental effects. They do not absorb moisture. Carbon fibre are an ideal choice for structures which are weight and /or deflection sensitive.

Aramid fibres:- Aramid fibres are manufactured from a synthetic compound called aromatic polyamide in a process called extrusion and spinning. In this fibre, molecular chains aligned and made rigid by means of aromatic rings linked by hydrogen bridges. Their main characteristics are high strength, impact resistance due to their energy absorbing capacity properties, moderate modulus and low density. In addition, FRPs manufactured from aramid fibres have low compressive and shear strengths as a consequence of the unique anisotropic properties of fibres. The fibres, themselves are susceptible to degradation from ultraviolet light and moisture but exhibit resistance to acids and alkalies.

Basalt fibres:- Basalt fibres are materials obtained by melting crushed volcanic lava deposits. Basalt fibres have better physical and mechanical properties than glass fire, but are significantly cheaper than carbon fibres. Their main advantages are fibre resistance, significant capability of acoustic insulation and immunity to chemical environments.

The following table illustrates typical properties of different types of fibres and steel showing their tensile strength, elastic modulus and density.

Table

Range of properties for fibres for FRP composites

Fibre type	Density (kg/m^3)	Tensile strength (GPa)	Elastic modulus (GPa)
Glass	2.46-2.58	2.4-3.5	72-87
Carbon	1.74-2.20	2.1-5.5	200-500
Aramid	1.39-1.47	3.1-3.6	58-130
Basalt	2.65-2.80	4.2-4.8	89-110
Steel	7.85	480-700	200

Other fibres that are now in the development phase for use in FRP products for structural engineering include ultra-high-molecular weight polyethylene fibres and polyvinyl alcohol fibres. Besides, some natural fibres have been used only in experimental applications to produce FRP products. However, it is expected that they will become more important in the construction industry due to their sustainability and recyclability.

Matrix:- The matrix is the binder of FRP and plays many important roles like binding the fibres together, protecting the fibres from abrasion and environmental degradation, separating and dispersing the fibres within the composite and transfer force to the fibres while being chemically and thermally compatible with forces. Primarily, there are two major types of polymers which determine the method of manufacturing and the properties of the composites, namely i) thermoplastics and ii) thermosetting. The first FRPs were all based on thermosetting polymers and besides the fact that thermoplastic have seen rapid growth in recent times, thermosetting is yet the most used in construction industry.

Thermoplastic matrix:- These are polymers composed of long chain molecules that are held together by relatively weak Van-der-Waals forces, but that have extremely strong bonds with in individual molecules. These polymers can be amorphous, which implies a random structure with a high concentration of entanglement, or crystalline, with a high degree of molecular order. In these materials, the molecules are free to slide over one another at elevated temperatures and so thermoplastics can be repeatedly softened and hardened by heating and cooling without significantly changing their molecular structure. The semi-crystalline polypropylene and nylon are especially popular as matrices.

Thermosetting matrix:- These polymers are also long-chain molecules built from monomers, but for these materials the molecular chains are cross-linked & networked through primary/strong chemical bonds. Thus, thermosets cannot be reversibly softened and will deteriorate when subjected to alternate heating and cooling. They are generally harder and stronger than thermoplastics. The principal thermosetting polymers that are used in construction are polyesters, vinylesters and epoxies. Two basis procedures are employed during polymerization; these are cold-cure systems that are cured at ambient temperatures and the hot-cure systems, in which the polymerization is performed at elevated temperatures. Thus, different resin and curing systems are required for site and factory manufacture of FRP composites e.g. cold cure systems for site work and hot cure systems for factory fabrication.

Limitations:-

FRP allows the alignment of fibres in the composite to suite specific design programmes. Specifying the orientation of reinforcing fibres can increase the strength and resistance to deformation of the polymer. Fibre reinforced polymers are the strongest and most resistive to deforming forces when the polymer’s fibres are parallel to the force being exerted and are weakest when the fibres are perpendicular.

Of course, FRP is used in designs that require a measure of strength or modulus of elasticity that non-reinforced plastics and other material choices are either ill-suited for mechanically or economically. This means that the primary design consideration for using FRP is to ensure that the material is used economically and in a manner that takes advantage of its structural enhancements specifically. This is however not always the case as the orientation of fibres also creates a material weakness perpendicular to the fibres as discussed above. Thus the use of fibre reinforcement and their orientation affects the strength, rigidity and elasticity of a final form and hence the operation of the final product itself. Using multidimensional alignment creates objects that seek to avoid any specific weak points due to the unidirectional orientation of fibres. The properties of strength, flexibility and elasticity can also be magnified or diminished through the geometric shape and design of the final product. These include such design consideration as to ensure proper wall thickness and creating multifunctional geometric shapes that can be moulded as single pieces, creating shapes that have more material and structural integrity by reducing joints, connections and hardware.

As a subject of plastic, FRPs are liable to a number of issues and concerns in plastic waste disposal and recycling. In addition to these concerns the fact that fibres are themselves difficult to be removed for the matrix. However, with the advent of new more environmentally friendly matrices, such as bioplastics and UV-degradable plastics, FRP is likely to gain environmental sensitivity.

Advantages:-

Fibre reinforce plastics (FRPs) are best suited for any design programme that demands weight savings, precision engineering, finite tolerances and the simplification of parts in both production and operation. A moulded polymer artifact is cheaper, faster and easier to manufacture than cast-aluminum or steel artifact and maintains similar and sometimes better tolerances and material strengths. To summarise, FRP provides an unrivalled combination of properties:

- Light weight
- High strength to- weight radio
- Design freedom
- High levels of stiffness
- Chemical resistance
- Good electrical insulating properties
- Retention of dimensional stability across a wide range of temperatures

Use / Applications:-

Now-a-days FRPs have vast areas of application from luxury power boats to ballistic armour and form chemical plants to marine industries as well. However, the typical applications are the following:

1) **Building and construction industry:-** With its low maintenance and low weight, FRP is finding many applications in building and infrastructure projects. Unsaturated polyester (UP) resins can be mixed with glass fibre and fillers to cast synthetic marble and solid surfaces for kitchens and bathrooms as well as roof tiles. For large projects such as bridges and wind generators, low weight for easier installation combined with low maintenance and durability make FRP an ideal alternative to conventional materials.

2) **Marine industry:-** Marine industry is an excellent example of an industry that has been completely transformed with the advent of FRP. Especially in the leisure boat sector, FRP has largely replaced traditional wood and steel building methods. An outer layer of gel coat gives it unlimited colour options, weather protection and a high gloss, low maintenance finish to boat hulls and decks. FRP is used in the construction of boats in all shapes and sizes from competition kayaks to sating yachts to floating gin palaces. The material is also used for noval vessels such as submarines, mine hunters and high speed patrol boats.

3) **Transportation industry:-** Low weight mouldability and high quality surface finishes make FRP an ideal material for automotive car body panels such as tailgates, tenders, roofs and complete truck cabs. High dimensional tolerances and heat resistance also make FRP parts highly suitable for structural and under bonnet parts such as engine sumps, valve covers and front assemblies. Separate metal components can be replaced by a single multifunctional FRP part.

Special grades of unsaturated polymer resins are available that give high level of fire retardancy and low smoke emission. These are important requirements for public transport applications, especially in trains and in tunnel applications like cladding and seating.

4) **Chemical plant and pipes:-** With its excellent resistance to corrosion and chemical attack, FRP is widely used in the chemical industry for the construction of pipe network and for chemical storage vessels, fume scrubbers and many other high performance applications. Vinyl ester and epoxy vinyl ester resins have been developed to give high levels of chemical resistance even in the most aggressive environments.

5) **Structure applications:-** FRP can be applied to strengthen the beams, columns and slabs for buildings and bridges. It is possible to increase the strength of structural members even after they have been severely damaged due to loading conditions. In the case of damaged reinforced concrete members, this would first require the repair of the member by removing loose debris and fillings in cavities and cracks with mortar or epoxy resin. Once the member is repaired, strengthening can be achieved through wet, hand layup of impregnating the fibre sheets with epoxy resin, then applying them to the cleaned and prepared surfaces of the member.

Two techniques are typically adopted for the strengthening of beams, relating to the strength enhancement desired : flexural strengthening or shear strengthening. But in many cases it may be necessary to provide both strength enhancements. For the flexural strengthen of the beam, FRP sheets or plates are applied to the tension face of the member (the bottom face for the simply supported member with applied top loading or gravity loading). Principal tensile fibres are oriented along the beam longitudinal axis, similar to its internal flexural steel reinforcement. This increases the beam strength and its stiffness (load required to cause unit deflection); however decreases the deflection capacity and ductility.

For the shear strengthening of a beam, the FRP is applied on the web (sides) of a member with fibres oriented transverse to the beam's longitudinal axis. Resisting of shear forces is achieved in a similar manner as internal steel stirrups, by bridging shear cracks that form under applied loading. FRP can be applied in several configurations, depending on the exposed faces of the member and the degree of strengthening required, which includes: side bonding, U-wraps (U-jackets), and closed wraps (complete wraps). Side bonding involves applying FRP to the sides of the beam only. It provides the least amount of shear strengthening due to failures caused by de-bonding from the concrete surface at the FRP free edges. For U-wraps, the FRP is applied continuously in a U-shape around the sides and bottom, (tension) face of the beam. If all faces of the member are accessible, the use of closed wraps is desirable as they provide the most strength enhancement. Closed wrapping involves applying FRP around the entire perimeter of the member, such that there are no free ends and the typical failure mode is rupture of the fibres. For all wrap configuration, the FRP can be applied along the length of the member as a continuous sheet or as discrete strips, having a predetermined minimum width and spacing.

Slabs may be strengthened by applying FRP strips at their bottom (tension) face. This results in better flexural performance, since the tensile resistance of slabs is supplemented by the tensile strength of FRP. In the case of beams and slabs, the effectiveness of FRP strengthening depends on the performance of the resin chosen for bonding. This is particularly an issue for shear strengthening using side bonding or U-wraps. Columns are typically wrapped with FRP around their perimeter, as with closed or complete wrapping. This is not only results in higher shear resistance, but more crucial for column design, it results in increased compressive strength under axial loading. The FRP wrap works by restraining the lateral expansion of the column, which can enhance confinement in a similar manner as spiral reinforcement does for the column core.

Also FRP stands / ropes can be used as a replacement for steel cables in elevators. It seals the carbon fibre in high friction polymer. Unlike steel cable, this can be designed for buildings that require upto 1000 meters of lift.

Glass Reinforced Plastic (GRP)

Glass reinforced plastic (GRP) is a type of fibre reinforced plastic or composite material of polymer where the reinforcement fibre is specially glass fibre. It is also other wisely known as glass fibre reinforced plastic or GFRP, where the glass fibre may be randomly arranged, flattened into a sheet (called a chopped strand mat), or woven into a fabric. The plastic matrix may be a thermoset polymer matrix - most often based on thermosetting polymers such as epoxy, polyester resin, or vinylester- or a thermoplastic. Fibre glass is unique in its properties with respect to specific strength.

The glass fibres are made up of various types of glass depending upon its use. These glasses all contain silica or silicate, with varying amount of oxides of calcium, magnesium and some-times boron. To be used in FRP, glass fibres have to be made with very low levels of defects.

Fibre glass is a strong light weight material and is used for many products. Although it is not as strong and stiff as composites based on carbon fibre, it is less brittle and its raw materials are much cheaper. It is bulk strength and weight are also better than many metals and it can be more readily moulded into complex shapes. Applications of fibre glass include aircraft, boats, automobiles, bath tubs and enclosures, swimming pools, hot tubs, septic tanks, water tanks, roofing, pipes, cladding, casts, surfboards and external door skins.

Production / Manufacture:-

The process of manufacturing fibre glass reinforced plastic is called pultrusion. The manufacturing process of glass fibres suitable for reinforcement uses large furnaces to gradually melt the silica sand, lime stone, kaolin clay, flourspar, colemanite, dolomite and other minerals to liquid form. It is then extruded through bushings, which are bundles of very small orifices (typically 5-25 micrometers in diameter for E-glass, 9 micrometer for S-glass).

These filaments are then sized (coated) with a chemical solution. The individual filaments are now bundled in large numbers to provide a roving. These rovings are then either used directly in a composite application such as pultrusions, filament winding (pipe), gun roving (where an automated gun chops the glass fibre into short lengths and drops it into a jet of resin, projected onto the surface of a mould), or in an intermediary step, to manufacture fabrics such as chopped strand mat (CSM) (made of randomly oriented small cut lengths of fibre all bonded together), woven fabrics, knit fabrics or uni-directional fabrics.

Chopped Strand Mat (CSM):- It is a special form of reinforcement used in GRP. It consists of glass fibres laid randomly across each other and held together by a binder. It is typically processed using a hard lay-up technique, where the sheets of reinforcing material are placed in a mould and brushed with resin. Because the binder dissolves in resin, the material easily conforms to different shapes when wetted out. After the resin cures, the hardened product can be taken from the mould and finished.

Using chopped stand mat gives a fibre glass with isotropic in-plane material properties.

Sizing:- It is an operation by which a coating or primer is applied to the roving to help protect the glass filaments for processing and manipulation. It also ensures proper bonding to the resin matrix, thus allowing for transfer of shear loads from glass fibres to the thermoset plastic, but for which the fibres can slip in the matrix causing localized failure.

Types of glass fibre used:- The most common types of glass fibre used in GRP is E-glass, which is alumino-borosilicate glass with less than 1% w/w alkali oxides, mainly used for glass reinforced plastics. Other types of glass used are A-glass (Alkali-lime glass with little or no boron oxide), E-CR-glass (Electrical / Chemical Resistance; alumino-lime silicate with less than 1% w/w alkali oxides, with high acid resistance), C-glass (alkali-lime glass with high boron oxide content, used for glass staple fibres and insulation), D-glass (borosilicate glass, named for its low dielectric constant), R-glass (alumino-silicate glass without MgO and CaO with high mechanical requirements as reinforcement), and S-glass (alumino silicate glass without CaO but with high MgO content with high tensile strength).

Pure silica (silicon dioxide), when cooled as fused quartz into glass with no true melting point, can be used as a glass fibre for GRP, but has the drawback that it must be worked at very high temperatures. In order to lower the necessary working temperature, other materials are introduced as fluxing agents (i.e. components to lower the melting point).

Properties:-

An individual structural glass fibre is both stiff and strong in tension and compression i.e. along its axis. Although it might appear that the fibre is weak in compression, it is actually only the long aspect ratio of the fibre which makes it seem so, i.e. since a fibre is long and narrow, it buckles easily. On the other hand, the glass fibre is weak in shear that is across its axis. Therefore, if a collection of fibres can be arranged permanently in a preferred direction with in a material and if they can be prevented from buckling in compression, the material will be preferentially strong in that direction.

Further more, by laying multiple layers of fibre on top of one another, with each layer oriented in various preferred directions the material's overall stiffness and strength can be efficiently controlled. In GRP, it is the plastic matrix which permanently constrains the structural glass fibres to the directions chosen by the designer. With chopped strand mat, this directionality is essentially an entire two dimensional plane with woven fabrics or unidirectional layers, the directionality of stiffness and strength can be more precisely controlled within the plane.

Of course, the mechanical functionality of GRP materials is heavily relied on the combined performance of both the resin (AKA Matrix) and fibres. For example, in severe temperature condition (over 180^0C) resin component of the composite may loose its functionality partially because of bond deterioration of resin and fibre. However, GRPs can show still significant residual strength after experiencing high temperature (200^0C).

Table

Mechanical properties of some common GRP types

Sl. No.	Material	Specific gravity	Tensile strength (Mpa)	Compressive strength (Mpa)
1.	Polyester resin (Not-reinforced)	1.28	55	140
2.	Polyester and CSM laminate 30% E-glass	1.4	100	150
3.	Polyester and woven rovings laminate 45% E-glass	1.6	250	150
4.	Polyester and satin wave cloth laminate 55% E-glass	1.7	300	250
5.	Polyester and continuous rovings laminate 70% E-glass	1.9	800	350
6.	E-glass epoxy composite	1.99	1770	-
7.	S-glass epoxy composite	1.95	2358	-

Advantages of GRP:-

Fibre glass is an immensely versatile material due to its light weight, inherent strength, weather resistant finish and a variety of surface textures. The following are the important advantages.

i) **High strength:-** GFRP has very high strength to weight ratio.

ii) **Light weight:-** Low weight of the material means faster installation, less structural framing and lower shipping costs.

iii) **High chemical resistance:-** Resists salt water, chemicals and the environment unaffected by acid rain, salts and most chemicals.

iv) **Seamless construction:-** Structural components could be designed together to form a one piece water tight structure.

v) **Able to mould complex shapes:-** Virtually any shape or form can be moulded limited only by the complexities and tolerances of the mould used for manufacture of the object.

vi) **Low maintenance:-** Maintenance cost is low as these is no loss of laminate properties after long years of performance.

vii) **Long durability:-** GRP products last for a very long time.

viii) **Corrosion resistant:-** It is highly corrosion resistant.

ix) **Non-conductive:-** It has high insulation against electrical conductivity.

x) **Economical:-** GRP is economical with respect to other comparable materials of similar strength and durability.

Limitation:- Despite so many advantages, GRP suffers from the following limitations.

i) **Warping:-** One notable feature of GRP is that the resins used are subject to contraction during the curing process. For polyesters, this contraction is often 5-6%, for epoxy, about 2%. Since the fibres do not contract, this differential can create changes in the shape of the part during curing. Distortions can appear hours, days or weeks after the resin has set. While this distortion can be minimized by symmetric use of the fibres in the design, a certain amount of internal stress is created and if it becomes too great, cracks form.

ii) **Health hazards:-** Fibre glass is sometimes, irritating to eyes, skin and respiratory system. Again, when the resins are cured, styrene vapours are released. These are irritating to mucus membranes and respiratory tract. In certain cases, it may create potentially explosive mixture. Further manufacture of GRP components may create fine dusts and chips containing glass filaments as well as tacky dust that may affect health and functionality of machines and equipments, which requires installation of effective extraction and filteration process.

Use / Applications:-

GRP has a wide range of applications. During World War-II, fibre glass was developed as a replacement for the moulded plywood used in aircraft radomes (GRP, being transparent to microwaves). Its first main civilian application was for the building of boats and sports car bodies. Then, its use was broadened to the automotive and sports equipments sectors. Of course, advanced manufacturing techniques such as pre-pregs and fibre rovings extend fibre glass's application and the tensile strength possible with fibre reinforced plastics.

Telecom Industry:-

GRP is also used in the telecommunication industry for shrouding antennas, due to its RF permeability and low signal attenuation properties. It is also used to conceal other equipments where no signal permeability is required, such as equipment cabinets and steel support structures, due to the ease with which it can be moulded and painted to blend with existing structure and surfaces. Other uses include sheet form electrical insulators and structural components commonly found in power industry products.

Sports Goods:-

Because of light weight and durability, GRP is often used in protective equipments such as helmets. Many sports use GRP protective gear such as goal tenders and catchers masks.

Storage tanks:-

Storage tanks can be made of GRP with capacities upto about 300 tonnes. Smaller tanks can be made with chopped stand mat (CSM) cast over a thermo plastic inner tank which act as a preform during construction. Much more reliable tanks are made using woven mat or filament wound fibre, with the fibre orientation at right angles to the hoop stress imposed in the side wall by the contents. Such tanks tend to be used for chemical storage because the plastic liner (often polypropylene) is resistant to wide range of corrosive chemicals. GRP can also be used for septic tanks.

House Building:-

Glass reinforced plastics are also used to produce house building components such as roofing laminate door surrounds, over-door canopies, window canopies and dormers, chimneys, coping systems and heads with keystones and sills. The materials reduced weight and easier handling, compared to wood or metal, allows for faster installation. Mass produced fibre glass brick effect panels can be used in the construction of composite housing and can include insulation to reduce heat loss.

Piping:-

GRP pipes can be used in a variety of above and below ground system, including those for desalination, water treatment, water distribution networks, chemical process plants, hot and cold water supply, drinking water, waste water / sewage, municipal waste, natural gas and LPG.

Decoration & Architecture:-

GRP can be used for both interior and exterior fixtures in a variety of shapes, styles and textures, in new buildings and restorative projects.

- Domes
- Fountains
- Columns
- Balustrade
- Planters
- Pannels
- Sculpture
- Entryways
- Mouldings
- Facades
- Cornice
- Porticos
- Cupolas
- Roofs

Besides GRP is used in sail planes, micro cars, drones, karts, lorries, wind turbine blades, bullet proof glass etc.

High Density Polyethylene (HDPE)

High-density polyethylene (HDPE) or polythene high-density (PEHD) is a polyethylene thermo-plastic made from petroleum. It is sometimes called “alkathene” when used for pipes. A linear polymer, High Density Polyethylene (HDPE) is prepared from ethylene by a catalytic process. The very absence of branching in molecules results in a more closely packed structure with a higher density and somewhat higher chemical resistance than LDPE or ordinary polyethylene. High density polyethylene is also somewhat harder and more opaque and it can withstand rather higher temperatures (120^0C for short periods and 110^0C continuously). High density polyethylene lends itself particularly well to blow moulding. With a high strength-to density ratio, HDPE is used in the production of plastic bottles, corrosion resistant piping, geomembranes and plastic lumber. HDPE is commonly recycled and has SPI resin identification code 2.

After its experimental preparation in the 1930s, the application in high frequency radar cables during World War-II gave impetus to its commercial production. Today HDPE is most widely used plastic with production in billions of pounds each year. In 2007, the global HDPE market crossed a volume of more than 30 million tons.

Properties:-

HDPE or high density polyethylene is known for its large strength-to-density radio. The density of HDPE can range from 0.93 to 0.97 g/cm^3. Although the density of HDPE is only marginally higher than that of low-density polyethylene, HDPE has little branching, giving it stronger inter molecular forces and tensile strength than LDPE. The difference in strength exceeds the difference in density, giving HDPE a higher specific strength. It is also harder and more opaque and can withstand somewhat higher temperatures (120^{0}C/248^{0}F for short periods). High density polyethylene, unlike polypropylene, cannot withstand normally required autoclaving conditions. However, the lack of branching is ensured by an appropriate choice of catatyst (e.g. Ziegler- Natta catatysts) and reaction conditions.

The physical properties of HDPE can vary depending on the moulding process that is used to manufacture a specific sample ; to some degree a determining factor are the international standardized testing methods employed to identify these properties for a specific process.

Advantages of HDPE:-

High density polyethylene has a lot of advantages:

i) It has good impact and wear resistance.

ii) Being flexible it can have very high elongation before breaking.

iii) Generally HDPE has good chemical resistance.

iv) Toughness quality of HDPE is also very good.

v) HDPE has good processability.

vi) Food contact of HDPE is acceptable.

Disadvantages of HDPE:-

HDPE suffers from following disadvantages:

i) It is sensitive to thick sections in some part. It may have voids, bubbles or sink.

ii) It suffers from poor dimensional accuracry.

iii) It has low mechanical properties i.e. low strength and stiffness.

iv) The thermal properties of HDPE are not good having high thermal expansion and poor temperature capability.

v) It suffers from poor wreathing resistance and subject to stress cracking.

vi) It is highly flammable and difficult to bond.

Property / Characteristics	Value
Apparent density	0.55 to 0.66 g/cm^3
Water absorption (73^{0}F, 24hr)	0.010 to 0.10%
Environmental stress cracking resistance (73^{0}F)	0.500 to 1130 hr
Carbon black content	1.9 to 2.7%
Tensile elongation at yield	10 to 27%

Co-efficient of friction	0.2 to 0.25

Use / Applications of HDPE:-

HDPE is resistant to many different solvents and has a wide variety of applications:

Swimming pool installation	3-D printer filament
Arena board (puck board)	Back packing frames
Ballistic plates	Banners
Bottle caps	Chemical-resistant piping
Coax cable inner insulator	Food storage containers
Fuel tanks of vehicles	Corrosion protection of steel pipe lines
Personal hover craft	Electrical and plumbing boxes
Far-IR lenses	Folding chairs and tables
Geo membranes for hydraulic applications (such as canals and bank reinforcements and chemical containment)	Geothermal heat transfer piping systems.
Natural gas distribution pipe systems	Heat resistant fire work mortars
Piping for water	Fire works
Plastic bags	Piping for sewer
Plastic lumber	Plastic bottles suitable for recycling
Root barrier	Plastic surgery
Storage sheds	Stone paper
Telecom ducts	Snow board rails and boxes
Wood plastic composites	Tyvek
Jugs and hollow goods	Pipes for domestic water supply and agricultural purposes.

HDPE geomembranes are manufactured from high grade resin blended with antioxidants and carbon black for enhanced UV (ultraviolet) resistance. Because no plasticizers are used, it is not subject to the embrittlement that can occur when plasticizers leach out. Due to its chemical structure, HDPE geo-membranes has the best chemical resistance among the available geo-membrane types.

HDPE is also used for cell liners in subtitle-D sanitary land fills, where in large sheets of HDPE are either extrusion-or wedge-welded to form a homogeneous chemical resistant barrier with the intention of preventing the pollution of soil and ground water by the liquid constituents of solid waste.

HDPE is preferred by the pyrotechnics trade for mortars over steel or PVC tubes, being more durable and safer. HDPE tends to rip or tear in malfunction instead of shattering and becoming sharpnel like other materials.

Milk jugs and other hallow goods manufactured through blow moulding are the most important application area for HDPE, accounting for about one third of world wide production, or so to say more than 8 million tons. There is some evidence that this form of recycling is less energy intensive than conventional recycling, which can involve a large embodied energy for transportation.

Above all, China, where beverage bottles made from HDPE were first imported in 2005, is a growing market for rigid HDPE packaging, as a result of its improving standard of living. In India and other highly populated emerging nations, infrastructure expansion includes the deployment of pipes and cable insulation made from HDPE.

Coloured Plastic Sheeting

Plastic sheets can be made up of polyethylene, polycarbonate or polyvinyl cholorde.

i) **Polyethylene sheets:-** Virgin polyethylene is the highest form of plastic sheeting today. These can be of thick sheets to thin films. The majority of plastic sheeing is made by laminating a woven mess of HDPE (high density polyethylene) between two layers of LDPE (low density polyethylene). Additional chemicals such as calcium carbonate are added to both the woven core and the exterior laminations to add colouring to make the material flexible to add UV (ultraviolet) stability and to alter the opacity.

These sheets are frequently printed with logos, manufacturing dates / batch numbers and markings to help with measuring. If reinforcement bands are added, they are usually welded on by the laminating machine. Reinforcement bonds are usually grey in colour.

Sheets are commonly produced on standard size loom (for example 1m or 2m wide and then heat welded together to form wider sheets). The resulting sheet is then either cut into rolls of standard length (commonly 50m to 60m long) or cut into individual sheets. If eyelets are to be added, the edges are welded over a reinforcement cord and the eyelets inserted.

Material specification (minimum) for a 200g/m^2 Rolls/sheets:-

Tensile strength of sheets outside of the reinforcement bands should be minimum 500N and inside of reinforcement bands 700N. The tear strength outside the reinforcement bands should be 100N (minimum). Bursting strength should not be less than 200N/cm^2 and UV resistance corresponding to maximum 5% loss on original tensile strength after a minimum of 1500 hours of UV exposure. Temperature resistance should vary in the range of 20 to 80^{0}C and should be ideally treated with fire retardant for adequate fire resistance.

Uses or applications of PE plastic sheeting:-

There are so many varied uses of plastic sheeting as given below:

1) **Shelters or temporary protection:-** During natural calamities plastic sheeting is often used to create temporary shelters. Sometimes, string reinforced plastic sheeting is used because it is stronger and will hold upto wind during cyclones.

2) **For outdoor coverings:-** String reinforced plastic sheeting is commonly used as well as non-reinforced plastic to make covers for a variety of items. Grommets and hems can be added to the plastic so it can be held down in place.

3) **Water proofing of ponds, lakes and canals:-** Liners for ponds, lakes and canals use a variety of plastic sheeting of HDPE to line their basins. This virgin polyethylene holds upto the sun and elements.

4) **Recreational uses:-** Plastic sheeting with the addition of special additives can be engineered for specific uses such as ice skating rinks, and slips and slides etc. which can work long and harbour the application it was designed for.

5) **Collection of rain water:-** There are special plastic sheeting that does not harm fish or humans and can thus be used for rain collection or aquaponics.

6) **Green house roofing:-** Plastic polyethylene sheeting is used to create green houses.

Besides these can be used for protecting flooring, black out curtain, closing off rooms, contaminant and under slab vapour barriers.

ii) **Polycarbonate sheets:-**

Polycarbonate sheet, also known as polycarbonate panel, is mainly composed of polycarbonate, a group of polymers that has great strength. It is a good replacement for glass, acrylic and other polyethylene membranes. It passes desirable features such as high impact strength which can be more than 200 times greater than tempered glass, has UV protection and better asthetic value and is bullet proof and light weight. It also has flame resistance, flexibility, energy efficiency and weather resistance attributes.

Rigid and corrugated plastic such as polycarbonate sheets for windows and polycarbonate roof is usually installed over patios, walk ways and terraces. It can be also be used in fencing which provides an indestructible barrier. This polycarbonate sheet also serves in other applications like green house, agriculture, ornaments and sound insulation barrier. This type of panel plays an important role in safety and environmental protection. It can be made into a bullet proof window used in banks or polycarbonate roofing sheets to filter ultraviolet sunlight.

A polycarbonate sheet can be translucent or completely opaque. It can be classified into a solid type or hollow type where in the main difference depends on the impact strength and the level of light transmission. Solid types are constructed with single heavy solid layer and are best used for applications where strength is the priority. Hollow types are made with at least two walls and are recommended for thermal insulation applications.

The corrugated polycarbonate sheets are manufactured in a variety of textures and colours and can be cut to fit any size. Other types of polycarbonate sheets include the frosted and embossed polycarbonate sheets that are specially for decoration purposes.

Applications:-

a) **Agricultures:-** Agricultural out buildings such as barn and energy efficient green houses are usually incorporated with UV treated polycarbonate roof panel. It can be single walled providing no light diffusion and less heat retention capability or can be thin walled giving additional strength, light diffusion as well as better insulating values. It can be also in the form of trippled walled polycarbonate sheeting for superior strength and better heat retention. The semi-opaque plastic sheet can also be installed vertically acting as wall unit which allows the warmth and light to reach inside.

b) **Decoration:-** Available in various colours and textures, the polycarbonate sheets provide some of its pleasing uses. It can be used as an alternate breakable glass type of door into a kitchen cabinet. It also serves as a light weight divider in rooms and other sites.

c) **Electrical and Electronics:-** A number of electrical and electronics goods are made from polycarbonate such as sensors, connectors, relays, computers and many more because it is light weight and has high impact strength. Hollow polycarbonate is a perfect choice for these kinds of materials in the electronic and electrical industry since it serves as perfect thermal insulation also.

d) **Automotive industry:-** The high performance, dimensional stability, rigidity, low moisture absorption and good heat resistance characteristics of polycarbonates made it a perfect choice in constructing a variety of automotive parts. It helps to improve the aesthetic look of the automobiles and is used to make headlight bezels, radiator grills, inner lenses, door handles and other transparent sections of a car.

iii) **PVC sheets:-** Polyvinyl chloride is formed in flat sheets in a variety of thickness and colours. As flat sheets, PVC is often expanded to create voids in the interior of the material, providing additional thickness without additional weight and minimal extra cost (e.g. closed- cell PVC foam board). Sheets may be cut using saw and rotary cutting equipments. Plasticized PVC is also used to produce thin, coloured or clear adhesive backed films which can be typically cut on a computer controlled plotter or printed in a wide format printer. These sheets and films are used to produce a wide variety of commercial signage products including car body stripes and stickers.

They can be of different variants. PVC clear sheet is water-clear and masked on two sides. Extruded PVC sheet has normal impact and high corrosion resistance and comes in a dark gray colour. Press laminated PVC sheets offer normal impact and high corrosion resistance and are available in thick gauges. They come in dark grey colour. The other types of PVC sheets although have same properties as regular PVC, are modified to provide higher impact strength. They are available in light grey colour or other shades.

1.3 Artificial Timber

The timber which is converted in a factory by some mechanical process so as to possess desired engineering properties such as shape, appearance, strength and durability etc. is termed as "Artificial Timber" or "Industrial Timber". It is also otherwisely called as "Engineered Wood" or "Composite Wood" / "Man-made Wood" or "Manufactured Board", which thus includes a range of derivative wood products which are manufactured by binding or fixing the strands, particles, fibres or veneers or boards of woods together with adhesive or other methods of fixation to form composite materials. These products are engineered to precise design specifications which are tested to meet desired standards. Artificial wood products are used in a variety of applications, from home construction to commercial buildings to industrial products. The products can be used for joists and beams that can advantageously replace natural timber in many building projects.

The ever increasing demand for good varieties of timber is so high that natural forests are unable to meet it consistent with ecological balance. Artificial wood aims to the meet the demand well by the use of less important species and waste materials. Also as a material, natural timber has a number of deficiencies such as it possesses a high degree of variability, it strongly anisotropic in both strength and moisture content, is dimensionally unstable in the presence of changing humidity and is often available only in limited sizes. Such deficiencies can be improved appreciably by reducing the timber to small units and subsequently, reconstituting it, usually in the form of large, flat sheets, though moulded items can also be produced.

Typically, engineered wood products are made from the same hard woods and soft woods that constitute timber. The raw materials for these wood products is the wood waste and inferior varieties of timber including those parts of trees such as branches etc. which cannot be used for structural purposes. Sawmill scraps and other wood waste can be used for artificial wood composed of wood particles or fibres, but whole logs are usually used for veneers, such as plywood, MDF or particle board. Some engineered wood products, like oriented strand board (OSB) can use trees of common but non-structural species. Alternatively, it is also possible to manufacture similar engineered bamboo from bamboo and similar engineered cellulosic products from other lignin-containing materials such as rye straw, wheat straw, rice straw, hemp stalks, kenaf stalks or sugarcane residue, in which case they contain no actual wood but rather vegetable fibres. However, the degree to which these products assume a higher dimensional stability and a lower level of anisotropy that is the case with solid timber depends on the size and orientation of the component pieces of timber and the method by which they are bonded together. Of course, sometimes, the gluing material used governs the durability of the product and should be selected carefully.

In comparison to timber, the board materials possess a lower degree of variability, lower anisotropy and higher dimensional stability and they are also available in large sizes. The reduction in variability is due quite simply to the random repositioning of variable components; the degree of reduction increasing as the size of components decreases.

To summarize, the use of artificial timber is justified over natural timber for the following reasons:

i) Available in large sizes-least joining required.
ii) More stable to atmosphere changes as compared to timber.
iii) Surfaces are plane and no jack-planning or machining is needed.
iv) Pasting of veneers or laminates is easier and more durable.
v) Stronger than the solid wood as it has same strength in all directions.
vi) The thinner sheets lend flexibility.
vii) Storing, stacking and transporting is easier.

It will not be out of place to mention that flat pack furniture is typically made out of man-made wood due to its low manufacturing costs and its low weight, making if easy to transport.

Following are the varieties of industrial timber:-

i) Veneers
ii) Plywood
iii) Fibre boards
iv) Particle board / chip board
v) Hand boards
vi) Block boards& lamin board
vii) Oriented strand board
viii) Laminated timber
ix) Laminated veneer
x) Glulam
xi) Cross laminated
xii) Parallel stand
xiii) Laminated stand
xiv) Batten board
xv) Impreg & compreg tibmers
xvi) Cement bonded particles board (CBPB)
xvii) Vertical studs and structural board beams
xviii) Finger jointed timber

However, they could be broadly divided into three major groups i.e. board materials, laminated timber and engineered structural timber.

Board materials

1. **Veneers:-** Veneers are thin sheets or slices of wood of superior quality having thickness varying between 0.4 mm to 6mm or more. The Indian timbers which are suitable for preparation of veneers are teak, sisso, mahogany, oak, rosewood etc. These good quality woods are cut into logs of 1.5 to 2.5m length and steamed. They are then cut into thin sheets by rotary cutting machines or by slicing manually. More than 90% of veneers are manufactured by rotary cutting. The veneers after being removed are dried in kilns to remove moisture.

Fig- p-207/rajput

The veneers are too thin to be used as separate entities, but are glued or cemented together or are glued to other inferior quality of wood to enhance the appearance and to protect their surface. Veneers when cemented in layers, with the grains of successive layers crossing each other, give stiffness and provide resistance to shrinkage and decrease the danger of cracking. Such multiple veneers are used in the construction of air craft.

The veneers form the starting point in the manufacture of plywood, lamin boards and batten boards. Their specifications are governed by BIS code is IS:303.

2. **Plywood:-** Plywood is a wood structural panel, which is of course, the original engineered wood product. Plywood is manufactured from sheets of veneer or thicker boards (plies) bonded under heat and pressure with durable moisture-resistant adhesives, where the panel strength and stiffness in both the directions are maximised by alternating the grain directions of veneers from layer to layer or cross-orienting. Thus, the directions of veneers in successive layers are kept at right angles to each other so as to get uniformly good strength in all directions. The outside layers are called faces, while the central portion is called core and others are called cross-bands. However, in order to have good appearance as well as to maintain economy, one face veneer is made of very good quality while the bulk is of ordinary quality.

Plywoods of the following types are manufactured

a) Ordinary grade used as a packing material.

b) Exterior grade, made of good quality wood and bonded with water proof glue.

c) Marine grade, in which the core and exterior, are of superior quality.

Plywood frequently contains an odd number of plies so that the system is balanced around the central veneer; some plywoods, however, may contain an even number of plies, but in that case, the two central plies have the same orientation, thereby ensuring that the plywood is balanced on each side of the central glue line. The thickness of various plywood boards are as given below:

3 ply- 3,4,5,6mm

5 ply- 5,6,8,9mm

7 ply-9,12,15,16mm

9 ply-12,15,16,19mm

11 ply-19,22,25mm

More than 11ply as per clients specification

Following are the guiding principles in respect of the thickness of plywood:

1) The plies holding identical positions on either side of the central or core ply must be of same thickness and same wood.

2) For 3-ply boards, the combined thickness of face veneers should not exceed twice the thickness of the central ply.

3) In multiply boards, the thickness of any veneer should not be more than twice the thickness of any other ply.

4) The sum of the thickness of wood with veneers in a given direction should be almost equal to the sum of the thickness of veneers at right angles to them and in no case, should be greater than 1.5 times this sum except for 3-ply boards as given above.

Fig- p-208/rajput

As the number of plies increases, so the degree of anisotropy in both strength and movement drops quickly from the value of 40:1 for the timber in the solid state. With 3-ply construction and using veneers of equal thickness, the degree of anisotropy is reduced to 5:1, while for 9-ply this drops to 1.5:1. However, the cost component of a ply wood increases markedly with the number of plies and for most normal applications a 3-ply construction is regarded as a good compromise between the isotropy and cost. Of course, the common multilayered plywood is technically known as “veneer plywood” where as ply woods in which the surface veneers overlay a core of blocks or strips of wood are called “core plywood”.

Depending upon the adhesives used, plywoods can be classified as:

i) Boiling water proof (BWF) grade
ii) Boiling water resistant (BWR) grade
iii) Warm water resistant (WWR) grade
iv) Cold water resistant (CWR) grade

Timber of Class-I grade is used for the manufacture of BWP and BWR grade plywoods. For the other two grades, the timber may be Class-I or Class-II. The mechanical and physical properties of plywood, therefore, depends not only on the type of adhesives used, but also on the species of timber selected. Both soft woods and hard woods within the density range of 400-700kg/m^3 are normally utilised. Ply woods for internal use are produced from the non-durable species and urea-formaldehyde adhesive (UF), while the plywood for external use is generally manufactured using phenol-formaldehyde (PF) resins. However, in case of marine grade plywood, either durable timbers or permeable non-durable timbers that have been treated with preservatives may be used. Also, while being glued, the veneers are either hot pressed or cold pressed depending on the type of adhesives used in bonding. Cold pressing is applied at the room temperature when vegetables glues are used whereas hot pressing becomes imperative when synthetic resins are used. In hot pressing, the material is raised to a temperature where the glue is perfectly liquefied between the temperatures of 150^0C to 260^0C and then a pressure varying between 7-14kg/m^2 is applied through hydraulic presses.

Properties of ply wood:- It is not possible to discuss about the strength properties of plywood in general terms since not only are there different strength properties in different grain directions but these are also affected by configurations of plywood in terms of number, thickness, orientation and quality of veneers and by the type of adhesives used. The actors that affect the strength of plywood are the same as that of the component timber, but the effects are not necessarily the same. Thus intrinsic factors such as knots and density, play a significant part than they do in case of timber, but the affects of extrinsic variables such as moisture content, temperature and time are very similar to those of timber.

Uses of ply wood:- Plywood is the oldest of the timber sheet materials and for very many years has enjoyed a high reputation as a structure sheet material. Its use in the aircraft and gliders in the 1940s and its subsequent performance in the construction of small boats, in seathing of timber frame housing, and in the construction of web and hollow box beams all bears testament to its suitability as a structural material.

However, ply woods fall into three distinct groups in respect of their use. The first comprises those that are capable of being used structurally. The second group of ply woods comprises those that are used for decorative purposes, while the third group comprises those for general purpose use. The latter are usually of very varied performance in terms of both bond quality and strength and are frequently use in doors for infill panels and certain types of furnitures.

Thus, ply woods are used for various purposes such as ceilings, doors, furnitures, partitions, panelling walls, packing cases, railway coaches, frame work for concrete etc. The ply woods, however, are not suitable in situations subjected to direct shocks or impacts. The use of ply wood and its products has become so common at present that it has totally changed the design and complex of various structures such as buildings, offices, theatres, restaurants, churches, temples and hospitals etc. The ply woods are available in different commercial forms such as batten board, lamin board, metal faced ply wood etc.

Advantages of ply wood:-

1) Ply wood has higher specific stiffness (modulus of elasticity per unit mass) than many other construction materials and also generally they have high specific strength.

2) It has resistance to splitting which permits nailing and screwing relatively close to the edges of boards; this is a reflection of line of cleavage along the grain which is a draw back of solid timber.

3) It possesses very high impact resistance (toughness) and for failure of ply wood a force greater than tensile strength of timber species is required.

4) They make use of rare and valuable timbres in a quite economical way and are available in a variety of decorative appearance.

5) They are easily workable and capable of being shaped to numerous designs.

6) Being a very good elastic material, is least affected by changes in atmosphere and moisture.

7) They posses uniform strength in all directions and hence versatility of use.

3. **Fibre boards:-** These are rigid boards and are also known as pressed wood or reconstructed wood. They are made by breaking down hard wood or soft wood residuals into wood fibres, combing with wax or a resin binder and forming panels by applying high temperature and pressure. They may be either homogeneous or laminated. They vary in thickness from 3mm to 12mm and are available in lengths varying from 3m to 4.5m and in widths of 1.2m to 1.8m. However, the weight of fibre boards depends on the pressure applied during manufacture, the maximum and minimum limits being 9600N/m^3 and 500 to 600N/m^3 respectively.

Fig-p-210/rajput

Depending upon their form and composition, the fibre boards are classified as insulating boards, medium hard boards, hard boards, super hard boards and laminated boards. They are also available under various trade names such as Eurakes, Indianite, Insulite, Masonite, Noudex, Treetex etc. Again, based on their manufacturing process, they may be divided into dry-process fibre board and wet-process fibre board.

Dry process fibres board:- This is also known as medium density fibre board (MDF) and is manufactured by a dry process in contrast to other types of fibre board. The fibre bundles are first dried to a low moisture content before being sprayed with an adhesive and formed into a mat, which is hot pressed to produce a board with two smooth faces similar to the production of particle board. Both multi-day light and continuous presses are employed. Again, various adhesive systems are made use of in the production of MDF; where the board will be used in dry condition, a UF resin is employed, while a board with improved resistance to moisture for use in humid conditions is usually manufactured using an MDF resin, though PF or IS resins are sometimes used. Of course, the specification for MDF includes both load bearing and non-load bearing grades for both dry and humid end uses. But the use of load-bearing panels under humid conditions is restricted to only short periods of loading. A very large part of MDF production is taken up in the manufacture of furniture, where the non-load bearing grades for dry use are appropriate.

Wet process fibre board:- Fibre board can be produced using a wet process, which was the original method of fibre board production before the advent of MDF. Production levels of wet-process boards have fallen over the years, but it is still used in certain application, such as insulation and the linings of doors and backs of furnitures, and as a cladding and roofing material in some countries.

This process of manufacture is quite different from that of other board materials in that the timber is first reduced to chips, which are then steamed under very high pressure in order to soften the lignin, which is thermoplastic in behaviour. The softened chips then pass to a defibrator, which separate them into individual fibres or fibre bundles without inducing too much damage.

The fibrous mass is usually mixed with hot water and formed into a mat on a wire mesh; the mat is then cut into lengths and like particle board, pressed in a multi-platen hot press at a temperature of from 180 to 210^0C. The board so produced is smooth on one side only, the underside bearing the imprint of the wire mesh. By modifying the pressure applied in the final pressing, boards of a wide range of density are produced, ranging from soft board (with a density of less than 400 kg/m^3) through medium board (with a density range of 400-900kg/m^3) to hard board (with a density exceeding 900kg/m^3). Fibre board, like the other board products, is moisture sensitive, but in the case of hard board, a certain degree of resistance can be obtained by passing the material through a hot oil bath, there by imparting a high degree of water repellency to the material, which is referred to as tempered hard board.

<u>Uses of fibre boards:-</u> The fibre boards form an ideal base for practically all types of decorative finishes such as distemper, oil paints etc. The hard boards are also suitable for polishing and varnishing. Several patterns of fibre boards with pre-decorated surfaces are available in the market and thus the necessity of treating them after fixing in position is eliminated.

The following are the major uses of fibre boards:

i) They are used for internal finish of rooms such as wall panelling, suspended ceilings , paring or flooring material, flush doors and table tops etc.

ii) These are used for fire and sound insulation in large commercial buildings and cinema houses.

iii) They are also used in making partitions and finishing cover to furnitures.

4. <u>Particle Board (Chip board):-</u> The particle board industry originated with the purpose of utilizing the waste timber and these boards are made of wood particles, saw mill shavings or even saw dust or rice husk or bagasse (remains of sugar cane after crushing), embedded in synthetic resins or other suitable binder and subjected to pressure. The industry has grown tremendously over the last four decades, for exceeding the supply of waste timber available and now relying to a very large extent on the use of small trees or branches of big trees for its raw material. Such marked expansion has been possible due to the much tighter control in processing and the ability to produce boards with a known and reproducible performance, frequently tailor made for specific end use.

The particle boards are manufacture either by pressing in parallel plates or by extrusion pressing. In the manufacture of particle board the timber which is principally soft wood, is cut by a series of rotating knives to produce thin chips, which are dried in automatic driers to reduce the moisture content of these wood wastes to barely 15% and then sprayed with adhesive or gluing material like formaldehyde etc. This adhesive coated material is blown on to flat platens in such a way that the central portion consists of coarser particles where as the outer portion consists of finer particles with higher resin content. The mat is usually first cut to length before passing into a single or multi-day light press where it is pressed in presence of heat (at a temperature upto 200^0C). The density of the boards so produced ranges from 450 to 750kg/m^3 depending on the end use classification, while the resin content various from about 9-11% in the outer layers to 5-7% in the central layer, averaging out for the board at about 7-8% on a dry mass basis. Now-days, the particle boards are being manufactured in large continuous presses, where the mat is fed at one end to reappear at the other end as a fully-cured board. This type of press has the advantage of being quick to respond to production changes in board thickness, adhesive type or board density.

Particle board can also be made continuously using an extrusion process in which the mat is forced out through a heated die. Though, a simple process, this results in the orientation of chips at right angles to the plane of the board, which reduces both the strength and stiffness of the material in contrast to pressing in parallel plates where the particles are oriented parallel to the plane of the board. Extruded board is used primarily as a core in the manufacture of doors and composite panels. Following are the four types of particle boards generally available in the market.

i) Flat pressed single layer board (FPSL)
ii) Flat pressed three layer board (FPTH)
iii) Extrusion pressed solid board (XPSO)
iv) Extrusion pressed tubular core (XPTU)

Fig- p-57/bhavikatti

The performance of particle board, like that of ply wood, is very dependent on the type of adhesive used. The particle boards made using urea-formaldehyde (UF) resin, because of its sensitivity to moisture, renders this type of particle board unsuitable for use where there is a risk of the material becoming wet or even being subjected to marked alternations in relative humidity over a long period of time. More expensive boards possessing some resistance to the presence of moisture are manufactured using melamine fortified urea-formaldehyde (MUF), or a phenol formaldehyde (PF), or isocyanate (IS) adhesive. Particle board, like timber, is a visco-elastic material and suffers from deformation over an extended period of time. Of course, the rate of creep is particle board is considerably higher than that in timber though it is possible to reduce it by increasing the quantity of adhesive or by modifying the chemical composition of the adhesive.

Particle boards are also produced from a wide variety of plant material and synthetic resin, of which flax board and bagasse board are very common. Particle boards of various sizes are manufactured as listed below:

Thickness (in mm) : 6,9,12,15,18,22,25,27,30,35,40

Width (in mm) : 450, 600, 900, 1000, 1200, 1500, 1800

Length (in mm) : 900, 1000, 1200, 1500, 1800, 2100, 2400, 2750, 3000, 3600, 4800

Particle boards are cheaper denser and more uniform than solid wood or ply wood and is substituted for them when cost is more important than strength appearance. They are stable and have reasonable strength. These boards are some times provided with plastic veneers. They can be sawn like wood and are mainly used for partition doors and furniture making. A major disadvantage of particle board is that it is very prone to expansion and discoluration due to moisture, particularly when it is not covered with paint or another sealer.

5. Oriented Strand Board (OSB):- It is a wood structural panel manufactured from rectangular-shaped strands of wood that are oriented length wise and then arranged in layers, laid up into mats and bonded together with moisture-resistant, heat-cured adhesives. The individual layers are cross-oriented to provide strength and stiffness to the panel. Produced in huge, continuous mats, OSB is a solid panel product of consistent quality with no laps, gaps or voids.

For the manufacture of oriented strand board (OSB), strands upto 75mm in length with a maximum width of half its length are generally sprayed with an adhesive at a rate corresponding to about 2-3% of the dry mass of the strands. However, it is possible to work with much lower resin concentrations than with particle board manufacture owing to the removal of dust and fines from the OSB line prior to resin application. In a few mills, powdered resins are used, though most manufactures use a liquid resin. In the majority of mills a PF resin is used, but in some other mills, of MUF or IS resin is employed. In the formation of the mats, the stands are aligned either in each of three layers or only in the outer two layers of the board. The extent of orientation, varies among the manufacture with properly level ratios in the machine to cross direction of 1.25 /1 to 2.5/1, thereby emulating plywood.

Indeed, the success of OSB has been as a cheaper replacement for plywood, but it must be appreciated that its strength and stiffness are considerably lower than those of high-quality structural grade ply-wood, though only marginally lower than those of many of the current structural soft wood plywoods. It is widely used for suspended flooring, sheathing in timber frame construction and flat roof decking.

6. Cement bonded particle board (CBPB):- This is very much a special end use product manufactured in relatively small quantities. It comprises by mass 70-75% port land cement and 25 to 30% wood chips similar to those used in particle board manufactured. It has following characteristics:

i) The board is heavy, with a density of about 1200kg/m^3.

ii) It is very durable (owing to its high pH of 11).

iii) It is more dimensionally stable under changing relative humidity (owing to the high cement content).

iv) It has a very good performance in reaction to fire tests (again because of the high cement content).

v) It has poor sound transmission (owing to its high density).

The CBPB is therefore used in high hazard situations with respect to moisture, fire or sound.

7. **Batten board:-** A batten board is a board having a core made up of strips of wood usually 80mm wide, each laid separately or glued or other wisely joined to form a slat which is glued between two or more outer veneers with the direction of the grain of the core running at right angles to that of the adjacent outer veneers.

The batten boards are light and strong and these boards are used for door panels, table tops etc.

Fig- p-209/rajput

8. **Hard boards:-** Hard board is made from wood or wood waste, which is pulped and mixed with water-repellent agents like paraffin wax and resins like phenol formaldehyde. The fibres so formed are wet felted or dry felted. In wet felting, a mat is formed from a low consistency felt and initially cold pressed and then hot pressed. In case of dry felting, relatively dry fibres are pressed by air or mechanical means. Its face is made smooth and hard while the back surface is made rough with pattern or cross lines. Hard boards are of three types:

i) Medium hand board: density 4.8-8.0KN/m^2

ii) Standard hard board: density 8-12 KN/m^2

iii) Tempered hand board: It is the standard hand board specially treated to increase strength and water resistance (density >12KN/m^3)

These boards are available in the following sizes.

Thickness (in mm) : 3,4,6,9,12

Width (in mtr) : 1-2 m

Length (in mtr) : 1.2, 1.8, 2.4, 3.0, 3.6, 4.8, 5.5

These boards are hard pressed and hence are more compact, strong and durable. They are used for making door shutters and also used to impart internal appearance and finish to a structure. These are least affected by the change in temperature and humidity of surroundings. They are impregnated with oil when properties of high non-absorbent nature is required.

9. **Block board:-** Block board are boards having a core made up of strips of wood, each not exceeding 25mm in width and are also known as solid core ply wood. The wooden strips of the core shall be cut from specified timber and seasoned to moisture content not exceeding 12%. The core strips should be of one species in a board and way consist of small lengths placed end-staggering manner. The edges of the strips are glued together to form a solid sheet, which is then finished with one or multiple cross bonded veneers on each face, so that the construction is well balanced around the centre line. Of course, the direction of grains of cores is at right angles to that of adjacent veneers.

The wooden strips also may be obtained from small round wooden logs, left-overs from solid timber conversion, or peeler cores remaining from veneer production. The total thickness of these boards is 18mm and above. The thickness of facing veneers is 0.5-1.5mm. The veneers shall be of ornamental quality, either on one or both the sides. These boards are extensively used in railway carriages, bus bodies, marine and river crafts, furniture making, partitions paralleling and prefabricated houses.

Note-i) When the core strips consists of large pieces of 80mm width, they are known as batten boards

ii) When the thickness of the core strips does not exceed 7mm, such boards are known as lamin boards.

Fig.p-209 rajput

10. <u>Lamin board:-</u> A lamin board is a board having a core of strips, each not exceeding 7mm in thickness, glued together face to face to form a slab which in turn is glued between two or more veneers, with the direction of the grain of core strips running at right angles to that of the adjacent outer veneers.

Fig- p-209/rajput

The lamin boards are light, strong and do not split or crack easily. They are used for walls, ceilings, partitions and packing cases.

<u>Comparative performance of board materials:-</u> In general terms, the strength properties of good quality structural softwood, plywood are considerably higher than those of all other board materials and they are usually similar to or slightly higher than those of softwood timber. Next to a good quality structural plywood in strength, are the hand boards, followed by MDF and OSB. Particle board is of lower strength but still stronger than the medium boards and CBPB.

However, the comparison of behaviour of these products with the effect on their behaviour after 24 hours cold water soaking reveals that CBPB is far superior to all other boards.

Laminated Timber

Laminated Timber:-

It is another type of processed wood consisting of suitably selected wood sheets or veneers that are glued together in such a way that the grains of all these sheets or laminations are parallel in the longitudinal direction. Each lamination used in the manufacture of laminated timber has a uniform thickness not exceeding 51mm and also each lamination is itself prepared by gluing together thin pieces of timber having no defects in them. Thus, laminated timber is broadly similar to natural timber in structure but without any of its defects.

The process of cutting of timber into strips and gluing them together again has three main advantages:

i) Firstly, defects in the original pieces of timber such as knots, splits, reaction wood or sloping grain are actually redistributed randomly throughout the composite member making it more uniform in quality than the original piece of timber, where the defects often result in stress raisers when load is applied. Consequently the strength and modulus of elasticity of the laminated product will usually be higher than those of the timber from which is was made.

ii) Second is the ability to create curved beams or complex shapes.

iii) The third is the ability to use shorter lengths of timber, which can be end jointed.

The laminated timbers comes in a wide variety of shapes and appearances. It is manufactured in three qualities- Industrial, Architectural and Premium grades. In the industrial grade laminated timber, small voids are allowed but one face is made free of loose knots and holes. It is used in garages or industrial plants. The architectural grade has a very smooth external surface in which all knots have been removed and voids so created filled with clear wood tissue. The premium grade is manufactured with great care and is used where highly appealing and smooth external finish is required.

12. Glued laminated timber (Glulam):- Glued laminated timber also called glulam; is generally composed of several layers of dimensional timber glued together with adhesives, creating a large strong, structural member that can be used as vertical columns or horizontal beams. Glulam can also be produced in curved shapes, offering extensive design flexibility. It is made up of solid wood without use of veneers.

Of course, glulam-the popular term for laminated timber-has been around for many years and can be found in the form of large curved beams in public buildings and sports halls. In manufacture, strips of timber about 20-30mm in depth are first dried and then coated with adhesives on their faces and laid up parallel to one another in a jig, the whole assembly being clamped until the adhesive has set. Generally, cold-setting adhesives are used because of the size of these beams. For dry end use a UF resin is employed, while for humid conditions a resorcinol formaldehyde (RF) resin is employed. The individual laminate are end-jointed using either a scraf (sloping) or finger (inter locked) joint. Glulam needs good workshop facilities to join together. Structural characteristic values for glulam are determined by the strength class of the timber (s) from which it is made, factored for the number and types of laminates used. The prime use of glulam is to make long-span beams and trusses for long-span column free roofs.

13. Vertical studs and structural beams:- The need to increase yields of medium-density structural timber has focused attention in the last decade on the up grading of lower-grade timber. This has been achieved in a manner similar to that used for glulam in that the battens are cross-cut to remove knots and other defects, dried to 10-20% content, their ends finger-jointed and coated with a durable adhesive (usually PF) prior to assembly into a long batten which, because it is only a single member in thickness, can be heat-cured (unlike glulam). These composite beams and studs are again much stronger and stiffer than the original component parts.

Green weld process:- A fairly recent extension of t his concept has been the gluing of green timber, thereby eliminating the time and cost of kilning This process has been made possible by the development of adhesives with low penetration of timber and high rates of curing. The best known of these adhesives led to the creation of t he green weld process. The process uses a specific phenol-resorcinol formaldehyde resin and an accelerator to give a 5 minute closed press time using conventional finger jointing machines on timber with a moisture content of upto 180% and at temperatures down to 0^0C.

Engineered structural timber

These products are similar in concept to glulam, but are formed from much smaller wooden components.

Laminated veneer (Lumber):- It is produced by bonding thin wood veneers together in a large billet. Of course, laminated veneer is produced from softwood logs that are rotary peeled to produce veneers 3mm in thickness, which after kiln drying, are coated with a PF adhesive and bonded together under pressure to produce large panels. This is then sawn into structural battens. The resulting product features enhanced mechanical properties and dimensional stability that offer a broader range in product width, depth and length than conventional timber. Its characteristic values for design are 50% to 100% higher than corresponding structural softwood timber. Laminated veneer is a member of structural composite timber family of engineered wood products that are commonly used in the same structural applications as conventional sawn timber including rafters, headers, beams, joists, rim boards, studs and columns.

Parallel strand (Lumber):- It consists of long veneered strands laid in parallel formation and bonded together with an adhesive to form a finished structural section. Actually, in this product, 2.5mm thick rotary peeled veneer is cut into strands 2.4m in length and 3m in width, which are then coated with a resin, pressed together and microwave-cured to produce battens upto 20m in length. A strong, consistent material, it has a high load carrying ability and is resistant to seasoning stresses. So it is well suited for use as beams and columns for post and beam construction and for beams, headers and lintels for light framing construction. Of course, it is a member of the structural composite lumber (timber) family of engineered wood products.

Laminated strand (Lumber):- Laminated strand or oriented strand lumber are manufactured from flaked wood strands that have a high length to thickness ratio. Here, the aspen veneer is cut into strands 300mm in length and 10mm in width and coated with IS resin before being aligned parallel to each other and pressed into thick sheets, which are cut up to produce battens. They offer good fastener-holding strength and mechanical connector performance and are commonly used in a variety of applications, such as beams, headers, studs, rim boards and mill work components. These products are members of the structural composite lumber family of engineered wood products. Thus, laminated strand lumber is manufactured from relatively short strands-typically about 1ft long-in contrast to the 2ft to 8ft long strands used in parallel strand lumber.

Cross laminated (lumber):- It is a versatile multilayered panel made of lumber. Each layer of boards is placed cross wise to adjacent layers for increased rigidity and strength. They can be used for long spans and all assemblies e.g. floors, walls and roofs. It has the advantage of faster construction times as the panels are manufactured and finished off site and supplied ready to fit and screw together as a flat pack assembly project.

Finger-jointed lumber:- It is made up of short pieces of wood combined to form longer lengths and is used in door jambs, mouldings and studs. It is also produced in long lengths and wide dimensions for floors.

Impreg and compreg timbers:- They are a class of processed timber products, indicating use of an advanced technology than plywood. In the impreg and compreg timbers, the veneers are treated with suitable types of resins. Depending upon the type of resin, the method of treatment and the type of raw material (veneers) used, there are a variety of such treated timbers.

In case of impreg timber, for instance, the veneers are immersed in resins, commonly phenol formaldehyde at ordinary temperature and pressure. Once the tissue is saturated and the resin is set, the consolidated mass is cured at raised temperature of nearly 150^0C. Then, it is given proper finishing treatment and is marketed under trade names such as sun mica.

The compreg timber, is a particular variety of impreg timber which is prepared by curing the resin impregnated timber at high temperature and high pressure. This type of curing results in a timber of high density and strength that is quite durable.

Various advantages of impreg & compreg timber are:

i) Very beautiful appearance

ii) Almost impervious outer surfaces

iii) Resistance to acids and solutions

iv) High strength, low shrinkage and much durability

Advantages of artificial wood:- Engineered wood products are used in a variety of ways, often in applications similar to solid wood products. Engineered wood products may be preferred over solid wood in some applications due to certain comparative advantages as follows:

i) Many secondary species of timber and all kinds of wood waste can be utilized.

ii) Since it is man-made, it can be designed to meet application specific performance requirements.

iii) These products are versatile and available in a wide variety of thickness, sizes, grades and exposure durability classifications, making the products ideal for use in unlimited applications in industrial and residential construction.

iv) They can be designed and manufactured to maximise the natural strength and stiffness characteristics of wood.

v) The products are very stable and even some of them offer greater structural strength than typical wood building materials.

vi) Engineered wood is felt to offer better structural advantages for residential construction.

vii) Due to cross-grained production, these materials are sufficiently strong in all directions and their shrinkages is less.

viii) Glued laminated timber (glulam) has greater strength and stiffness than comparable dimensional lumber and even, pound for pound, stronger than steel.

ix) They have better insulation properties and their aesthetic appeal can be enhanced.

x) They can be given plastic coating and made functionally superior.

xi) Some artificial wood products offer more design options without sacrificing structural strength.

xii) Engineered wood panels are easy to work with using ordinary tools and basic skills. They can be cut, drilled, routed, joined, glued and fastened. Plywood can be bent to form curved surfaces without loss of strength. Also large panel size speeds up construction by reducing the number of pieces to be handled and installed.

xiii) They make optimal and more efficient use of wood as these can be made from small pieces of wood, wood that has defects or underutilized species.

xiv) Use of artificial timber advocates for sustainable design since it can be produced from relatively small trees rather than large pieces of solid dimensional lumber that requires cuttings of a large tree.

xv) Their high strength to weight ratios makes them suitable for long span beams and trusses, offering flexibility in floor layouts and roof constructions.

Disadvantages

However, the artificial wood products suffers from the following disadvantages:

i) They are flammable and some products way burn more quickly than solid lumber depending upon their resin content.

ii) They require more primary energy for their manufacture than solid lumber.

iii) The adhesives used in some products may be toxic. The release of formaldehyde in the finished product is a concern with some resins and it is often seen with urea-formaldehyde bonded products.

iv) Cutting and otherwise working with some products can expose workers to toxic compounds.

v) Some engineered wood products, such as those specified for interior use, may be weaker and more prone to humidity-induced warping than equivalent solid woods. Most particle and fibre-based boards are not appropriate for outdoor use because they readily soak up water.

1.4 Miscellaneous Materials :

ACOUSTIC MATERIALS

Acoustic is a term used for the science of sound in general. Sometimes it is more commonly used for the special branch of that scene called architectural acoustics which deals with construction of that areas so as to enhance the hearing of speech or music. It could as well be regarded as the branch of technology that deals with the control of sound which show cases the reflective and absorptive properties of sound.

In majority of cases, the acoustics of an enclosure will be satisfactory if a proper balance between sound-absorbing and sound-reflecting materials is created. In achieving this, reverberation as a factor should be taken into consideration. For modifying reverberation, the architect has two types of materials, sound-absorbent and sound reflecting, to coat the surfaces of ceilings, walls and floors. Soft materials such as cork and felt absorb most of the sound that strikes them, although they may reflect some of the low frequency sounds. Hard materials such as stone and metals reflects most of the sound that strikes them. The acoustics of a large auditorium may be very different when it is full from when it is empty; the empty seats reflect sound, where as an audience absorbs sound. Hence, a study of the acoustic properties of various building materials is necessary to facilitate the selection of quality materials that will ensure good acoustics all round a space. Besides there is a emerging branch of study called highway or traffic acoustics, that is concerned with the control of noise level created by traffic and is of recent interest. This encompasses sound barriers or masking of noise etc.

Acoustic properties of building materials:

It acoustics, it is important to distinguish between sound absorption and sound transmission loss. Sound absorbing materials control sound with the spaces and function by allowing the sound to pass through them easily. They are generally porous and absorb sound as a result of many interactions. Conversely, a material or system, that provides a good sound transmission loss is usually non-porous and a good reflector of sound.

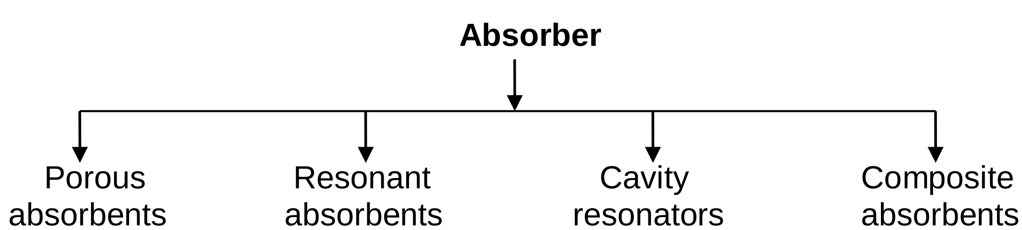
Sound absorptive properties of materials :

The material having hard, rigid and non-porous surface, provide the least absorption, whereas those which are flexible, soft, porous and can vibrate, absorb more sound. The efficiency of sound absorption, however, depends more upon the porosity of the material used as sound absorbent. The term used to express the percentage of the incident sound that can be absorbed by the material is known as absorption coefficient of the material. Thus, if the absorption coefficient of a material is 0.65, this would mean that the material is capable of absorbing 65% of the incident sound. Of course, the absorption coefficient differs with the frequency of the incident sound and in general, low density materials have higher absorption coefficient at higher frequencies than at low frequencies.

Noise is generally controlled within a space using sound absorbing materials. Sound absorption relates to the percentage that effectively disappears when the sound wave hits a body or surface. Sometimes, sound absorption is evaluated by measuring the reverberation time of an enclosure. The reverberation time is defined as the time taken for the noise (sound pressure level) to fall to 60dB below its original level when a sound source ceases to operate. If the reverberation time is long, then the room will be live and the conditions will be acoustically uncomfortable for most activities. If the reverberation time is too short, then sounds such as music may appear flat and lack character. Assuming that the material has greater sound absorption than the room surface on which it is installed, the reverberation times which are again measured will now be shorter than in the empty condition. A hard concrete surface has a very low sound absorption coefficient (less than 0.05 at most frequencies), where as a thick carpet and under lay can approach 1.

Acoustic consultants use the absorption coefficients of materials to estimate the reverberation time of specific buildings. However, in many enclosures, for example small offices, it is sufficient to specify totally covering one or two surfaces with a good sound absorbing product such as carpet or a mineral fiber tile ceiling.

<u>CLASSIFICATION OF SOUND ABSORBING MATERIALS</u>



a) Porous absorbents – When sound wave strikes the surface of porous materials, a part of the ware gets reflected while a part enters the pores of the materials and is thought to be dissipated into heat energy (produced on account of the friction developed between the sound waves in motion in the restricted pores of the material). The efficiency of this type of absorbent increases with the increase in the resistance offered by the material to air flow, its thickness and the porosity. Slag wool, glass wool, wood wool, asbestos fibre spray, foamed plastic and perforated fibre boards are some of the categories of porous absorbents. In general, porous materials are selected mainly to absorb sound having high frequency.

b) Resonant absorbents – In this system, the absorbent material is fixed on sound framing (usually timber) with an air space left out between the framing and the wall at the back. Such an arrangement is most efficient for absorbing sound waves at low frequency. Hence the principle of sound absorption is that sound waves of appropriate frequency cause sympathetic vibrations in the panel which acts as a diaphragm. The absorption of sound takes place by virtue of the dampening of the sympathetic vibration in the panel by means of the air space behind the panel. Dampening effect of this system can be improved appreciably by placing a porous material in the air space.

c) Cavity resonators – A cavity resonator is virtually a container with a small opening and it functions by the resonance of air in it. They can be designed to absorb sound of any frequency.

d) Composite absorbents – These are comparatively of recent development that combines the functions of all the above three absorbents. It consists of perforated panel fixed over an airspace containing porous absorbent. The perforations in the panel should form at least 10% of the total area to allow the porous materials to absorb sound at higher frequencies.

Types of sound absorbing materials :

The most important property of any sound absorbing material is its high sound absorption coefficient. Some of the sound absorbing materials are as described below.

1) Hair felt – This material was used by Mr. Sabin, the father of acoustics, in his experiments on sound absorption. 25 mm thick hair felt provides sound absorption coefficient of 0.60.

2) Quilts and Mats – These are made from materials like mineral wool or glass wool and are mostly used as sound absorbing materials. The sound absorption value depends on its thickness, perforations, density, mode of fixing and frequency of sound.

3) Acoustic plaster – It consists of granulated insulated material mixed with cement. The 20mm thick plaster of this material having density of 0.1 gm / cm^3 has sound

absorbing coefficient of 0.3 at 500 cycles / sec. Accoustic plaster boards are also available in the market which have a coefficient of absorption varying from 0.15 to 0.30. Acoustic plaster is also known by the name fibrous plaster.

4) Straw board – This material is a very good sound absorbent material. It has sound absorption coefficient of 0.30 at 500 cycles / sec with 12 mm thickness.

5) Compressed fibre board – This material is available in perforated or unperforated forms. Perforated forms has sound absorption coefficient of nearly 0.3 unperforated type has the value of coefficient as high as 0.52.

6) Wood wool boards – This material in normally available in thickness of 2.5 cm. Its absorption coefficient is 0.20.

7) Perforated plywood – This material is generally used by suspending it from roofing trusses. Its average value of absorption coefficient when used by forming composite panels with mineral wool and cement asbestos may be as high as 0.95. But, when used with mineral wool and hard boards, the value of its absorption coefficient reduces to 0.2.

8) Compressed wool particle boards – Its absorption coefficient with 13mm thickness is about 0.40. This material has perforations and if required, it can be painted also.

Sound reflective properties or transmission loss of materials :

Sound can be enhanced within a space through the use of reflectors and diffusers. Sound absorption relates to the percentage that effectively disappears when the sound wave hits a body or surface. Transmission loss(TL) is the loss in sound power that results when sound travels through a partition. The more power that is lost, the greater the TL. Also sound absorption is evaluated by measuring the reverberation time of a room. Therefore, wherever possible, we deisgn a space to have an optimum reverberation time for its use. In construction, different building materials are used for the purpose of acoustics and these materials vary accordingly to their location and are also based on the amount of sound required in the space. Also, the idea of curved surfaces is imbided in a way to enhance the reflective properties of the room.

Sound insulating materials:

All the materials absorb sound but to a varying extent. The sound energy has to be ultimately converted into the heat energy. On striking the solid material, the sound waves experience greater resistance than while travelling in air. If the sound waves strikes a resilient and porous surface, considerable energy will be discipated as heat in passing through it pores which are inter connected through a series of small channels. The resultant absorption is relatively very high. The capacity of different materials in absorbing sound depends on the frequency of sound. Sound insulation values of various types of materials and constructions are given in the following table.

Table

Sl. No.	Materials or Type of construction	Average wt (Kg/m2)	Average sound reduction(dB)
	Single panel continuous construction		
1	19.0 mm Particle board	12.00	26
2	3- mm sheet glass	9.5	25
3	10 mm gypsum plaster board	10.0	25
4	6.5 mm plate glass	17.0	28
5	6.0 mm asbestos cement sheet	12.25	26
6	50mm wood – wool cement slab plastered 12.5 mm both sides	70.0	35
7	200mm hollow dense concrete block plastered 12.5mm both sides	245	45
8	Half brick (115 mm) brickwork, plastered 12.5 mm both sides	270	45
9	One brick (230mm) brick work, plastered 12.5 mm both sides	490	50
10	Two brick (460mm) brick work plastered 12.5 mm both sides	930	55

	Semi-discontinuous construction	
1	20mm boarding on timber joints, with 12.5mm gypsum plaster board ceiling with skim coat plaster.	30-35
2	20mm boarding on timber joints with expanded metal lath and 20mm gypsum sanded plastering ceiling.	35-40
3	As in (2), plus pugging on trays at 80kg/m^2 the puging to be air tight (for example, sand & mortar).	
	As in (2), plus floating floor boarding on battens on resilient quilt.	45-48

4	Timber stud partition with metal lath and 20mm plaster both sides (8 kg/m^2).	43-45
5	Double partition of half (115mm) brick each with 50mm cavity and thin wire ties and 12.5 mm plaster both sides.	35
6	Cupboards used as partitions	
	Discontinuous constructions	50-55
7	Two leaves of 60mm concrete plastered and separated by a 50mm air space associated with suspended ceiling and floating floors.	
1		25-35
	a) Measured across the walls	
	b) Measured through the floor	
	As in (1) but with a third leaf or 50mm concrete between the two discontinuous shells, each air space 50mm, measured across the walls or through the floor.	50-60
2	As in (1), but with walls of half (115)mm brick, plastered	65-75
	a) Measured across the walls	
	b) Measured through the floor	66-75
3		
		60-70
		65-70

Sound insulation of timber floors :

Sl. No.	Treatment	Improvement over Sl. No. 1 in dB
1.	Boarding on joist with ceiling of lath and plaster or plaster or plaster on plaster board	0

2.	As in (I) plus carpet or under felt	5-10
3.	As in (I) plus floating floor of boarding on battens on 12.5 mm fibre board	5
4.	As in (I), plus floating floor of boarding on battens on 25mm mineral wool battens	10-15
5.	As in (I), plus pugging of sand or ashes 80 kg/m^2 or mineral wool 10kg/m^2	8-10
6.	As in (I) plus puging of sand or uses 100 gm/m2	10
7.	As in (I) but with floor replaced by boarding on cross battens on 25mm mineral wood batts	5-10
8.	As in(7) plus pugging of sand 50kg/m^2	20
9.	Boarding on Joists with separate joists for ceiling	5
10.	Carpet on under felt with boarding on joists for ceiling as above.	10-15
11.	Boarding on joists, pugging of sand or ashes 10 kg/m^2 with ceiling as above	15
12.	Floating floor, boarding on battens on 25mm mineral wool batts on subboarding, with joists and ceiling as above	15-20

Impact sound insulation of typical floors other than timber floors

Sl. No.	Treatment	Improvement of bare concrete floors (dB)
	Resilient surface material on concrete	
1.	Bare Concrete	0
2.	Linoleum	5
3.	Wood blocks or thin carpet or rubber	5-10
4.	Carpet or under_felt	10
	Floating Floor	

a) 1. 2. b)	50 mm dense concrete screed on : Mineral wool /glass wool quilt 25mm nominal thickness (density 80-120 kg/m^3) Mineral wool batt (density 80 kg/m^3), two nominal 25mm layers. Boarding on battens on :	 15-20 25
1.	Clips unlined	5-10
2.	Asbestos or felt pads, 12.5mm	5-10
3.	Fibre board pads, 12.5mm	10
4.	Felt pads, 25mm or rubber pads, 12.5	10-15
5.	Mineral wool battens, 25mm nominal thickness	15-20
6.	Glass wool battens, 25mm nominal thickness or rubber pads 25mm	15-20
	<u>Suspended ceiling</u>	
1.	10mm (single coat or 12.5 mm (two coats) plasters on 12.5mm fibre board on 50m x 50m battens in clips	5-10
2.	5mm (single coat) or 12.5mm (two coats) plaster on 10mm plaster board, on battens in felt-lined clips	10-15

ACOUSTIC NATURE OF MATERIALS :

1. Concrete, stone and other masonry materials:-

In general, increasing the mass of a wall or floor improves the sound insulation of a building; hence concrete and masonry offer a good barrier to airborne sounds, while the impact sound is easily controlled with appropriate floor and ceiling finishes. Masonry materials are great for sound isolation, especially when used in floors and walls where the masonry material is quite thick. A solid concrete wall, 1 ft thick rarely causes clients to complain about sound isolation, for two reasons. One is the materials rigidity; meaning that it will not flex and create sound waves on the quiet side of the wall. The other is concrete’s mass. Nothing stops sound waves quite like massive materials and they are especially capable of stopping the critical flow frequencies that are so hard to stop with less massive materials. Therefore, good acoustic properties can be achieved for multi-occupancy residences using a range of concrete options; one example being tunnel-form construction, in which the walls, floors and ceilings are made from cast-in-situ concrete using specialist reusable framework. Stone and brick are very similar to concrete in mass and concrete masonry units, although they are lighter, can do a very good job when they are fully filled with concrete, instead of just filling the cells that contain the rebar. Concrete slabs also do a good job of isolating sound between floors- something that is very different to do any other way. Natural clay bricks are great acoustic and thermal performers, they are strong, safe, long lasting, low maintenance and recyclable with colour that never fades.

DL-II Fig-(B-1)

2) Wood and wood products:

Wood is much less dense than masonry and provides much less in the way of sound isolation for that reason. Wood products like MDF, on the other hand are somewhat more massive and are sometimes used in interior walls to add mass. OSB is less dense than MDF, but can be useful as well, as part of an integrated system. Plywood comes in varying densities and again can contribute something to the equation in a multilayered wall.

Wood can produce sound (by direct striking) and can amplify or absorb sound waves originating from other bodies. For these reasons, it is a unique material for musical instruments and other acoustic applications. The pitch of pound produced depends on the frequency of vibration, which is affected by the dimensions, density, moisture content and the modulus elasticity of the wood. Smaller dimensions, lower moisture content and higher density and elasticity produce sounds of higher pitch. However, wood’s real beauty lies in its ability to reflect sound in a pleasing way, meaning that it is a useful material for sound treatment. Since wood reasonates easily, it has a way of absorbing some of the sound energy as it vibrates, letting some of the sound pass through to the other side and reflecting some of the sound back from where it came. This gentle quality of wood is one reason it is widely used in the making of musical instruments and thus wood has a major role to play as an interior finish material in good sounding norms.

When sound wave of extrinsic origin strike wood, they are partly absorbed and party reflected and the wood is set in vibration. The sound can be amplified as in musical instruments or it can be absorbed, as in wooden partitions and barriers. Normally, wood absorb very small portion of acoustic energy(3-5 percent) but special construction in-corporating empty spaces and porous insulation boards can increase absorption to as high as 90 percent. The velocity of sound in wood is reduced by moisture, which therefore contributes to faster damping of sound. However, abnormalities such as delay affect the acoustic properties of wood which must be taken into consideration.

3. Steel:

Steel is a quite dense material, but because of its expense, it is rarely used as a sound insulation material. Steel’s density actually becomes a liability in structural uses where its dense nature causes it to carry sound vibrations for long distances. If one strikes an I-beam with a hammer and place one’s ear to the other end, one can see that the sound carries quite well through the steel. This type of sound transfer is called structure borne vibration, where sound is carried through some material other than air for a time.

Of course, steel studs can actually transmit less structure-borne vibration than wood, even though steel is more prone to this problem simply because flimsy steel studs have much less cross sectional area to carry the vibrations between the two wall surfaces.

4. Dry wall and plaster :

Dry wall is the poor man’s masonry, and for interior walls can provide a lot of mass for the money. But one ½’’ layer doesn’t do all that much. Multiple layers are used in sound studies and broadcast facilities where high mass walls are needed.

5. Roofing:

Asphalt shingles are fairly massive, but they are also thin. Installation with a large overlap, heavy felt and even double layer sheathing can help quite a bit. Ceramic and clay tiles are more massive than wood shakes by far and can do a reasonable job in residential applications. Metal roofing, through has mass but is thin and also requires that the under lying structure be fairly massive.

6. Glass and other transparent materials

The effectiveness of glass as a sound barrier has been known for many years. For example, increasing the thickness of glass will reduce sound transmission through the glass. Since glass is a very dense material, the added weight of thicker glass creates economic and structural concerns that make using thick sheets of solid glass an unattractive choice for most applications. As it turns out, glass is not a good thermal insulator, so in exterior applications, the most common glazing choice is dual-pane or “insulated glazing”. It is typically fabricated from two sheets of glass that are separated by continuous metal spacer placed around the perimeter, then sealed air-tight for all eternity. The sealing process is especially important for exterior applications, because the window may fog up from moisture condensation in the air space if the seal is lost or broken. In the ‘old days’, the typical airgap for an insulated window was about ¼’’ whereas the optimum air space from thermal insulation point of view is about 5/8’’.

Another technique for improving the acoustical performance of glass is to laminate the two layers of glass together with a clear, plastic material. The plastic inner layer bonds to both pieces of glass creating what appears to the naked eye as a single pane of glass. As it turns out, the plastic inner layer (or laminate) provides a significant amount of internal structural damping to the glass. This damping effect has a major impact on the sound transmission properties of glass at high frequencies, especially near its critical frequency. The critical frequency is the acoustic frequency at which the wave length of bending waves in the glass surface equals the wavelength of sound in air. At frequencies in the vicimity of critical frequency, sound waves will pass through the glass much more readily than at other frequencies. This effect (reduced sound isolation in the region of critical frequency) is called the coincidence effect. The critical frequency for glass depends only on the thickness of glass. Thicker glass will have lower critical frequency than thinner glass. Tests have shown that the reduction of sound as it passes through laminated glass in the coincidence frequency region is much greater than with regular (non-laminated) glass. That is to say, the laminated glass provides better sound control than regular glass (of the same total thickness), but the improvement occurs only in the frequency range of the coincidence effect.

Again, glass is quite massive- about three times as massive as dry wall. So in a sound wall with three 5/8'' layers of dry wall on one side, one layer of 5/8'' glass may be inserted to create a window on that side, provided that it is properly sealed. A corresponding piece of glass would be required on the other side of the wall at the appropriate thickness.

A relatively recent development is the invention of absorptive glass like products that offer pretty good transparency while absorbing enough sound to reduce the harsh reflectivity usually associated with glass. These products are made from Plexiglas or thin transparent foils, perforated with tiny holes. Their use is however confined to professional sound studios.

7. Insulating materials (fibre glass, foam, cork wool etc.)

Insulating materials have little mass, so they have limited uses for sound isolation. However, fibre glass has good sound absorption characteristics and is very useful as a sound treatment material for interiors. Fibre glass and rock wool, which have similar acoustic properties, absorb sound by slowing down the velocity of the air particles carrying the wave. Wood, on the other hand, absorbs sound best when in the pressure zone of a sound wave. Sound waves are at highest pressure when at slowest velocity, so care must be taken to place the materials, appropriately. Waves are generally at highest pressure at room boundaries, particularly multiple boundaries like dihedral and trihedral corners.

8. Plastics and Rubber (Vinyl, neoprene)

Plastics are sometimes used in the manufacture of low cost acoustical devices, but have limited usefulness. Rubber, particularly, neoprene rubber is very good as a mechanical isolator- for floating glass and preventing the diaphragmatic vibrations of the glass from transmitting into the wall, for instance.

Mass loaded vinyl can be used inside wall cavities to increase sound isolation, and is hung in a limp, as opposed to stretched fashion.

9. Metals

In case of traffic noise control, metal barriers have some advantages compared to conventional concrete barriers. These metal barriers have narrow and light weight construction which enables these barriers to be built in confined spaces, bridges and flyovers. They have pleasing look and also found to be less obstructive to the surrounding areas.

Fig-B2

DL-II

10. Mechanical and plumbing materials (Duct work, metal and plastic pipes)

Metal and plastic pipes are often transmitters of structure-borne vibrations and can be isolated or deadened with rubber materials. Refrigerant lines are especially bad for transmitting high-pitched whining noises through buildings, so one has to locate them carefully and decouple them from the structure.

Duct work should be of heavy sheet metal, lined with at least 1'' thick acoustic liner. Flex duct is virtually acoustically transparent and should be avoided when you are picky about cross stock between the ducts in attics and other mechanical spaces.

11. Fabrics and other soft materials

Fabrics, carpets and other soft materials can be useful for sound treatment. Heavy stage type curtains are much more effective than thin fabrics. Carpets, although some times better than nothing, can soak up too much mid and high frequency sound while leaving boomy lower frequencies untreated. As part of an overall plan, carpet can be put to good use, but area rugs are much more versatile and adjustable.

12. Auditorium materials:

a) Teak timber wood is used in the wall slats as well as in the stage wall and ceiling panel. It is good for acoustics due to its reflective nature. The timber is treated with a matte varnish. They play with timber slats gives a neutral for the largely red colour scheme taming it.

Fig-(A-1) (DL-II)

b) Fibre board has been used in the acoustic ceiling panels because of its ability to reflect sound in a controlled manner. The dark grey colour used on the fibre board reduces distraction by the ceiling panels keeping the focus on the stage.

Fig-(A-2)

c) Cork flooring has been used because of its durability and its ability to absorb sound. This reduces ambient noise caused by the movement of people within the auditorium. It is also able to handle the expected heavy traffic without requiring much maintenance.

Fig- (A-3)

d) Polyurethane foam has been used in the seats as well as in wall panels at the back of the auditorium. It has been used because of its ability to absorb sound and prevent echo. The seating is designed to absorb sound even when the auditorium is not fully occupied. The seats use high density foam because of its long lasting nature in the heavy traffic area. The wall panels are then covered in dark coloured leather keeping it mute.

Fig-(A-4)

13. Specialty acoustic products

Specialty products generally fall into two categories-those used for sound isolation and those used for acoustical treatment. Those used for sound isolation include various shock absorbs used to isolate air handlers and duct work, and even to float concrete slabs, as well as neoprene isolators used for floating dry wall off of studs (in conjunction with metal furring channel). Specialized door seals also utilize neoprene and the best ones are adjustable, so that the installer can tweak any gaps between the door and the neoprene. Neoprene is also used under floor plates to isolate wall from floors. When specifying neoprene, care must be taken to get the proper durometer or firmness of neoprene, so that it does not bottom out and cease to work as a shock absorber. Sound deadening broad can be used between layers of dry wall or between the dry wall and the studs, to reduce structure borne vibration while also deadening resonances.

Sound treatments for professional sound facilities include absorber and diffuser panels. Diffusors re-scatter sound back into the room, helping to reduce wave interference without absorbing as much sound energy as absorber panels, which must be used judiciously in order to not over-deaden the room. Many home theaters and workshop spaces also utilize absorber and diffuser panels. They can be specified in standard modular dimensions for use in standard T-grid ceilings. Special CMUs are available with a built-in diffusive shape, which, when laid up in the proper sequence can create entire walls of diffusion. In this way, the structure of the building itself can become the subject of sound treatment. Porous CMUs are quite absorbent at mid and high frequencies, so ground-face block are some times used to avoid other absorption at those frequencies. These blocks have build-in Helmholtz reasonators – cavities filled with absorbent that are very effective at low frequencies. Diffuser blox are also used for road side noise barriers, since they are so capable of stopping sound at all frequencies, without reflecting harsh echoes.

(A) Special sound absorbing materials

The following materials have good sound absorbing qualities.

i) Acoustical ceiling tiles : These are light weight non-fibrous ceiling tiles having no fibre glass content. Being moisture resistant are suitable for both indoor and outdoor applications. These are fairly impact resistant.

Of course, these are made up of semi-rigid porous expanded poly-propylene acoustical bead foam (P.E.P.P.) and are non-abrasive, slightly textured and porous. Additionally, these are bacteria and fungi resistant and have a trackable surface.

These are available in nominal size of 2' x 2' or 2' x 4' of 1'' or 2'' thickness of white or charcoal colour. Also available in custom sizes have good flame spread resistance and low smoke generation characteristics. This can be installed by gluing up direct or as a lay-in tile in a suspended T-bar grid system.

These find wide applications in gymnasiums, auditoriums, class rooms, swimming pools, ice arenas, cafeterias and restaurants etc. including enclosures like gun ranges, dog kennels and locker rooms etc.

Fig- Page-5/A-5/DL-III

ii) Noise S.T.O.P Acoustic board :

These are made up of recycled wood fibre residence (cellulosic fibre) having panel sizes of 2' x 4' or 4' x 8' of thickness 1'' or 2''. Except for being low cost, it has good sound deadening, sound absorbing and insulating characteristics. Acoustical board can be used as a flooring underlayment or as a damping layer between studs and gypsum board to improve sound transmission class (STC) of gypsum dry wall partitions in schools, apartment buildings and condominiums. Acoustical board meets the requirements of the specification for cellulosic fibre insulating board.

However, noise S.T.O.P acoustic board is combustible and may smolder if ignited. Therefore, it should not be exposed to flame or prolonged excessive heat above 212^0F without sufficient thermal protection or should be used between layers of non-combustible materials.

iii) Foam S.T.O.P. pyramid (Melamine foam sound absorber)

These are prepared from open cell melamine acoustical foam having pyramid pattern for monolithic appearance, which gives it increased surface area, high performance, light weight and dramatic visual effect. These are available in size of 2'x2' or 2'x4' having thicknesses of 2", 3" or 4" besides being available in custom sizes. These are fibre free high performance absorber having increased absorptive surface area and Class-A fire retardant characteristics. Being available in wide array of colours like natural white, latex, or in cleanable Du Pont Hypalon paint of black, light grey, almond or white, finds their application in ceilings, walls, industrial, commercial, broad-casting and recording studios.

iv) Absorptive / noise barrier quilted curtains:

These are made from melamine foam or fibre glass core, faced with quilted aluminized fabric with optional noise barrier septum. Being available in quilted diamond pattern, it is an effective and durable sound absorber with mass loaded vinyl barrier option. Generally it is used as an economical, effective noise barrier and sound absorber to enclose a variety of noise sources or work areas. The curtains can be custom fabricated to almost any application. Being water and chemical resistant, it can be used in exterior applications like waste water treatment facilities, industrial, commercial and residential applications as cost effective room dividers or equipment enclosures. These are normally available in 48” or 54” width and lengths upto 25’ having thickness of 1”,2,”3” or 4” and can be easily installed with the help of hook and loop fasteners, grommet hangers, curtain span port hardware.

(B) Special sound reflective materials

The following materials have good sound reflective properties necessary to enhance a good acoustics within and outside a space.

i) Silent screen panels:

Silent screen absorption panels are designed to provide both sound absorption and sound transmission loss. These panels consists of individual sections, each 12” wide, mounted horizontally on top of one another or vertically, side by side. Each section consists of a 2 ¾ inch deep, 16 to 22-gauge tray. Typically the tray is filled with six-pound density mineral wool and covered with a perforated 22-gauge face panel.

Fig-A-9/P-II/DL-III

ii) VISTA panels:-

When some degree of visibility is required for safety or monitoring purposes, EAS acoustical panels can incorporate a high strength Lexan type material which has a clarity rivaling glass, but is much stronger. VISTA panels also are abrasion and ultraviolet resistant. These can be easily combined with mineral wool filled panels or double wall panels to solve a wide variety of sight and sound problems.

iii) Reflective panels

Silent screen reflective panels are designed to provide sound transmission loss only. The panels consists of interlocking sections, typically 12” wide, and can be mounted horizontally or vertically. Reflective panels provide a light weight, aesthetically pleasing noise wall and acoustical barrier.

Fig-A-II

iv) Mass loaded vinyl noise barrier:

These are high density limp material to reduce noise transmission. It has a smooth finish and available in various sizes in the form of rolls or sheets. Normally, they have black, grey (reinforced), Tan and Clear (transparent or translucent) colour. They have reduced noise transmission when used in ceilings, walls, floors and machinery enclosures, duct-work etc. The material can be nailed, screwed, stapled or can be reinforced and grometted and hung like a curtain and can be applied over suspended ceilings on studs or joists.

<u>CLADDING FOR BUILDINGS</u>

The term cladding generally refers to the components that are attached to the primary structure of a building to form non-structural external or internal surfaces. This is as opposed to the buildings in which the external surfaces are formed by structural elements themselves, such as masonry walls or applied surfaces such as render. Thus, cladding is the application of one material over another to provide skin or layer intended to control the infiltration of weather elements, or for aesthetic purposes. Cladding does not necessarily have to provide a water proof condition but in instead a control element. This control element may only serve to safely direct water or wind in order to control run off and prevent infiltration into the building structure. This is also a central element for prevention of noise from entering or escaping.

While cladding is generally attached to the structure of the building, it typically does not contribute to its stability. However, cladding does play a structural role, by transferring wind loads, impact loads, snow loads and its own self weight back to the structural frame work. In particular, wind causes positive and negative pressure on the surface of buildings and cladding must have sufficient strength and stiffness to resist this load, both in terms of the type of cladding selected and its connections back to the structure.

Claddings in a building is not only applied on external walls but it can be applied on internal walls, roofs, ceiling, door, windows opening and entrances also. Cladding applied to windows is often referred to as window capping and it is a very specialized field.

Cladding system is often pre-fabricated in panels that are attached to the structural frame of the building and some cladding systems can be purchased ‘‘off the shelf’’. Cladding systems may include additional components, such as windows, doors, gutters, roof lights, vents and so on.

Factors affecting design of cladding:

When selecting or designing a suitable cladding, designers might pay particular attention to :

a) Design detailing

b) Control of air leakage

c) Control of condensation

d) Integrity and continuity of insulation

e) Prevention of water penetration or provision of drainage

f) Control of thermal movement

g) Ease of installation

h) External attachments and fixings

i) Provision of cleaning

j) Maintenance, remedial work and renewal

k) Resilience, strength and durability.

Limitations of cladding:

Wall cladding has also limitations like scarcity of skilled work force for installation, availability of materials, insufficient dissemination of knowledge and the poor quality of materials being supplied by some suppliers. Cladding needs to be carried out by trained professionals to ensure correct installation and thus best results where as today there exists a major issue of trained work force. Of course, cladding is costlier as compared to exterior finish of painting.

Necessity and advantages of cladding:

Cladding is an exterior finishing system skin to a skin or an additional non-load bearing layer which serves a dual purpose. It not only helps in protecting the interiors of the house from the harsh weather elements but also makes the outside decorative and attractive and improving the aesthetic appeal of course, the primary roles of claddings are for weather proofing purposes, while providing a sturdy, graceful and stylish appearance. Additional advantages range from providing sound and thermal insulation to being naturally flame relordant and pollution resistant cladding is needed to :

- Create a corbelled internal environment
- Protect the building from external weathering agents
- Provide privacy and security
- Prevent transmission of sound
- Provide thermal insulation
- Create an external façade
- Prevent the spread of fire
- Generate an air tight building envelope
- Providing opening for access, daylight and ventilation.

Thus, high-quality, well-designed, properly-installed cladding can help maximize thermal performance, minimize air leakage and optimize natural day lighting. This can help reduce the need for mechanical and electrical building services and so improve energy efficiency and lower capital and running costs. Extremely quick to install, when done by professionals, cladding is exceptionally durable and robust and can last for a very long time if looked after properly depending on the quality of materials and weather condition the house endures in a typical year. But poor design, detailing or installation may compromise cladding performance and can even lead to collapse of cladding or cladding panels pulling away from the structure.

Considerations for selection of cladding:

While selecting the appropriate cladding material, a lot of things need to be taken into consideration and one's choice of cladding should be made after careful assessment. Right from the weather and budget to personal preferences, there are several types of cladding materials available which serve different purposes and functions, so one has to find the one that is most suitable for him/her.

The nature of cladding selected for a particular building will depend on considerations such as:

i) How the building is going to be used.

ii) Internal and external conditions.

iii) Durability

iv) Local context

v) Planning requirements

vi) Buildability

vii) Appearance

viii) Availability

ix) Budget

x) Maintenance requirements

xi) Structural requirements

Importance of cladding:

External cladding scores in a number of ways – including its protection against weather elements, relatively lower maintenance (compared to painted exterior surfaces) which is achieved by mere regular washing, ability to reduce water absorption into the building, providing resistance to pollution and increasing the mechanical strength of the structure. It further provides thermal insulation and reduces temperature variation inside the building and improves the acoustic. With its varied finishes (rough, finished and polished) cladding can transform a dull and lifeless structure into a lively enclosure. It can also contribute to green concept in buildings, making them energy efficient.

Types of cladding:

There are a variety of cladding systems. The options are available in materials (stone, brick, wood, RCC, Laminates, plastic, metal) in colours and in techniques (antiscratch, anti-vandal-resistant designs etc.) However, these could be broadly devided based on exposure conditions i.e. external and internal, albeit very often there could be no sharp line of distinction.

External Cladding:

Stone cladding – Stone is a natural and eco-friendly material, which as a cladding material is very popular as it gives a very brilliant earthy and rustic look to the building. They include granite, slate, marble, sand stone, lime stone and kota stone as well as stone veneers. Specific stones such as Jodhpur stone, Jaisalmer stone etc. are also available. Stone cladding helps to create a natural stone look while bringing in a touch of style and elegance to the walls. Perfect for both interiors and exteriors, it exude a feeling of warmth by highlighting some walls. Stone cladding makes use of thin layers of natural or faux stone cut into slabs or panels of uniform thickness which are extremely easy to install, virtually maintenance free and gracefully ages with time. The thihckness of the stone cladding determines its durability – more the thickness, more will be the durability. The maintenance is simpler with textured walls requiring only regular vacuuming or feather dusting to ward of the dust. As in all materials, a proper installation is much needed else stone cladding can lead to leakages especially in rainy zones. Thus, long lasting durability with no painting requirement, a timeless quality, customization but an expensive upfront investement are the features of stone cladding. One also sees an implementation of mosaic stones available in fine texture and durable sheen.

Fig-

The advantages of stone cladding may be enumerated as follows :

a) It acts as very good heat insulating layer which reduces the carbon foot print of the building. It acts as a neutral layer preventing any heatloss or heat gain in the building ultimately leading to energy efficiency.

b) It is an extremely durable material which lasts for a lifetime without loosing its colour or lushine when exposed to direct sun light.

c) It helps in sound insulation by acting a barring between the external sounds and the sounds of the interiors.

d) Stone cladding being a non-prouds and non-absorbent material, does not absorb any moisture and protects the internal walls from water absorption. However, care should be taken that the wall is dry and moisture is not trapped during installation.

e) After all, it is weather resistant.

ii) Wood / Timber cladding :

One of the most popular methods of cladding is through the use of timber soft woods that are relatively knot free and have a natural resistance to decay and moisture. These can be readily stained or painted and altered to create a range of profiles. Hard woods can also be used but often they contain high tannin levels which can result in leaching and streaking after exposure to the weathering elements. Besides, hard wood cladding also requires pre-drilling which can add to installation time and costs. Thermally modified timbers are also being used which are softwoods heated to high temperatures removing moisture and resins resulting in a stable and durable material.

Some of the most common laying styles are as follows:

a) Square edge - A uniform thickness, usually between 12-18mm, while the width of boards vary from 125-225mm.

b) Feather edge- Boards are tapered across their width, producing a rustice, rural aesthetic.

c) Shiplap- Has a shaped front face and profile so that the top of each board fits behind the bottom edge of the adjacent board, providing a heat finish.

d) Tongue and groove-Produce a uniform look that suits the contemporary houses. They have a flat face and in the absence of any over lapping, the way the groove covers the tongue of the board below keeps out rain.

Fig___ C-2

Timber cladding provides a highly attractive and durable external finish which is renewable, reusable, biodegradable and contains minimal embodied energy. It helps create a stunning façade and is a great way to protect the building from the weathering elements. Suitable for both interiors and exteriors, it helps create a highly distinctive character as nothing breaks the look of real wood while blending wall with any décor. Exterior cladding is individually placed and protects the structural integrity of the building while also enhancing the external appearance by several notches. Extremely durable and highly energy efficient, owing to its insulation properties, wood cladding helps to make the home a tranquil heaven. In spite of these merits, it is vulnerable to fire, attack of insects and fungi, deterioration under adverse weather conditions particularly when subjected to alternate wetting and drying, despite being expensive compared to other alternative claddings.

iii) Glass cladding:

Glass cladding helps to transform the building exteriors and offer a gamut of customization and design options. Glass always impresses and this cladding is available in wide range of tempered, laminated, curved and enameled options while being cost effective and convenient.

Further more, glass creates a remarkably modern and contemporary look while offering enormous freedom in shape, design, composition and size, meaning it is optimally suited for modern cladding applications.

FIG – C-3/p--5

Advantages of glass cladding :

1. Use of glass in cladding adds beauty to the building.

2. Its use often fulfills the architectural view for external decoration.

3. Glass cladding in building fulfils the functional requirement of lighting, heat retention and energy saving.

4. It is an excellent cladding material for thermal insulation and water proofing.

5. Glass is fully weather resistant and so it can withstand the effects of wind, rain or sun and can retain its appearance and integrity.

6. Glass does not rust so it does not degrade gradually by chemicals and surrounding environmental effects.

7. Glass has a smooth glossy surface so it is dust proof and can be easily cleaned.

8. Glass is completely recyclable and does not degrade during the recycling process without loss of quality and purity.

9. It is UV stable and hence discolouration does not occur.

10. It has excellent abrasion resistance and hence not easily affected by flat rubbing or contact with another material.

11. It is very light weight and hence does not contribute significantly to the dead load of the building.

Disadvantages of glass cladding :

1. As special glasses are very expensive, it may increase the budget cost of construction work.
2. Since glass is a fragile material, it use also enhances the cost of security.
3. Its use in hilly area and desert may cause more maintenance cost.
4. Use of glass as a cladding material is unsafe for earthquake prone area.
5. Glass absorbs heat and hence act as a green house and so not suitable in warm and hot climates.
6. Glare is a major problem in glass façade buildings.

iv) **Metal profile cladding**

Metal cladding is currently being extensively used as an architectural solution for both internal and external application with various finishes and forming. New metal wall panels can be installed over almost any cladding, including brick, block, pre-cast concrete, stucco, synthetic stucco (EIFS) or even an existing metal system.

Most metal and metal composite wall profiles are fashioned from painted, galvanized steel and aluminum, though natural metals such as zinc and copper as well as stainless steel, are becoming increasingly popular alternatives. Insulated metal wall panels are also widely used in applications where achieving and maintaining a particular temperature range is critical, such as cold storage facilities. Cladding profiles range flush from flat to to several corrugated patterns and other profiles such as trapezoidal, sinusoidal or half round. The profiles are manufactured from sheets of metal fed though banks of forming rollers.

The installation method is standard throughout the industry; typically, 16-gauge metal furring is secured over the existing cladding to provide new sub-framing. The depth of the furring should reflect the insulation thickness and available airspace to reduce energy consumption and waste. The most common installations are vertical, though some design schemes allow for a horizontal layout. To ensure that retrofit metal wall installations are fully moisture resistant, all systems come with matching flashings that are installed around window sills, windows, corners and coping. Of course, the installation of cladding adjacent to roof flashings should always be coordinated with a roofing contractor. When retrofitting a wall system with metal, a professional engineer should be consulted to calculate the load and arises the integrity of spans and furring assess attachments. Before attaching metal to the older masonry walls, it is advisable to conduct a fastener pull out test to determine the stability of the underlying substrate.

FIG-9

Metal cladding is generally a favourite with industrial buildings. Aluminium and steel claddings have changed the way the buildings have ever looked. Steel is used for exterior as well as interior surfaces and comes in various furnishes like mirror, hair-line, texture, custom and perforated designs. Its advantages includes its attractive aestheties durability, resistance to corrosion and flame, termites and its ability to be carved in different shapes. It is a good option in high-humidity surroundings. However, its affinity to rust (except the rust resistant grades like galvanized steel) and regular maintenance have to be kept in mind. Of course, mild and stainless steel are the two primary torms employed. While the mild steel is used for cladding, stainless steel is used for back plashes and furniture tops, balustrades etc. In case of aluminum, solid aluminum, aluminium composite panels (ACP), extruded aluminum are used in wall claddings. They are light weight, non-corrosive and re-cycle able in nature, have high strength to weight ratio and come in diverse colours and finishes (that can mimic other materials like marble or wood). ACP's further come in different varieties-Brush faced, Mirror faced, Wood textured, marble faced, basar and acrylic-based ACP. Extruded aluminum cladding is used for walls, farcades and column covers. However, steel scores over aluminum in terms of strength. But copper, another type of metal cladding is used for its aesthetic alone. Zinc, a very expensive option, is aesthetically eye-catching and is durable. Titanium zinc, gaining popularity in India is said to have a much longer life. Making buildings practically maintenance free, the usage of sealants is avoided in this dry joint system. It also has green properties of zero VOCs, 100% recycle ability and scrap management.

a) Aluminum cladding- Aluminium is an extremely popular choice and is used extensively for cladding purposes. Aluminum cladding with its top notch recyclability and minimal maintenance does not rust or corrode like other metals which help preserve its original design and texture for years at a stretch for proven life time performance. Aluminum is protected through galvanizing, powder coating or anodizing which is totally integrated into the metal to provide all-round protection. Different colours and varying patterns can easily be imprinted on this layer thus providing new and infinite texture and design possibilities for building exteriors without affecting its UV resistance.

Fig ---C-5

b) Aluminum composite panel (ACP) cladding system :

It is made from light aluminum and is frequently used for external cladding as it is very rigid and strong despite being very light in weight. Two sheets of aluminum combine together to a non-aluminum core so as to form a composite aluminum panel. The in fill layer could be polyethylene and the outer layer could further be coated with PVDF (Polyvinylidene fluride) Moreover, aluminium being weather and UV resistant for a bevy of customization options including colours, prints, patterns and shading, available in varying thickness levels; it enable quick installation while also being versatile enough to be used for facias, canopies, partitions and even false ceilings. The salient characteristics of ACPs are:

1) It is a light weight rigid and durable material, mainly used for external cladding of buildings and to create signage. ACP gives a very classy look to the buildings and the design goes very well when combined with glass curtain walling systems.

2) It is weather proof and its colour does not fade after exposure to sun light.

3) ACP is economical and readily available. It is easy to install and requires very low maintenance.

4) It is available in numerous metallic and non-metallic colour options and can very easily imitate the design of wood or marble on it.

5) These panels are relatively cheap and economical when compared to other cladding materials.

6) ACP has very good heat insulation and sound reduction properties.

7) It possesses very good fire resistance.

Fig------C-6

v) Tile cladding -

A fairly new entrant to the cladding world, tile cladding is an extremely versatile option and comes in the form of a panel and tiles suited for both exteriors and interiors of buildings. Long lasting and easy to maintain, these can transform a house to a contemporary abode. One can play with either sleek modern design or opt for a natural textured look. Incredibly durable and long lasting, one can even combine tiles that are of different shapes and sizes to give a house a truly unique and suave look. Moreover, these tiles also act as great insulators thus proving to be energy efficient as well.

Fig- C-7

Tile cladding comes in various materials (concrete, granite, ceramic, brick or glazed tiles, marble, stainless steel) as well as various designs (rustic, strip, wave etc.). Whereas concrete tiles are durable, fire and water resistant (with usage both in load-bearing and non-load bearing walls), the weather resistant granite tiles are good for exteriors as well as interiors (where they can introduce a feeling of sophistication and royalty). Marble tiles, through expensive and relatively needing more maintenance, have remained most popular. Vitrified ceramic tiles have low water absorption (good for cold areas) and are resistant to stain and corrosion. Mosaic cladding tiles find their way in bath rooms since they dry up easily.

vi) Ceramic cladding – Ceramic cladding solutions have been around for ages and been a popular choice for architects around the world for decorative purposes. Being light weight, it requires very little maintenance while possessing a superior resistance to chemical and atmospheric attacks from pollution, acid rain and smog. Its innovative design and durability also facilitate greater versatility in terms tile size and arrangements.

Fig-C-8

The ceramic tiles are available in unlimited colours, designs and textures which make it suitable for cladding options. For ceramic cladding, the substrate is first cleaned and made ready with the adhesives after which the tile is fixed. Mechanical fasteners in the form of nuts and bolts can also be fixed as an additional support so as to prevent the tile from falling from above and creating safety issues. The following are a few more benefits of using ceramic tiles.

1) It has a very good appearance and aesthetic appeal and is usually used to refurbish old buildings by giving it a new look.

2) Ceramic cladding is non-flammable, scratch resistant and resistant to UV rays.

3) Good for thermal insulation and has heat saving properties.

4) Very good for noise insulation.

5) Ceramic cladding has relatively low weight giving little addition to dead load of the structure and is cheaper than other cladding materials like glass.

viii) Porcelain Cladding :

Porcelain cladding is widely used as a means for external cladding because of its exceptional properties. Scratch and abrasion resistant with a surface tougher than granite or steel, it is durable, tough and extremely strong and does not accumulate surface dirt. Additionally, it is non-porous and impervious to chemicals while also being freeze and thermal shock resistant, which makes it the ideal material for creating cost effective, low-maintenance and hard-wearing surfaces.

Fig- C-9

Manufacturing porcelain tiles that have low levels of water absorption requires the use of pure day and selection of minerals. They are then shaped through the process of dry pressing before being fired at temperatures in excess of 1200^{0}C. Fully verified tiles, that are stronger than natural stone is resulted from this process. They make a very reliable, durable and attractive building material for use in either external or internal surfaces. Because of these qualities, they have a number of possible building applications that other cladding materials are not suited to.

viii) Un-plasticized polyvinyl chloride (uPVC) cladding:

One of the cheaper forms of cladding is uPVC with white being the cheapest option. It often has fewer detailing requirements than timber and requires less maintenance, although it can dis-colour with age. uPVC cladding helps to add a different dimension to a building and requires absolutely zero maintenance. This basically translates to no time – consuming painting or cumbersome repains. Ideal for both internal and external walls, uPVC cladding not only suits every kind of home but also not prone to severe damage by weathering elements. Besides being economical, its quite easy to add insulation as well, can be fully customized and comes in a range of colours. Of course, seen mostly in interiors and somewhat in exterior cladding too, uPVC, on account of its water resistant nature scores as a good bet in wet areas like kitchens and bath rooms. It comes out to be much cheaper (as compared to wood, fibre, cement, stucco, brick and stone sidings) and easier to install than tiling and exists in a variety of colours and styles. The accumulated dirt is easier to clean however, it remains a non-friendly environmental material.

Fig- C-10

ix) Miscellaneous cladding materials and systems :

a) Concrete cladding-Used for commercial, industrial, institutional and residential applications, glass-fibre-reinforced concrete (GRC) is used as a cladding material for decorative purposes. With easy maintenance and installation, and without any requirement of painting and plastering, they can be fixed directly over brick work or masonry.

b) Bricks cladding and brick slips – A cheaper alternative and one that has been used for a long time, brick cladding repels water and asthetically can be stimulating with its variety of patterns or courses that it can run into. In abroad, the dry form of construction without mortar also exists.

Brick slips are thin layers of masonry and are of similar appearance to conventional bricks. They are available in a variety of styles and colours.

c) Shakes and shingle – Shakes and shingles are produced from split logs and look similar to timber tiles. Shakes are typically split from the log using a chiesel and mallet whilist shingles are sawn off.

d) Boards – The market today has designer and compressed cement boards, gypsum boards, calcium silicate boards, fibre cement boards, e-boards and even eco-friendly boards. These can be finished in various options. Laminates also remain an ideal option for interiors. Today high pressure laminates (which control the growth of harmful bacteria) are used in places like hospitals where hygiene is most important.

e) Unique cladding materials - many innovative cladding materials are being noticed in buildings today especially in public buildings. There are materials like dichroic film which can reflect light. Weinberger's use of clay roof files as façade coverings is an innovation too.

f) Curtain walling – Curtain wall systems are a non-structural cladding systems for the external walls of buildings. They are generally associated with large, multistorey buildings. Typically curtain wall systems comprise a light weight aluminum frame on to which a glazed or opaque in fill panels can be fixed. These infil panels are often described as 'glazing' whether or not they are made of glass.

g) Sandwitch panels – Sandwitch panels (some times referred to as composite panels or structural insulating panels (SIP) consists of two layers of a rigid material bonded to either side of a light weight core, so that the three components act as a composite. They are used in applications where combination of high structural rigidity and low weight is required. Its versatility means that the panels have many applications and come in many forms; the core and skin materials can vary widely and the core may be honey-comb or a solid filling. These cladding have good energy efficiency and sustainability.

h) Patent glazing – The term patent glazing refers to a non-load bearing, two-edge support cladding system. Palent glazing bars provide continuous support along two edges of glazing infill panels (rather than four edge curtain walling) and are fixed back to the main structure of the building. This system supports its own weight and provides resistance to wind and snow loading; but does not contribute to the stability of the primary structure of the building.

i) Rain screen – A rain screen (sometimes referred to as a 'drained and ventilated' or 'pressure equalized' façade) is part of a double wall construction. The rain screen cladding includes an outer skin (of rear-ventilated) cladding attached to an existing / new building. While the outer layer takes care of the exterior weather elements, the inner layer provides thermal insulation and carries the wind load, hence conserving energy. The rain screen it self simply prevents significant amounts of water from penetrating into the wall construction. Thermal insulation, air tightness and structural stability are provided by the second, inner part of the wall construction. Therefore, in this kind of cladding, the structural frame is maintained absolutely dry and a ventilated cavity acts as defence against any moisture that may seep from the exterior to the interior layer, besides allowing ventilation.

Internal cladding:

There are several types of wall cladding and they serve differently. Cladding being one of the most important parts of a house, one will need appropriate material for it to achieve efficiency and comfort.

i) Vinyl cladding – It is the most common cladding material in developed countries. Houses use this material because its gives enough protection while remaining affordable for most people. However, it is not as good as wood or other superior cladding materials.

ii) Aluminium cladding – Compared to vinyl, aluminium cladding is a lot more expensive. However, this material offers better durability that allows less frequent replacement and more long lasting cladding for wall. It is used on specific rooms like storage and basement.

iii) Wooden cladding – This cladding is a lot stronger than aluminium and vinyl but it is used commonly on aesthetic reason. The cladding is commonly from teak or deodar etc. While at one time wood was used only for paneling, but today entire walls are covered in wood. Several wood alike materials and products are also being used now which are equivalent in their look to wooden cladding. Even in adverse weather conditions they are known to retain their textures. But it needs expensive maintenance and the installation also costs a lot.

Fig___C -11

iv) Fibre cement cladding – This material is alternative for strength and aesthetic. It is strong enough and it is made to appear like it is made of wood. However, the installation is pretty affordable and it needs almost no maintenance action.

v) Brick cladding – Brick cladding will add nice detail inside a house. However it is hard to install and it can cost a lot of money too. Those people who does not like wood, they commonly choose bricks. Even though it is expensive, brick is pretty long lasting.

vi) Stone cladding – Unlike brick, stone cladding is considered fresh and more natural. People like to use it indoor in their bathroom, indoor garden, living room and any other rooms. It is long lasting but it takes huge effort to install and much money for it.

vii) Laminate cladding – This cladding is better than the ceramic tiles. It is commonly used on wet areas like bathrooms. It is strong and it doesn’t chip or fade. This alternative is also cheaper compared to any other cladding options.

Fig- C-12

viii) Steel cladding – Even though rare enough, some houses and buildings use this material for interior cladding. Houses and buildings with a lot of storms and extreme weather should use this. It is long lasting even though quite expensive.

ix) Wall papers – Used for interior decorative cladding, wall papers find their presence in residences, hotels, resorts or in offices. Used for completely aesthetic purposes, they are available in infinite number of patterns and designs and can completely alter the look of the interiors. Due to their texture and sheen, they score over paints. They are paper, vinyl and real fabric based. It is a quick fix solution and today there are environment-friendly wall papers plus digital wall coverings too using latest digital printing techniques to create amazing patterns available in rich colours.

As mentioned above, each material has its own values and benefits. It depends on our needs and personal preferences. Financial condition, weather and climate as well as style preference has a lot to do with the choosing of the right type of cladding.

Plaster Board

Plaster board or dry wall, is a remarkably versatile product consisting of gypsum
plaster sandwitched between layers of thick paper. It is usually used on walls and ceiling and can be plastered over or painted. Thus, plaster board is basically an inner layer of gypsum sandwitched between two outer layers of lining paper including various additives in the gypsum layer, and varying the weight and strength of the lining paper, will give the finished board different properties.

There are various types of plaster boards to cater for most situations found in the domestic or commercial environment. Plaster board is a popular building product and has become a standard covering for stud partioning and ceilings. It is also used to line internal masonry walls where the sheets are simply attached to the masonry by using dab of adhesive such wall linings are referred to as dry lining. Variations to the plaster recipe or the sandwitching material can result in plaster board sheets which are water resistant or can be used for sound proofing. However, the glass-fibre-reinforced gypsum board is not made in the traditional way with paper lining. Instead, the boards are strengthened with layers of glass-fibre immediately below each surface. This gives them good all-round performance, a high quality durable plaster finish and enables them to be easily bent for use on curved structures. They are excellent for semi-exposed areas such as soffits or the like. Of course, while standard plaster board is ideal for most environments, it should not be used in constantly wet conditions. For kitchens, bathrooms and similar wet areas, specially designed fibre boards with silicone additives in the core or a highly water resistant non-combustible glass reinforced gypsum board, should be used. Various makes of plaster board are used for different situations and hence a different type of board is used when the surface is to be plastered opposed to be painted.

Installation of gypsum boards:- Standard sheets of plaster boards are traditionally available in sizes of 8ft x 4ft (2.4m x 1.2m), but smaller sheets called plaster board laths are also available for easy transportation and ease of handling. However, plaster boards of lengths upto 6m and width upto 1350mm are also available. Other widths are available for specific systems, for instance 900mm width for the metal stud housing participation system and 600mm sheets for use where the space is limited. Plaster board comes in several thicknesses including 9.5mm or 3/8 inch and 12-5mm or 1/2inch. However, 15mm and 19mm sheets of plaster board are not uncommon for boards which have a specific task such as fire proofing or sound insulation. Ceiling plaster board needs to be reinforced for strength, so it tends to be slightly thicker. Of course, most walls are constructed using 9.5mm or say 10mm thick plaster board. Once, the frame of the house has been erected and the wiring and plumbing have been installed, it is ready to install plaster board to create interior walls and ceilings.

Most plastered boards comes with the option of either tapered edge or untapered / square edge. Tapered edge boards are ideal for either joining or skimming, while square edge is generally used for textured finishes. Tapered board tapers in thickness towards the edges. This is the more common style and in most cases, is easier to use provided that the taper on two pieces butt together, the joint can then be concealed by using scrim and joint compound to fill the depression resulting from the tapers. Untapered boards having square edges makes it hard to achieve a hidden seam unless the surface in skimmed with plaster.

Most plaster boards have a white or ivory paper finish on one side with the other side being a grey or brown thicker paper. The white or ivory paper size is front side (i.e. the finished side for decorating) and the liner on this face is specially designed to accept a plaster skim or other finishes-the grey or brown side is not suitable for any type of finish.

When used in modern dry lining techniques, the front face is often not given a plaster skim. Although, wall paper can be directly applied to the front surface, but this might cause a problem, when the wall paper needs to be removed for redecoration. So before wall papering directly onto new plaster board, a couple of coats of dry wall primer should be applied which will make it easier to strip the wall paper when that becomes necessary.

Joint cracking on plaster board ceilings is almost invariably caused by warping of the joists as the wood dries out. Screw fixing the boards will generally prevent the occurrence of this problem. To avoid seeing any joints in the plaster board wall, as discussed earlier, a tapered board is used when the wall is to be painted. This means the thickness of the board is reduced very slightly as one moves towards the edge. Two thin edges are butted upto each other and same plaster board tape is stuck over the joint. Then, a thin layer of plaster board joint filler is applied with a wide scrapper and lightly sanded down so the surface of the filler finishes absolutely flush with the face of the board. This means the joint is not noticeable and the plaster board tape stops the filler cracking, should the wall move at all.

Types of plaster board:-

There are a number of types of plaster board, each with its own characteristics which makes it most suited to particular uses.

i) **Wall board:-** It is the basic type or common type and is used to line ceilings, stud portioning and is also used in dry lining. It is simply made up of a layer of hardened gypsum plaster between two layers of paper and is suitable for most applications where normal sound levels, structural properties and fire specifications are found. However, this normal wall board can be fixed at a double thickness to give greater resistance with fire and sound levels. It is usual to plaster on to the ivory or white face of the board and decorate directly onto the brown or grey face but it makes no real difference which way round the board is fixed.

ii) **Insulated board:-** It is similar to common plaster board but incorporates a layer of insulating foam to the rear side to improve its thermal insulation.

Iii) **Damp proof board:-** Damp proof board is similar to ordinary plaster board but incorporates a damp proof membrane on the rear face, usually a coloured silver foil.

iv) **Moisture / water resistant board:-** This type of plaster board has water repellant additives in the core making them suitable for base for tiling some wet areas. This type of plaster board usually comes with a green face and is not usually plastered. They are excellent for high humidity areas like bathrooms, showers, kitchens etc. where it could come in contact with water (although not immersed in it). But as all gypsum plasters soak up moisture quickly, it would be counterproductive to plaster them.

v) **Sound insulation or acoustic plaster board:-** It is characterized by a higher density core providing a good level of sound insulation. It is effective on thin walls and ceilings making it very useful in blocks of flats. It is most often used in conjunction with mineral wood and various sound proofing fixing methods such as resilient bars which keep the surfaces of the board slightly away from the surface they are on to prevent the passage of sound vibrations.

vi) **Fire resistant board:-** It offers increases resistance to fire. Although other types of plaster board do offer certain degree of fire barrier, but the fire resistant board has much better resistance, because it has glass fibre and alter additives in the core to protect against fire in most domestic situations. Usually fire resistant plaster-boards come with a pink face which can be painted or plastered.

vii) **Vapour barrier / vapor check plaster board:-** This plaster board has a thin metallic film on the reverse of the sheet. This film stops warm vapoors from passing through the board which could lead to condensation when they come in contact with a colder surface. It is commonly used when dry lining a building to keep it warm and well insulated.

viii) **Impact plaster board:-** It has a very dense core designed to resist impact and day to day knocks.

ix) 4-in-1 plaster board:- With recent developments in technology some manufactures now produce plaster board that features not only ability to be used as a normal wall board but are also water proof, fire resistant and also impact resistant.

Most of the above boards are available in taper edge and vapour check and all can be used in dry lining situation.

Advantages of plaster board:-

The plaster board has following advantages:

i) **Ease of installation:-** Installing plaster board is relatively simple and effective method of creating interior surfaces inside the building.

ii) **Fast and affordable:-** It is fast to set up and affordable because using plaster board as a wall finish can be much cheaper than the wet plastering.

iii) **Versatile finishing:-** Once the plaster board is installed, it can be easily finished with various treatments including paint, wall paper, tiles, wainscoting and rendering.

iv) **Sound insulation:-** Plaster board is good for cutting down noise transmission particularly air borne sounds such as speech and music. High performance plaster boards have a specially designed core that provides even better insulation against sound.

v) **Fire resistance:-** It has good fire resistance because gypsum is made up of crystals containing a small amount of inbuilt water called the water of crystallization. In a fire this water in driven-off, helping to keep the temperature of the fire down and preventing rapid spread of fire. Plaster boards are therefore used extensively for fire protection proving upto 4 hours protection in some special multi-layer system applications.

vi) **Easy to repair:-** Plaster board is easy to repair. It can hold onto any excess interior paint if it is needed to paint over plaster board patches.

vii) **Recyclable and low environmental impact:-** The constituents of plaster board are recyclable and it has a relatively low environmental impact since paper liners are generally made from recycled paper which is a big plus for the environment.

Disadvantages:-

The plaster board suffers from the following disadvantages.

i) **Prone to cracks and breaks:-** Plaster board is quite thin and brittle, which makes it vulnerable to cracks and breaks.

ii) **Vulnerable to immersion in water:-** Paper plaster board ordinarily does not tolerate flooding with water. If it comes in contact with excessive amounts of moisture, it will become mouldly and will need to be replaced.

Micro-Silica

Micro-Silica, also known as silica fumes, is an amorphous (non-crystalline) polymorph of silicon dioxide. It is an ultra fine powder collected as a by product of the silicon and ferrosilicon alloy production and consists of spherical silicon oxide particles with an average particle diameter of 150 nanometer (nm) or 0.15 μ and extremely high specific surface. Silica fume is usually categorized as a supplementary cementious material; exhibiting pozzolanic properties, cementious properties and a combination of both the properties. Due to these properties, it can affect the behavior of concrete in a variety of ways, the main field of application being as pozzolanic material for high performance concrete. When added to concrete in doses of around 30kg/m^3, it changes the rheology and reacts with the cement hydration products to dramatically improve concrete strengths, durability and impermeability, thereby allowing concrete to be used in ways never before possible. It has been shown that the Portland cement-based-concretes containing silica fumes have very high strengths and low porosities. Extensive research and further development of silica fume has made it one of the world's most valuable and versatile admixtures for concrete and cementitious products. Preliminary indications suggest that micro silica may be useful in controlling heat generation in mass concrete. It has also been found useful in combination with flyash. Early-age strength development of concrete in which flyash replaces cement tends to be slow because flyash is relatively inert during this period of hydration. Adding micro-silica, which is more reactive in early hydration, can speed the strength development. Durability of OPC based concrete is considerably enhanced due to the use of micro-silica.

Production / Manufacture:-

Silica fume is a byproduct in the carbo thermic reduction of high-purity quartz with carbonaceous materials like coal, coke, wood-chips, in electric-arc-furnances in the industrial production of elemental silicon and ferrosilicon alloys. The ferrosilicon or silicon product is drawn off as liquid from the bottom of the furnance and the vapour rising from the furnance bed at a temperature of around 2000^{0}C is oxidized which when cooled condenses into particles that are trapped in huge cloth bags. Processing of this condensed fume to remove impurities and control particle size yields micro-silica. The chemical and physical properties of this inorganic product are different as compared to other amorphous and crystalline silica polymorphs.

Properties:-

Silica fume is an ultrafine material with spherical particles less than 1 μ in diameter, generally 100 to 50 times finer than average cement or flyash particle. The bulk density of silica fume depends on the degree of densification in the silo and varies from 130 (undersified) to 600kg/m^3. The specific gravity of silica fume is generally in the range of 2.2 to 2.3. The specific surface area of silica fume can be measured with the BET method or nitrogen absorption method. It typically ranges from 15000 to 30000 m^2/kg.

Typical physical and chemical composition of micro-silica / silica fume

Parameter	Unit	Values / Magnitude
SiO_2 content	%	90-98
CaO content	%	0.2-0.7
Al_2O_3 content	%	0.4-0.9
Fe_2O_3 content	%	1-2
Other	%	2-3
Bulk density	Kg/m^3	550-650
Specific gravity	-	2.2-2.3
Specific surface	m^2/kg	20000

Due to this unique chemical and physical properties, micro-silica has become a versatile mineral admixture for a multitude of applications as a property enhancer. Micro-silica in concrete contributes to its strength and durability in two ways:

As a pozzolanic material, micro silica provides a more uniform distribution and a greater volume of hydration products. As a filler, micro-silica decreases the average size of pores in the cement paste.

However, the effectiveness of micro-silica as a pozzolamic material or as a filler depends largely on its composition and particle size which in turn depends on the design of the furnance and the composition of raw materials with which the furnance is charged.

Working mechanism of micro-silica in concrete:-

Micro-silica enhances the property of concrete through following mechanisms.

a) Pozzolanic effect:- When water is added to Ordinary Portland Cement (OPC), hydration occurs forming two products as shown below:

OPC+H_2O→ Calcium Silicate Hydrate+ Ca $(OH)_2$

In presence of micro-silica, the silicon dioxide from the micro-silica will react with the calcium hydroxide to produce more aggregate binding calcium Calcium Silicate Hydrate as follows:

$C(OH)_2$+SiO_2+H_2O→ Calcium Silicate Hydrate

Thus, the reaction reduces the amount of calcium hydroxide in the concrete. The weaker calcium hydroxide does not contribute to the strength, rather when combined with carbon dioxide, it forms a soluble salt which will leach through the concrete causing efflorescence, a familiar architectural problem. Concrete is also more vulnerable to sulphate attack, chemical attack and adverse alkali-aggregate reactions when high amounts of calcium hydroxide is present in concrete.

b) **Micro filler effect:-** Micro-silica is an extremely fine material, with an average diameter of about 100 times finer than cement. At a typical dosage of 8% by weight of cement, approximately 100000 particles for each grain of cement will fill the water spaces in fresh concrete. This eliminates bleeding and the weak transition zone between the aggregate and paste found in normal concrete. This micro filler effect will greatly reduce permeability and improve the paste-to-aggregate bond of silica fume concrete compared to conventional concrete. The silica react rapidly providing high early age strength and durability. The efficiency of micro-silica is 3-5 times that of OPC and consequently vastly improved concrete performance can be obtained.

Finer than flyash, this pozzolana increases strength and density, reduces concrete permeability. Since micro-silica particles are only about 1/100 the size of cement grains, the material may be hard to batch and ship. These handling problems may be overcome by mixing. Micro-silica with water (and sometimes other admixtures) in a slurry which replaces part of the normal concrete mixing water. Densification and pelletization may be adopted to simplify the mixing and handling.

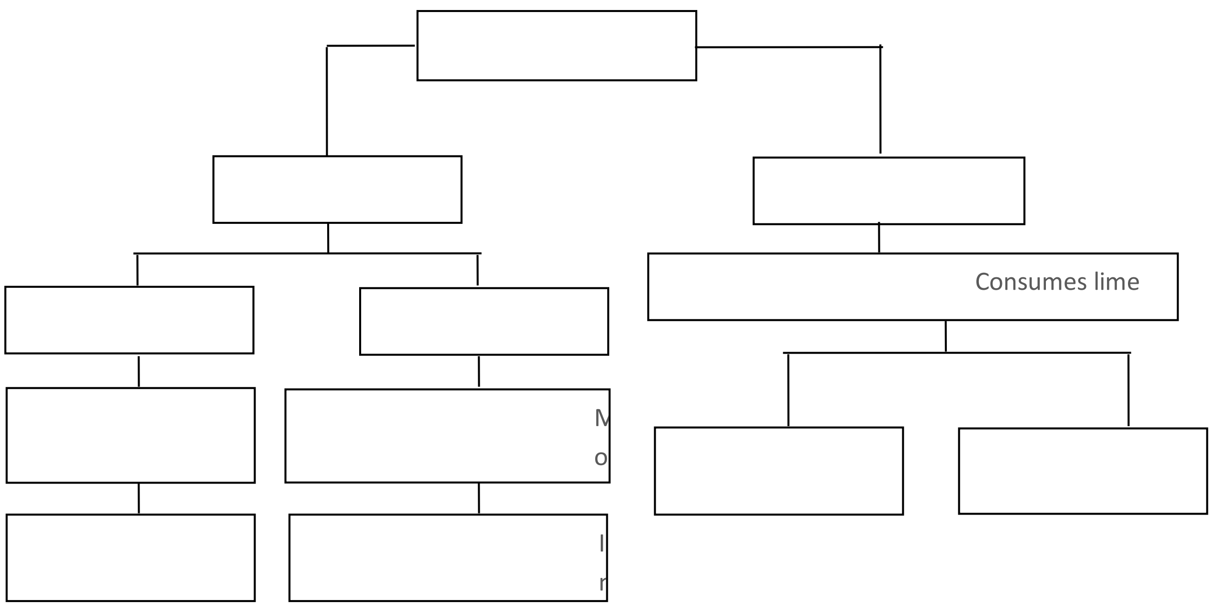


Figure- Flow chart of micro-silica for improving concrete

Uses of micro-silica:-

Now-a-days, more than 500,000MT of micro-silica are sold to the building industry world-wide and are used in fibre cement, concrete, oil well drilling, refractories and even in polymers. Micro-silica contains trace amount of heavy metal oxides and organic deposits, which originate from natural raw materials. Since the concentration of these impurities is very low, micro-silica complies with the company policies and international regulations from Health Safety and Environment stand point. Recently micro-silica based concrete is being used for bridge deck overlay and repair of dam stilling basins for its excellent abrasion resistance.

Advantages /application of silica fume in concrete:-

Owing to the pozzolanic and micro filler effect of micro-silica, its use in concrete can improve many of its vital properties opening up a wide range of applications. At present, there is no standard specifications for silica fume or its applications. Dosages of micro-silica used in concrete have typically been in the range of 5 to 20 percent by weight of cement, but percentage as high as 40 have been reported. The following are its major advantages or effects on the properties of fresh and hardened concrete.

i) Corrosion Resistance:- The reduced permeability of micro-silica provides protection against intrusion of chloride ions thereby increasing the time take for the chloride ions to reach the steel bars embedded in concrete and initiate corrosion. In addition, micro-silica concrete has much higher electrical resistivity compared to OPC concrete thus slowing down the corrosion rate. The combined effect generally increases structure's life appreciably.

ii) Sulphate Resistance:- Micro-silica concrete has a low penetrability and high chemical resistance that provides a higher degree of protection against sulphates than low C_3A sulphate resisting cements or other cementitious binder systems.

iii) Heat Reduction:- By replacing a part of binder (cement) with micro-silica, it has been observed that a lower maximum temperatures rise and temperature differential will take place for concrete with the same strength. It performs better than slag and fly-ash blends in thick sections or mass concreting operations. It is also the most effective way of achieving low heat without sacrificing early age strength.

iv) Water Proof Concrete:- Because of its low permeability, micro-silica can be used as an integral water-proofer for underground structures where some dampness is acceptable, e.g. car parkings.

v) High Strength Concrete:- Micro-silica in conjunction with super-plasticizers is used to produce very high strength concrete (70-120Mpa).

vi) Pumped Concrete / Shotcrete :- Micro-silica may be used in shotcrete whether produced by wet or dry process to reduce the rebound, to increase the application thickness per for pass, improvement of wash out resistance in marine construction or wet areas as well as to improve the properties of hardened concrete. With fibres it can eliminate mesh and reduce cracking. As silica fumes enhances plasticity it is much easier to pump micro-silica concrete up the high rise buildings during construction.

vii) **Early Strength Development:-** When used in combination with fly-ash, it aids in early strength development in concrete. Concrete in which fly-ash is used as a replacement for cement, the early age strength development tends to be slow since fly-ash is relatively inert during this stage of hydration. However, addition of micro-silica, which is more reactive in early hydration, can hasten the strength development.

viii) **Abrasion Resistance:-** Micro-silica concrete has very high abrasion resistance. In floor and pavement construction, its use is economical and time saving and improves operational efficiency. It also enhances the hydraulic abrasion-erosion resistance of concrete thus making it suitable for use in dam spill ways.

ix) **Chemical Resistance:-** Micro-silica concrete is widely used in industrial structures exposed to an array of aggressive chemicals. In the alimentary industry, the exposure occurs from the fatty acids and other acids, detergents etc. In the chemical industry, there is exposure from mineral acids, phosphates, nitrates petrochemicals etc. Micro-silica concrete is therefore, in valuable in industrial and agricultural sectors.

x) **Reduced segregation and bleeding:-** Use of silica flume reduces bleeding significantly in concrete, because the free water is consumed in wetting large surface area of silica flume causing reduction of bleeding. It is also responsible for blocking the pores in fresh concrete, so water within the concrete is not allowed to come out preventing segregation.

x) **Freeze-thaw durability:-** The small micro silica particles are very good at infiltrating and plugging capillary pores in concrete-making pores smaller and fewer and concrete more dense. This gives the concrete good resistance to freezing and thawing.

Disadvantages or limitations:- The loss of slump in concrete mix with time is directly proportional to increase in silica fume content due to introduction of large surface area in the mix due to its addition. When no water reducing agent is used, the addition of micro silica to concrete mix calls for more water to maintain a given slump. However, the water content can be held the same by using a super plasticizer along with the micro-silica.

Artificial Sand

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles, being finer than gravel and coarser than silt. The main natural and cheapest source of sand is river or nallah. Natural or river sands are weathered or worn out particles of rock and are of various grades or sizes depending upon the amount of wearing. Also the composition of sand varies depending on the local sources and conditions. It is a fact that the natural sand, which is available locally, are often deficient in many respects. It may not have required gradation and the presence of deleterious materials and other impurities makes it inferior for use in construction, because they shorted the life of the work. Thus, not all but a few deposits of natural sand are suitable for construction activities such as for making concrete, mortar or building blocks. Because of the rapid growth of population and consequent construction actively, there is huge demand for this kind of sand, where as the natural resources are running low. Now-a-days, good sand is not readily available and it has to be transported from a long distance. Also use of sand in large quantities has resulted in extensive dredging operation, raising several environmental concerns and government have put a ban on the uncontrolled dredging of sand from the river bed. This has necessitated to find some suitable substitute for natural river sand called artificial or manufactured sand. The artificial sand of required gradation and characteristics produced by proper machines has been found to be a better replacement of natural sand. However, artificial sand affects the workability of concrete adversely making it stiff which can be improved by the use of fly ash.

Manufacture of artificial sand:-

Artificial sand is manufactured from stones of required quality generally granite or basalt and the process involves three stages i.e. crushing, screening and washing. The crushing of stones into aggregates is done by vertical shaft impactor (VSI) machine and then fed to rotopactor to crush aggregates into sand of required grain sizes (as fines). Screening is done to eliminate dust particles and washing of sand eliminates the presence of very fine particles within. The end product should satisfy all the requirements of relevant standard code of practice to be used in concrete and other construction work. The VSI plants are available in capacities upto 400t per hour. Only the sand manufactured by the VSI crusher or Rotopactor is cubical in shape with rounded edges. Sand made by other types of machines such as jaw crusher, core crusher or roll crusher often contain higher percentage of dust and have flaky / angular particles which are unsuitable.

General requirements of manufactured sand:-

1. All the sand particles should have uniform as well as higher crushing strength.
2. The surface texture of the particles should be smooth for less water requirement for lubrication.
3. The shape of the particles should be cubical and edges should be rounded for better workability and strength.
4. The ratio of fines below 600μ in sand should not be less than 30%.
5. It should be free from organic impurities.
6. The silt content in sand should not be more than 2% for crushed sand.
7. The permissible limit of fines below 75μ in manufactured sand should not exceed 15%.

Properties of artificial sand:-

Table-A

Comparative technical specification- Natural Vs Artificial Sand

Sl. No.	Property / Characteristics	Natural sand	Artificial sand	Remarks

1.	Shape of particles	Spherical	Cubical	Good
2.	Percentage of fines passing 75μ sieve	Presence of silt shall be less than 3%	Presence of dust particle shall be less than 15%	Limit 3% for uncrushed and 15% for crushed sand
3.	Silt and organic impurities	May be present	Absent	Limit 5% for uncrushed and 2% for crushed sand
4.	Specific gravity	2.3-2.7	2.5-2.9	May vary depending on source
5.	Water absorption	1.5-3%	2-4%	Limit 2%
6.	Gradation	No control	Can be controlled	-
7.	Ability to hold surface moisture	Upto 7%	Upto 10%	-
8.	Grading zone and fineness modulus (FM)	Zone II & III FM 2.2-2.8	Zone II FM 2.6-3.0	Recommended for concrete
9.	Soundness (Sodium Sulphate- SS and Magnesium Sulphate-MS) (5cycles)	Relatively less sound (Ex.>5)	Relatively sound (Ex<5)	Limit 10% SS 15%MS
10.	Alkali- silica reactivity	0.002-0.01	0.001-0.008	Limit 0.1% expansion

Table-B

Comparative behavior of Natural Vs Artificial Sand

when used in concrete & mortar

Sl. No.	Property / Characteristic	Natural sand	Artificial sand	Remarks`
1.	Workability and its retention	Good and good retention	Less and less retention	Control of fines & use of plasticizers
2.	Setting	Normal	Comparatively faster	Water absorption correction and use of retarders

3.	Compressive strength	Normal	Marginally higher	-
4.	Permeability	Poor	Very poor	Ideal for water proof structures
5.	Cracks	Nil	Tend to surface crack	Early curing & protection of fresh concrete

Advantages of artificial sand:-

Of course, the sand in the concrete does not add any strength but is used as an filler / adulterant for economy. It also prevents the shrinkage and cracking of mortar in setting. When sand is in proper gradation, it results in less voids and the cement requirement decreases. Thus use of such sand will be more economical.

It has been observed that the strength of concrete increases with artificial sand. Moreover, the presence of fines in artificial sand increases the plasticity and gives more sound concrete. The slabs made with the artificial sand are better leak proof than with the river sand.

The sand available in the river bed normally contains very high percentage of silt and clay due to the passage of muddy water during monsoons, which reduces the strength of concrete and holds dampness. Fine particles below 600 microns must be upto at least 30% to 50% for good results. But these particles are not present in river sand upto the required quantity. Again, natural river sand is mostly the production of sedimentation and a lot of other organic impurities occur in it. The presence of impurities above certain level renders the sand unfit for concrete work.

Particle shapes of fine aggregate is very important for making good quality concrete. Sand having cubical particles and rounded edges gives higher strength and workability. Also considerable variation in the strength of mortar takes place due to the form and hardness of particles. These can be achieved only in case of artificial sand made with the help of machines and using raw materials of higher strength.

As the river sand cannot meet the rising demand of the construction sector, demand for manufactured fine aggregates (sand) for making concrete is increasing day by day. Again, considering the huge short coming on the quality of river sand, its high cost and greater impact on transportation and adverse effects on environment, the construction industry has started using the artificial sand as an alternative and economic solution of the problems. Further local authorities / government are encouraging the use of manufactured sand in all construction works as far as possible.

Disadvantages of artificial sand:-

Usually fine cubical particles of stone below 4.75mm are used to replace the river sand. But as these particles have sharp edges and rough surface texture, its use in concrete requires some admixtures to be added to increase the plasticity of the wet concrete and mortar. Such machine made sand may contain flacky particles which decreases the workability and requires more water cement ratio. The effect of higher water cement ratio in concrete reduces its ultimate strength substantially.

Use of artificial sand:-

Artificial sand has a variety of uses as in the case of natural sand and in addition it may have some specific use. It can be used for manufacture of bricks /building blocks, production of concrete and mortar of desired characteristics, road and railway construction for textured finish of painted surface, building landscapes and recreation ground, preparing filter medial for water purification and sewage treatment plants, as an abrasive in sand blasting operations. Besides the above, it is used for sand casting of metals and sand animation, in agriculture for crop growing, making aquaria as a low cost base material, beach protection and artificial reefs and as on and so forth.

Bonding Agents

Bonding agents are natural, compounded or synthetic materials used to enhance the joining of individual members of a structure without employing mechanical fasteners. These products are often used in repair applications such as the bonding of fresh concrete, sprayed concrete or sand / cement repair mortar to hardened concrete.

Two of the critical factors affecting the bonding between new and old concrete, provided sound concrete practices are followed are:

i) Strength and integrity of the old surface

and ii) The cleanliness of the old surface

When a weak layer of concrete (laitance) exists on the old surface or when the old surface is dirty, a poor bond is obtained. The surface condition thus plays a critical role in bond development, although the strength of the bond depends on other factors such as proper compaction of the new concrete and proper surface preparation, that takes into account the density of the base concrete. For a sound base concrete, for example, acid etching will surface, while mechanical cleaning will be imperative if the old concrete contains a weak or deteriorated surface.

The main types of bonding agents used in the construction industry are latex emulsions and epoxies. Although good adhesion may be obtained without a bonding agent, generally a bonding layer consisting of cement and sand slurry, cement/ latex slurry or epoxy increases the bond strength.

Latex Emulsions:-

As bonding agents, there are a variety of applications for latex emulsions, as depicted in Table A. As far as their bonding properties are concerned, some have a greater degree of water resistance than others. The latex emulsions generally used in cementious compositions are of the oil-in-water type and sometimes contain more than 50% water. They are generally stable in the cement / water system. However, not all emulsions are compatible with cement and the selection of an appropriate product for a given application requires an understanding of its chemistry or alternatively, consultation with the manufacturer.

Three methods can be used to modifying a latex to make it an useful bonding agent :

i) A neat cement slurry ultilizing the latex as part of the mixing water may be prepared.

ii) A 1:1 water : latex diluted material may be used.

iii) A re-emulsifiable latex, which can be softened and re-tackified upon contact with water may be used.

The use of method (ii) is now being discouraged because of the lack of bonding encountered in field applications (corroborated by laboratory studies). The use of latex without any cement in the mix produces a failure plane because of the lack of film formation at the bond interface.

Table-A

Comparative chart of properties of latex bonding agents

Property / test method	Acrylic	Polyvinyl acetate (non-re-emulsifiable)	Butadiene-styrene	Polyvinyl acetate (re-emulsifiable)
Appearance	Milky white	Milky white	Milky white	Milky white or clear
Solids content	45%	55%	48%	50%
Primary use	Bonding fresh concrete to old concrete	Bonding fresh concrete to old concrete, thin layer toppings	Bonding fresh concrete to old concrete, concrete admixture, thin layer toppings	Bonding to plaster
Application methods	Brush, broom, spray roller as adhesive, trowel as topping	Brush, broom, spray roller as adhesive, trowel as topping	Brush, spray, roller as adhesive, trowel as topping	Brush, spray roller
Applications	Underlayment's, stucco, grouting mortar, terrazzo, crack fillers			
Cleaning, surface preparation	Remove oil, grease wet surface	Remove oil, greese	Remove oil, greese	
Compressive	22.0	23.45	22.75	22.0 (air)

strength (Mpa) 50mm cubes ASTM C109	28.27	24.82	27.58	26.08 (wet)
Tensile strength (Mpa) 25mm thick briquettes ASTM C109	4.0 4.24	2.41 3.10	3.10 4.0	2.06 (air) 2.83 (wet)
Flexural strength Bar (Mpa) ASTM C-348	6.55 9.65	6.90 8.62	8.62 11.38	6.38 (air) 5.17 (wet)
Where to use	Indoor & outdoor exposures, on steel, concrete, wood, gunniting, thin section topping. May be used as a plaster bond within 45-60 min.			Indoor ceilings, primarily limited use as a concrete bonding agent.
Where not to use	Not for extreme chemical exposure, not for conditions of high hydrostatic pressure		Not for extreme accelerations, not for extreme chemical exposure, not for constant water	Not for use as an admixture, not for use under wet or humid conditions. Not for use at temperatures below 10^0C.

The following description of the advantages and limitations of the various types of emulsions used as bonding agent is likely to serve as a preliminary guide for the user and specifier.

a) **Styrene Butadiene (SBR):-** The styrene butadiene latex, which is compatible with cementious compounds, is a co-polymer. This type of latex shows good stability in presence of multivalent cataions such as calcium (Ca^{2+}) and aluminum (Al^{3+}) and is unaffected by the addition of relatively large amounts of electrolytes (e.g. $CaCl_2$). SBR latex may coagulate if subjected to very high or very low temperatures or severe mechanical action for prolonged periods of time.

b) **Polyvinyl Acetate (PVA):-** There are two main types of PVAs that are used in repair : non-re-emulsifiable and emulsifiable. The non-re-emulsifiable PVA forms a film that offers good water resistance, ultraviolet stability and aging characteristics. Because of its compatibility with cement, it is widely used as a bonding agent and as a binder for cementitious water-based paints and water proofing coatings. On the other hand, the emulsifiable PVA produces a film that can be softened and re-tackified with water. This type of latex permits the application of a film to a surface long before the subsequent application of a water-based over lay. Its use is limited to specific applications where the possible infiltration of moisture to the bond line is precluded. It is most widely used as a bonding agent for plaster and to bond finish- or base-coat gypsum, or Portland cement plaster, to interior surfaces of cured cast-in-place concrete.

c) **Acrylic latex:** Acrylic ester resins are polymers and co-polymers of the esters of acrylic and methacrylic acids. Their physical properties range from soft elastomers to hard plastic plastics. This type of emulsion is used in cementious compounds in much the same manner as SBR latex.

d) **Epoxy latex:-** Epoxy emulsions are produced from liquid epoxy resin mixed with the curing agent. In addition to serving as an emulsifying agent, the curing agent also serves as a wetting agent. From the time of mixing until gelation occur, the emulsions are stable and can be diluted with water. Pot life can be varied from 1 to 6 hours depending on the curing agent selected and on the amount of water added. Most epoxy emulsions are prepared on the job site just before use because phase separation occurs in pre-packaged emulsions. Equal parts of epoxy and curing agents are mixed, then blended for 2 to 5 minutes and allowed to set for 15 minutes to enable polymerization to begin. While the mixtures is being mechanically agitated, water is added slowly to form the emulsions.

As an alternative to these liquid-based systems, which require on site measurement and pre-dilution, it is now possible to obtain factory blended powders containing a mixture of cement, spray-dried latex powders, sand and other additives, which are simply mixed with water on site. The resultant 'stipple' finish provides a good 'key' for repair mortar or over lays. The stipple grout coat minimizes the loss of water from the overlay to the substrate, preventing desiccation of the cement and the resultant poor bond. Although the grout coat does provide points of anchorage for bonding, the application of the repair mortar or overlay while this key coat is still tacky is strongly recommended.

Epoxy bonding agents:-

Various epoxy products are available for the bonding of freshly placed concrete to cured concrete and of concrete to steel. Most of the products contain resins that are 100% solids. They may or may not contain fillers, such as calcium carbonate or silica flour and other additives to enhance any particular properly or reduce cost. Products are available in a variety of consistencies, ranging from highly filled paste (for over head work) to liquids with a viscosity of 100cp (0.1 Pa.s), which is similar to that of water.

Because the formulations can combine different resins, hardeners and modifiers to produce a great variety of end products, the user and specifiers need guidance on the options available to them. The ASTM (American Society for Testing and Material Standards) standard ASTM C881-78 "Epoxy-resin-based Bonding Systems for Concrete" is quite informative in this respect. It is performance specification based on end use and there are no specification limits on chemical composition. Instead, the material selected must meet the requirements related to physical properties such as viscosity, bond strength, shrinkage and thermal compatibility.

The specification classifies the epoxy-resin bonding system by type grade and class. The type is determined by the end use [Ref: ASTM C881, Table-1, “Physical requirements of bonding systems”]. The systems can be summarized as follows:

Type-I - For bonding hardened concrete and other materials to hardened concrete.

Type-II- For bonding freshly mixed concrete to hardened concrete.

Type-III- For bonding skid-resistant materials to hardened concrete (or for use as a binder in epoxy mortars or concretes).

The grade of a system is defined by its flow characteristics. For example, materials of low viscosity suitable for injection into cracks and where flow is required, are grouped in Grade-I, Grade-II comprises medium-viscosity materials for general purpose use and Grade-III materials are of a non-sagging consistency for over-head work or for bonding non-mating surfaces. The materials are further divided into classes by the test temperature at which the gel times are determined (gel time is the interval between the beginning of mixing an epoxy system and the first formation of a gelatinous mass within the system). The materials are not, however, restricted to use at the temperature designated for each class.

Class-A- Systems for use below 5^0C.

Class-B- Systems for use between 5^0C and 15^0C.

Class-C- Systems for use above 15^0C.

Three properties stipulated in the ASTM specification are of great importance, namely : bond strength, shrinkage and thermal compatibility. ASTM tests C882, C883 and C884 determine the respective values for these properties required by the specification. Moreover, these tests are an effective means of screening products that are unsuitable for the intended use. For example, the bond strength test (ASTM C882) will eliminate systems that are adversely affected by bleed water from plastic concrete, if the intended use is the bonding of fresh concrete to hardened concrete. The shrinkage test (ASTM C883) will eliminate systems containing solvents, excessive quantities of diluents or other chemicals that will induce shrinkage. If a bonding system has a high modulus of elasticity, a patch or overlay may delaminate as a result of changes in temperature. The ASTM C884 test measures this tendency.

Although the ASTM C881 specification provides a means of screening out materials that are likely to perform poorly, other properties not addressed in the specification should be taken into account when making a final choice among similar epoxy resin systems.

Most epoxy bonding products have a pot life or setting time of 15-30 minutes at 25^0C, making it necessary to mix only the amount that can be properly used in that period of time. At temperatures below 0^0C, the setting time is considerably longer (4-5 hours). Some of the application factors that should be considered are shown in table-B.

Table-B

Application factors for epoxy bonding agents

Mixing rations	Vary from 100:1 to 1:1
Pot life	Instantaneous to several months; also influenced by the amount of material mixed and the ambient temperature.
Exotherm	Can vary from 0^0C to over 100^0C, in which case the cured system is literally charred.
Viscosity	Can vary from liquid of 100 cp (0.1 Pa.S), the consistency of water to very heavy paste.
Penetrability	A function of viscosity and lubricity – varies widely.
Curing time	Varies from a few minutes to several days and is directly dependent upon the application temperature. (Some systems will not cure unless exposed to very high temperatures).

Where extensive repair work is necessary such as slab replacement or surfacing of vertical walls or columns-epoxy bonding agents, in combination with new concrete, often provide the most economical solution. The use of bonding agents ensures that the repair will have the strength of monolithically cast concrete.

Application of bonding agents in repair / maintenance work:-

One of the critical factors governing the achievement of an effective repair is good adhesion at the interface of the repair material and the concrete substrate. Good adhesion is imperative for structural repairs where monolithic character is required for the transfer of load. A proper bond between the repair material and the substrate can be obtained by diligent workmanship - involving surface preparation, consolidation and curing - without the use of bonding agents.

However, bonding agents play a significant role where it is critical to ensure bond at the surface. For example, weak and pliable substrate may need strengthening to match the modulus of the repair material. A bonding agent may be required because of the prevailing poor ambient conditions. Notwithstanding, the advantages provided by the bonding agents, they should not be used to compensate for poor workmanship.

Adhesives

An adhesive is any substance that when applied to any one surface, or both surfaces of two separate items, binds them together and resists their separation. In other words, any substance that is capable of joining materials by attachment of their surfaces can be grouped as an adhesive. It may be used interchangeably with the names like glue, cement, mucilage or paste. Different adjectives may be used in conjunction with the word “adhesive” to describe properties based on the substance’s physical and chemical form, the type of materials joined or the conditions under which it is applied. The process of joining the materials using adhesives is called Adhesive Bonding and is a class in itself like welding, soldering and fastening. The use of adhesives offers many advantages over binding techniques such as sewing, mechanical fastening, thermal bonding etc.

Adhesives may be found naturally or produced synthetically. While use of natural adhesive are age old, only since the last century has the development of synthetic adhesives accelerated rapidly and innovation in the field continues to the present. The adhesive manufacturing market is double figure billion dollars at present. In the course of time and during their development, adhesives have gained a stable position in an increasing number of production processes. There is hardly any product in our surroundings that does not contain at least one adhesive-be it the label on a beverage bottle, protective coatings on automobiles or profiles on window frames. Market researchers forecast a turnover of almost fifty billion dollar for the global adhesive market by 2020.

Classification or grouping of adhesives

Many natural and artificial products possess adhesive qualities. There are five groups of adhesive generally recognized in the industry as given below:

i) Glues from animal and vegetable sources
ii) Thermoplastic adhesives
iii) Thermosetting adhesives
iv) Elastomer adhesives
v) Ceramic adhesives

Among the glues, the animal glues are extracted from the bones and hides of the animals by heating them in water tanks. The vegetables glues are obtained from seeds, corns, stems and other parts of the plants. Common examples of organic glues are: hide glue, bone glue, casein glue, zein glue and starch glue.

Starch based adhesives are used in corrugated board and paper sack production, paper tube winding and wall paper adhesives. Casein glue is mainly used to adhere glass bottle labels. Animal glues have traditionally been used in book binding, wood joining, and many other areas but now are largely replaced by synthetic glues except in specialist applications like the production and repair of stringed instruments. Albumen made from the protein component of the blood has been used in the plywood industry. Masonite, a wood hard board, was originally bonded using natural wood lignin, organic polymer, though most modern particle boards such as MDF use synthetic thermosetting resins.

However, the resin adhesives form the important groups of adhesives. They are indispensible for high-grade bonding. These may be natural or synthetic in nature. The list of natural resins include shellac, asphalt and resin.

The synthetic resins include two main groups: thermosetting and thermoplastic.

The thermosetting resin adhesives form heat resistant and insoluble compounds after their application. They form useful adhesives where high strength, stability at elevated temperature and resistance to moisture are the required qualities. Examples of this group include the phenolic adhesive. It is used extensively for the bonding of plywood and other boards, metal and glass surface. Other examples are: Urea formaldehydes, melamine formaldehyde and phenol resorcinol.

The thermoplastic resin adhesives are general purpose adhesives used for common types of bonding that are stable at ordinary temperatures only and in dry conditions. Moisture and heat will break the bond developed by these types of adhesives. Polyvinyl alcohol is the best example from this category; cellulose nitrate, cellulose acetate, polyvinyl acetate and polystyrene are other examples.

The elastomer adhesives are derived from the rubber. They have many useful properties and find extensive applications in wood, glass and leather industries. Sometimes, they are also referred to as rubber cements. Among the important qualities of these adhesives is their capacity to bind together materials having different thermal expansion. These adhesives are not good for binding metals.

Ceramic adhesives are used to join or repair broken pottery ceramic, stone or china clay products. Generally the epoxies and cyanoacrylates are used for the purpose. They require a tight fit with a very thin film layer between the parts to be joined for proper bonding and therefore will not fill in voids.

Types of adhesives:

Adhesives may be typically organized by their method of adhesion. These are then organized into reactive and non-reactive adhesives, which refer to whether the adhesive chemically reacts in order to set or harden. Alternatively they can be organized by whether the raw stock is of natural or synthetic origin or by their starting physical phase.

I. Types of reactivness

A. Non-reactive adhesives:- These adhesive do not require any chemical reaction to take place for their hardening or setting, rather are dependent on physical process like evaporation, pressure or surface contact.

Drying adhesives:- There are two types of adhesives that harden by drying; solvent based adhesives and polymer dispersion adhesives, also known as emulsion adhesives. Solvent based adhesives are a mixture of ingredients (typically polymers) dissolved in a solvent. White glue, contact adhesives and rubber cements are members of the drying adhesive family. As the solvent evaporates, the adhesive hardens. Depending upon the chemical composition of the adhesive, they will adhere to different materials to greater or lesser degree. Polymer dispersion adhesives are milky-white dispersions often based on polyvinyl acetate (PVAc). They are used extensively in the wood working and packaging industries. They are also used with fabrics and fabric based components and in engineered products such as loud speaker cones.

Pressure sensitive adhesives:- Pressure-sensitive adhesive (PSA) form a bond by the application of light pressure to marry the adhesive with the adherend. They are designed to have a balance between flow and resistance to flow. The bond forms because the adhesive is soft enough to flow (i.e. wet) to the adherend. The bond has strength because the adhesive is hard enough to resist the flow when stress is applied to the bond. Once the adhesive and the adherend are in close proximity, molecular interactions, such as Van-der-Walls forces, become involved in the bond, contributing significantly to its ultimate strength.

PSAs are designed for either permanent or removable applications. Examples of permanent applications include safety lebels for power equipments, foil tape for HVAC duct work, automotive interior trim assembly and sound / vibration damping films. Some high performance permanent PSAs exhibit high adhesion values and can support kilograms of weight per square centimeters of contact area, even at elevated temperatures. Permanent PSAs may be initially removable (for example to recover mislabeled goods) and build adhesion to a permanent bond after several hours or days.

However, removable adhesives are designed to form a temporary bond and, ideally can be removed after months or years without leaving residue on the adhered. Removable adhesives are used in applications such as surface protection films, masking tapes, book mark and note papers, bar code levels, price marking labels, promotional graphic materials and for skin contact (wound care dressing, EKG electrodes, athletic tape, analgesic and transdermal drug patches etc.) Some removable adhesives are designed to repeatedly stick and unstick. Usually they have low adhesion and generally can not support much weight.

Pressure-sensitive adhesives are manufactured with either a liquid carrier or in 100% solid form. Articles are made from liquid PSAs by coating the adhesive and drying off the solvent or water carrier. They may be further heated to initiate a cross-linking reaction and increase molecular weight 100% solid PSAs may be low viscosity polymers that are coated and then reacted with radiation to increase molecular weight and form the adhesive or they may be high viscosity materials that are heated to reduce their viscosity enough so as to allow coating and then cooled to their final form. Major raw material for PSAs are acrylate-based polymers.

Contact adhesives:- Contact adhesives are used in strong bonds with high shear-resistance like laminates, such as bonding Formica to a wooden counter and in foot-wear, as in attaching out soles to uppers. Natural rubber and Neoprene (poly-chloroprene) are commonly used contact adhesives. Both of these elastomers undergo strain crystallization. In the construction industry, a specialized proprietary adhesive known as Liquid Nails (or liquid nails as the generic) is used. This also copes with tasks such as sealing artificial turf. Of course, contact adhesives must be applied to both the surfaces and allowed some time to dry before they are pushed together. Some contact adhesives require as long as 24 hours time to dry and once the surfaces are pushed together, the bond forms very quickly. It is usually not necessary to apply pressure for a very long time and so there is less need for clamps.

Hot adhesives:- Hot adhesives, also known as hot melt adhesives, are thermoplastics, applied in molten form (in the range of 65-180^{0}C) which solidify on cooling to form strong bonds between a wide range of materials. Ethylene-vinyl acetate-based hot-melts are particularly popular for crafts because of their ease of use and the wide range of common materials they can join. Use of glue gun is one method of applying hot adhesives. The glue gun melts the solid adhesive, then allows the liquid to pass through its barrel onto the material, where it solidifies.

Thermoplastic glue perhaps was invented as a solution to the problem that water based adhesives, commonly used in packing earlier, failed in humid climates, causing packages to open.

B. **Reactive adhesives:-** These are the adhesives that harden by some sort of chemical reaction among the components or external agents like UV, heat or moisture.

Multi-part adhesives:- Multi component adhesives harden by mixing two or more components which chemically react. This reaction causes polymers to cross-link into acrylics, urethanes and epoxies.

There are several commercial combinations of multi component adhesives in use in industry. Some of these combinations are:

- Polyester resin-polyurethane resin
- Polyols –polyurethane resin
- Acrylic polymers-polyurethane resins

Of course, the individual components of a multi-component adhesive are not adhesive by nature. The individual components react with each other after being mixed and show full adhesion only on curing. These multi-component resins can be either solvent-based or solvent-less. The solvents present in the adhesives are a medium for the polyester or polyurethane resin. The solvent is dried during the curing process.

One –part adhesives:- One part adhesives harden via a chemical reaction with an external energy source, such as radiation, heat and moisture. Ultra violet (UV) light curing adhesives, also known as light curing materials (LCM), have become popular within the manufacturing sector due to their rapid curing time and strong bond strength. Light curing adhesives can cure in as little as a second and many formulations can bond dissimilar substrates and withstand harsh temperatures. These qualities make UV curing adhesives essential to the manufacturing of items in many industrial markets, such as electronics, telecommunications, medical, aerospace.

II. Types by Origin

C. **Natural adhesives:-** Natural adhesives are made from organic sources such as vegetable starch (dextrin), natural resins or animals (e.g. the milk protein casein and hide-based animal glues). These are often referred to as bio-adhesives. One example is a simple paste made by cooking flour in water.

D. **Synthetic adhesives:-** Synthetic adhesives are based on elastomers, thermoplastics, emulsions and thermo-sets. Examples of thermosetting adhesives are : epoxy, polyurethane, cyano-acrylate and acrylic polymers. Pressure-sensitive adhesive is used in paste-it notes. Synthetic adhesives were first commercially produced in 1920s.

Method of application of adhesives:-

Common ways of applying an adhesive include brushes, rollers, using films or pellets, spary guns and applicator guns (e.g. caulk gun). All of these can be used manually or automated as part of a machine.

Applications of different adhesives are designed according to the adhesive being used and the size of the area to which the adhesive will be applied. The adhesive is applied to either one or both of the materials being bonded. The pieces are aligned and pressure is added to aid in adhesion and rid the bond of air bubbles.

Mechanism of adhesion:-

For an adhesive to be effective, it must have three main properties.

i) It must be able to wet the substrate
ii) It must harden and
iii) Finally it must be able to transmit load between two surfaces / substrates being adhered.

Adhesion, the attachment between the adhesive and substrate may occur either by mechanical means, in which the adhesive works it way into small pores of the substrate or by one of several chemical mechanisms. However, the strength of adhesion depends on many factors, including the means by which it occurs.

In some cases, an actual chemical bond occurs between the adhesive and substrate. In others, electrostatic forces, as in static electricity, hold the substances together. A third mechanism involves the Vender Walls forces that develop between the molecules. A forth means involves the moisture aided diffusion of the glue into the substrate, followed by hardening.

Failure of the adhesive joint:- There are several factors that could contribute to the failure of two adhered surfaces. Sunlight and heat may weaken the adhesive. Solvents can deteriorate or dissolve adhesive. Physical stresses may also cause the separation of surfaces. When subjected to loading, debonding may occur at different locations in the adhesive joint.

The following are the major fracture types:

Cohesive fracture:- Cohesive fracture takes place if a crack propagates in the bulk polymer which constitutes the adhesive. In this case, the surfaces of both adherends after debonding will be covered by fractured adhesive. The crack may propagate in the centre of the layer or near an interface. For this last case, the cohesive fracture can be said to be “cohesive near the interface.”

Adhesive fracture:- Adhesive fracture (sometimes referred to as interfacial fracture) occurs when debonding take place between the adhesive and the adherend. In most cases, the occurrence of adhesive fracture for a given adhesive goes along with smaller fracture toughness.

Fig. P-8

Other types of fractures:- These include:

i) The mixed type, which occurs if the crack propagates at some spots in a cohesive and in others in an interfacial manner. Mixed fracture surfaces can be characterized by a certain percentage of adhesive and cohesive areas.

ii) The alternating crack path type which occurs if the cracks jump from one interface to the others. This type of fracture appears in the presence of tensile pre-stresses in the adhesive layers glass and optical. Unlike traditional adhesives, UV light curing adhesives not only bond materials together but they can also be used to seal and coat products. They are generally acrylic based. Heat curing adhesives consists of a pre-made mixture of two or more components. When heat is applied the components react and cross-link. This type of adhesives includes epoxies, urethanes and polyamides. Moisture curing adhesives cure when they react with moisture present on the substrate surface or in the air. This type of adhesive includes cyano acrylates and urethanes.

Fracture can also occur in the adherend if the adhesive is tougher than the adherend. In this case, the adhesive remains intact and is still bonded to one substrate and remnants of the other. For example, when one removes a price lebel, the adhesive usually remains on the lebel and the surface. This is cohesive failure. If however, a layer of paper remains stuck to the surface, the adhesive has not failed. Another example is when someone tries to pull apart Oreo cookies and all the filling remains on one size; this is an adhesive failure, rather than a cohesive failure.

Design of adhesive joints:-

As a general design rule, the material properties of the object need to be greater than the forces anticipated during its use (i.e. geometry, loads etc.). The engineering work will consist of having a good model to evaluate the function. For most adhesive joints, this can be achieved using fracture mechanics. Concepts such as the stress concentration factor and the strain energy release rate can be used to predict failure. In such models, the behavior of the adhesive layer itself is neglected and only the adherends are considered.

Failure will also very much depend on the opening mode of the joint. Mode-I is an opening or tensile mode where the loadings are normal to the crack. Mode-II is a sliding or in-plane shear mode where the crack surfaces slide over one another in directions perpendicular to the leading edge of the crack. This is typically the mode for which the adhesive exhibits the highest resistance to fracture. Mode-III is a tearing or anti-plane shear mode.

Fig. P-9

As the loads are usually fixed, an acceptable design will result from a combination of a material selection procedure and geometry modifications, if possible. In adhesively bonded structures the global geometry and the loads are fixed by t he structural considerations and the design procedure focuses on the material properties of the adhesive and on local changes on the geometry. Increase of joint resistance is usually obtained by designing its geometry so that:

- The bonded zone is large
- It is mainly loaded in mode II
- Stable crack propagation will follow the appearance of a local failure

Shelf life:-

Some glues and adhesives have a limited storage life and will stop working in a reliable manner of their safe shelf life is exceeded.

Advantages of using adhesives:-

The adhesives offer a lot of advantages over other joining methods and processes. These include the ability to bind different materials together, to distribute the stress more efficiently across the joint, the cost effectiveness of an easy mechanized process, an improvement in aesthetic design and increased design flexibility. These can be summarized as follows:

i) By and large, they offer a bond allowing uniform stress distribution over a large area. This is different than in rivets and bolts which cause stress concentration at the place of application.

ii) Materials of different nature and composition may be bonded together; rubber to glass, metal to wood, metal to glass and so an.

iii) Size and shape are no limitation for binding. Blocks, grains and powder, all can be bonded together or any other material. These are the best materials for achieving bonds of thin sheets.

iv) The adhesive joints provide good resistance to fatigue and moisture transfer.

iv) Many adhesives provide electrical insulation to certain degree.

Disadvantages of using adhesives:-

Despite a number of advantages, there are certain disadvantages also in the application of adhesives which include decreased stability at high temperatures, relative weakness in bonding large objects with a small bonding surface area and greater difficulty in separating objects during testing. The following are the major draw backs:

i) A long time is often required before the bond is obtained after application. Strength development is not instantaneous rather all adhesives require some time to cure and become hard.

ii) In many cases, curing may require heat or pressure or both. Hence the process involves additional labour, equipment, cost and time.

iii) In all most all cases, the surfaces to be bonded together require though preparation, which in some cases may prove to be quite arduous.

iv) Most common adhesives have service temperature limitations, they are stable only upto certain temperatures.

Use of adhesives:-

Adhesives find very wide spread applications in industries ranging from match box making to aircraft manufacture. It goes without saying that each article of common use, be it house hold furniture, automobile or aircraft components, makes use of one or another adhesive. The following listing of the application of adhesives is only indicative rather than exhaustive.

1. Paper and packing industry- corrugated cardboard making.
2. Plywood and fibre board industries.
3. In the preparation of laminated paper, wood and board.
4. Book binding, envelope and stamps.
5. Sand paper, emery paper and abrasive cloth making.
6. Tobaco industry –in cigarattes.
7. As the mastic in floor and wall tiles, linoleum and other furnishings.
8. Shoe, foot wear and baggage industry.
9. In automobile industry for interior cladding as well as stickering.
10. Aerospace (Air craft & rocket) industry for wing flaps, floor panels, bonding skin to fuselage etc.

CHAPTER-2

PREFABRICATION

Introduction :

Prefabrication is the practice of assembling the components of a structure in a factory or other manufacturing site and transporting complete assemblies or sub-assemblies to the construction site where the structure is to be erected or located. It distinguishes the process from the more conventional construction practice of transporting the basic materials to the construction site where all assembling is carried out. The term prefabrication also applies to the manufacturing of things other than structures at a fixed site. It is frequently used when fabrication of a section of a machine or any movable structure is shifted from the main manufacturing site to another location and the section is supplied, assembled and ready to fit. Thus, prefabrication is used in the manufacture of ships, air crafts and all kinds of vehicles and machines where the sections previously assembled at the final point of manufacture are assembled elsewhere instead, before being delivered for final assembly. However, it is not generally used to refer to electrical or electronics components of a machine or mechanical parts such as pumps, gear boxes and compressors etc. which are usually supplied as separate items, but to sections of the body of the machine which in the past were fabricated with the whole machine. Prefabricated parts of the body of the machine may be called 'sub-assemblies' to distinguish them from the other components.

Prefabricated construction is a relatively new approach to get buildings up fast, where in many parts of the building are pre-made in factories in order to out down on construction time and lower the overall cost of a project. Previously, this method was used almost exclusively for small homes, but in recent years, pre-fabricated construction components have become available for other structures as well such as tunnels, bridges, flyovers, culverts, retaining walls etc. However, in this chapter, we will restrict our discussion to the prefabrication of buildings. Generally, in prefabrication of buildings the advance production of standardized components of buildings are ready for quick assembling and erecting at building site, wherein, often the production of units is undertaken at a factory & work area away from the actual site itself. Prefabrication i.e. the industrial method of house construction is the most suitable technique for the mass production of houses. Buildings of any height can be constructed by this method and blocks of houses can be erected in any geological and climatic conditions.

Necessity & scope of prefabrication of buildings :

Of course, housing constitutes one of the three basic human needs and is apty regarded as a major factor in the economic and social progress of any nation and hence occupy a pivotal position in developmental programmes. The living standards of people are directly linked with the adequacy of shelter. Good housing, indeed foster social well being. Although, India has already acquired self-sufficiency in food and there has been impressive achievement in clothing sector, the performance in the housing sector in India is quite dismal. With the rapidly increasing demographic explosion in our country, the housing problem today has acquired the gigantic proportion. Out of the 125 crores population in India, nearly 40% live in cities and remaining 60% in villages and each year a population equivalent to Australia is being added to it. The present trend of development of the existing cities, towns and villages does not seem to have comprehensive plans for housing these people. Therefore, the common public as well as government are to realize the responsibility ahead and expediously formulate wide ranging programmes to provide shelters – modest, in-expensive and comfortable to all citizens.

By the turn of the last century, the housing shortage was around 41 millions units and the shortage of housing units is increasing at a faster rate day by day. According to the data available by the Federation of Indian Chamber of Commerce and Industry, the then total demand for housing was around 209.2 millions units and the usable housing stock available was about 168.2 millions units, leaving a shortage of 41 millions units. Considering the present rate of construction, it would take another century to mop up the present lag. Even if the building materials and finances are made available to handle this huge task, traditional methods of building construction will not suffice the purpose, unless a construction revolution is brought about in a massive scale in line with the Green revolution. This can be accomplished only by adopting the industrialized building and prefabricated systems. Adoption of prefabrication technique in mass housing projects is likely to solve the problem more effectively by achieving speed in construction and economic use of building materials particularly the scarce materials like cement, steel etc.

In this context, we have, to certain extent, gained experience to build up momentum in the field of prefabrication in India. Some factories have already been set up both in private and public sector like the Hindustan housing factory at New Delhi by the Government for the manufacture of precast components and construction of fully prefabricated houses with technical assistance from its own research and development ring and financial aid from the National Building Organization (NBO). Some prefabrication has been done in Bombay by Shah Construction Company which constructed 4 to 24 storey blocks. UCOPAN system has been evolved by the Culcutta metropolitan planning organization (CMPO). The Tamilnadu housing board has also build many prefabricated houses with the help of the Structural Engineering Research Centre (SERC), Madras (Chennai). Also, small roofing, flooring and walling units have been developed by Central Building Research Institute (CBRI), Roorkee which are ideally suitable for low cost housing.

In addition, the important factor for facilitating the development of the building industry is the proper coordination among the manufacturers, architects, designer and users. The architects and designers are required to go for standardization of main parameters of building components by incorporating modular coordination in their planning and design, which may result in manufactur of standardized components in mass scale and consequently economy. Moreover the users/ builders should be conscious of quality, strength and economic aspect of the prefabricated components, because unless it is accepted by the user, all efforts in this direction will go to a waste. Therefore, it is imperative to educate them by way of advertisement, seminar, symposium, workshop, exhibition and frequent demonstration of the prefabricated system.

But for the success of the prefabricated system, the Government should take steps for establishing building factories which must be suitably located to cater to the needs of the whole country. Again, for assuring the continuous flow of production from the factories, a stable market must be available for the purpose. To bring this into effect, the Government should fix the annual quota for the construction of prefabricated houses for mass housing as the government policy of housing strongly effects the building industry. Of course, in western countries industrialized housing is much more wide spread and popular, the chief reason being the Govt. involvement in housing is more extensive and this provides a large single market that makes the industrialization both possible and attractive. For a developing country like India, where the capital is very scare and the supply of unskilled manpower is abundant, it is logical to encourage a partially industrialized labour intensive technology rather than an unduly capital intensive fully prefabricated technology that demands more mechanization. In other words, prefabrication industry in India should go in for light prefabrication like roofing/ flooring R.C. units for low cost housing. These units can be manufactured at site and handled manually or by employing simple lifting devices. In the process, the construction time is drastically reduced there by requiring less capital for the purpose. Again, other precast building components which can be used to increase the speed of construction are lintels, stair case units, door and window frames, chajja and sunshade, flooring tiles etc.

History of Prefabrication :

The concept and the practice of prefabrication in one form or another has been in use as a part of human experience since ancient times. For instance, it is claimed that the world's oldest known engineered road way, the Sweet Track constructed in England around 3800 BC, employed prefabricated timber sections brought to the site rather than assembled on site. Also Sinhalese kings of ancient Srilanka have used prefabricated building technology to erect giant structures, which dates back as far as 200 years, where some sections were prepared separately and then fitted together, specially in the kingdom of Anuradhapura and Kingdom of Polonaruwa. In the 19th century Australia, a large number of prefabricated houses were imported from the United Kingdom. The crystal Palace, erected in London in 1851, was a highly visible example of iron and glass prefabricated construction; which was followed on a smaller scale by Oxford Rewley Road railway station.

However the modern sense of prefabrication dates backs from the beginning of the 20th century. Until the invention of modern methods of conveyance like gasoline - powered tracks etc. prefabricated units – as distinct from precut building materials such as stones and logs – were of ultra light construction. Since World War–I, the prefabrication of more massive building elements has developed in accordance with the fluctuation of building activity in the united states, the Soviet Union and Western Europe. Moreover, the method was widely used in the construction of prefabricated housing in the 20th century, such as in the United Kingdom to replace houses bombed during World War–II. Assembling sections in factories saved time on site and reduced cost. But, some times, the quality was low and when such prefabricated housing was left in use for longer than its designed life, it was found to acquire a certain stigma.

Current uses of prefabrication :

In Civil Engineering and particularly in building construction, the most widely used from of prefabrication is the use of prefabricated concrete and prefabricated steel sections in structures where a particular part or form is repeated many times. In fact, it is difficult to construct the form work required to mould concrete components on site and also delivering wet concrete to the site before it starts to set requires precise management. On the contrary, pouring concrete sections in a factory brings the advantages of being able to re-use moulds and the concrete can be mixed on the spot without having to be transported to and pumped wet on a congested construction site. Of course, prefabricating steel sections reduces out site cutting and welding costs as well as the associated hazards.

Now-a-days, the prefabrication techniques are being used in the construction of apartment blocks and housing developments with repeated housing units. The quality of prefabricated housing units has increased to such point that they may not be distinguishable from the traditionally built units to those that live in them. The technique is also being used in office blocks, ware houses and factory buildings. Prefabricated steel and glass sections are widely used for the exterior of large buildings.

Unit recently, the detached houses, cottages, log cabin, saunas etc. are also sold with prefabricated elements. The prefabrication of modular wall elements allows buildings of complex thermal insulation, window frame components etc. on an assembly line, which tends to improve in quality over on site construction of each individual wall or frame. In particular, wood construction benefits a lot from the improved quality. But, tradition often favours building by hard in many countries and the image of prefab as a cheap method only slows its adoption. However, the current practice already allows the modification of floor plan according to the customer’s requirements such that the selection of surfacing material can be customized e.g. a personalized brick façade can be masoned even if load supporting elements are timber.

Actually prefabrication saves a lot of engineering time on the construction site in civil engineering projects, which can be vital to the success of projects such as bridges flyovers, retaining walls and avalanche galleries, where the weather or site conditions may only allow a brief periods of construction. Prefabricated bridge elements and systems offer bridge designers and constructors significant advantages in terms of construction time, safety, environmental impact, constructability and cost. Prefabrication also helps to minimize the impact on traffic from flyover or bridge building. Additionally, small, commonly used structures such as concrete pylons are in most cases prefabricated.

Radio towers of mobile phones and other services often consists of multiple prefabricated sections. Modern lattice towers and guyed masts are also commonly assembled of prefabricated elements.

Prefabrication has become widely used in the assembling of air craft and space craft, with components such as wings and fuse large sections often being manufactured in different countries or states from the final assembly site.

The theory and the process of prefabrication :

Prefabricated construction is a relatively new way to get buildings up fast. Many part of the building are pre-made in factories in order to cut down on construction time and lower the overall cost of a project. In other words, a prefabricated building component that is mass produced in an assembly line can be made in a shorter time for lower cost than a similar element fabricated by highly paid skilled labours at a building site. Many contemporary building components also require specialized equipment for their construction that can not be economically moved from one building site to another.

The theory behind the method is that time and cost is saved if similar construction task can be grouped, and assembly line techniques can be employed in prefabrication at a location where skilled labour is available, while congestion at the assembly site, which wastes time, can be reduced. The method finds application particularly where the structure is composed of repeating units or forms or where multiple copies of the same basic structure are being constructed.

Savings in material costs and assembly time are facilitated by locating the prefabrication operation at a permanent site. Materials that have become highly specialized, with attendant fluctuations in price and availability, can be stockpiled at prefabrication shops or factories. In addition, the standardization of building components makes it possible for construction to take place where the raw material is least expensive. Thus, the term is used to distinguish this process from the more conventional construction practice of transporting the basic materials to the construction site where all assembly is carried out. An example from house building illustrates the process of prefabrication. The conventional method of building a house is to transport bricks, timber, cement, sand, steel and construction aggregate etc. to the sit and to construct the house on site from these materials. But in prefabricated construction, only the foundations are constructed in this way, while the sections of walls, floors and roofs are prefabricated (assembled) in a factory (possibly with window and door frames included), transported to site, lifted into place by a crane and bolted together.

Prefabrication avoids the need to transport so many skilled workers to the construction site, and other restricting corditions such as lack of power, lack of water, exposure to harsh weather or a hazardous environment are avoided. Against these advantages, must be weighed the cost of transporting prefabricated sections and lifting them, into position as they will usually be larger, more fragile and more difficult to handle than the materials and the components of which they are made. But a major drawback of prefabrication is dilution of responsibility. A unit that is designed in one area of the country may be prefabricated in another and shipped to yet a third area, which may or may not have adequate criteria for inspecting materials that are not locally produced. This fragmentation of control factors increases the probability of structural failure.

As has been stated earlier, the prefabrication requires the cooperation of architects, suppliers and builders regarding the size of basic modular units. In the American building industry, for example, the 4x8 foot panel is a standard unit. Building plans are drafted using 8 foot ceilings and floor plans are described in multiplies of four. Suppliers of prefabricated wall units build wall frames in dimensions of 8 feet high by 4,8,16 or 24 feet long. Insulation, plumbing, electrical wiring ventilation systems, doors and windows are all constructed to fit within the 4x8-foot modular unit. Another prefabricated unit widely used in light construction in the roof truss, which is manufactured and stockpiled according to angle of pitch and horizontal length in 4 foot increments. Ornthe scale of institutional and office buildings and works of civil engineering, such as bridges and dams, rigid frame works of steel with spans upto 120 feet (37m) are prefabricated. The skins of large buildings are often modular units of procelainized steel. Stair wells are delivered in prefabricated steel units. Race ways and ducts for electrical wiring, plumbing and ventilation are built unto the metal deck panels used in floors and roofs. The Verrazano – Narrows bridge in New York City (with a span of 4260 feet or 1298 m) is made of 60 pre fabricated units weighing 400 tons each. Precast concrete components include slabs, beams, stairways, modular boxes and even kitchens and both rooms complete with precast concrete fixtures.

After considering the way that prefabricated building projects may benefit of disadvantage a company's profitability, it may be easier to decide if this type of building component is desirable. It is important to note, however, that this type of construction is growing in some parts of the country more than others. If one lives in an area where prefabricated structures are less popular, it may not be worth ones time to train a team in how to work with this type of product. On the other hand, if prefabricated construction projects are booming in one's region, offering this type of service may be necessary to remain competitive with similar construction companies in the area. Moreover, many construction companies find it beneficial to research possible contract with the manufacturers of prefabricated building components. By creating a situation in which they recommend prefabrication services to their costomers – or even working out an exclusive contract-those that are serious about getting into this field of construction may be able to ensure that they have a reliable customer base.

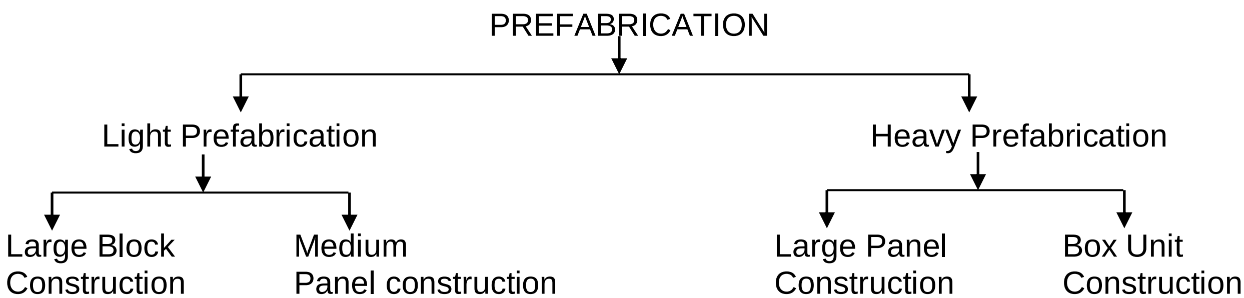
Types of prefabricated systems :

There are two main types of prefabrication, namely volumetric (often referred to as modular) and panelized. Both of these types of construction can be made in timber, steel and concrete and also can be mixed with in the same scheme. Whereas the steel systems for housing are usually light gauge galvanized steel, the timber systems can be relative by traditional in that the construction mirror what might be produced at site using components such as timer studs and seathing. It can make use of timber I-beams which give longer spans with a relatively lighter weight.

Another option is the structurally insulated panel systems which use fewer studs and rely in part on the bond between rigid insulation core and outer seathing materials for strength. However, one factor that differentiates all prefabricated timber systems from what might be termed traditional timber frame is the amount of work under taken in the factory. While there does not appear to be a formal definition separating the two, the prefabricated panel might include any insulation material, the seathing boards and possibly some services.

Classification of prefabrication :

The prefabricated systems may be classified as per the weights of the prefabricated units.



i) Large block construction :

The elements are large enough to enable speedy construction and small enough to be produced and handled easily. Normally the block size does not exceed one square meter in surface area. These blocks can be used in both floors and walls. But the disadvantage of this construction is that the number of joints and the site work is more. Again, larger is the number of joints, the weaker is the structure.

ii) Medium panel construction :

In contrast to large blocks, these are bigger in size having less number of joints. These elements may be used as stretching from floor to floor as walling units and wall to wall as flooring units. Generally, the width of such panels is roughly one meter or even less. These units can be handled by simple mechanization.

iii) Large panel construction :

These are bigger and heavier elements compared to the large block construction or medium panel construction and covers the whole wall or floor / roof of a room. Of course, the joints are completely eliminated with in the room space except at corners. Although erection time is quicker in this system, but the panels being larger and heavier, heavy mechanization is required.

iv) Box unit construction :

The specialty of this types of construction is that the box like element completely encloses a functional space in the form of a room like bed room, drawing room, kitchen, toilet etc. in complete. In this case, the boxes may be welded side by side and one above the other or may be kept apart. The elements being very heavy, requires heavy and sophisticated mechanization starting from the production process to erection level. However, there being little site work, the speed of construction is tremendously increased.

Advantages and disadvantages of fig prefabrication:

Advantages:- The main advantages of prefabrication are as follows:

i) Faster construction: As the parts are largely manufactured and assembled in separate factories and then transported to the construction site, the speed of construction is considerably increased. The construction period could be reduced by about 40% for single strayed buildings and 25 to 35% for multistoried buildings. Thus prefabrication of saves considerable engineering time on the construction site in civil engineering projects.

ii) Cost effective solutions :

The economy lies in the re-use of frame work, shuttering and optional use of labour and material etc. With an assured demand, the cost could be reduced by atleast 15 to 20%.

iii) Disciplined use of scarce materials:

By adopting suitable design methods involving optimization techniques etc. the consumption of scare materials like cement and steel could be reduced to minimum. Moreover, the materials that has become highly specialized with attendant fluctuations in piled and availability, can be stock priced at prefabrication shops or factories. In addition, the standardization of building components makes it possible for construction to take place where the raw material is least expensive.

iv) High production capacity :

Better organizational facilities, supervision and labour specialization generally results in high productivity enabling the realization of large important time bound projects. Consequently this allows the construction companies to work on more projects and potentially earn more money.

v) Good technical control :

The units are mostly factory made products having quite good technical control over various factors such as storage, handling, grading, proportioning, mixing, curing of materials and accurate dimensioning of members and proper position of reinforcement etc. Thus there is ample opportunity for good architecture, healthy buildings with reduced energy consumption.

vi) Quality surveillance system :

With effective control over the process of manufacture, it becomes possible to improve upon the strength and quality of products. Also uniformity of the quality of products can be assumed under such conditions by the use of specialized equipments.

vii) Improved quality of construction :

With the effective control over the process of manufacture, it becomes possible to improve upon the strength and quality of materials. As a consequence, higher working stresses of materials can be adopted for design purposes which result in saving of materials.

viii) Healthy working condition :

Regular transportation of so many skilled workers to the construction site and other restricting conditions such as lack of power, lack of water, exposure to harsh weather or a hazardous environment are avoided. Thus an improved working condition for the labours prevails at the work site because they are guaranteed of minimum amenities by factory rules. The establishment cost at the final construction site is reduced to the minimum and since the on site construction hazards are avoided, the safety aspects of construction is increased.

ix) Environmental friendly :

Prefabrication of buildings mostly result in environmental friendly way of construction with optimum use of materials, reduction of construction waste with even recycling of waste products as well as clean and dry work site. Moreover, the noise and dust nuisance is reduced to the minimum. It has minimum impact on traffic problems.

X) Independent of adverse weather conditions :

Production in the prefabrication workshops / factories are not affected and can proceed even under adverse weather conditions such as rain, snow, frost, summer heat, cyclone or such other climatic conditions. Again, during cold winter, the errection can be continued even upto – 20^0C.

xi) Reduction of establishment cost :

These is appreciable reduction in the establishment cost as on site storage, handling and security costs as well as cost towards temporary shelter for workmen are avoided at different construction sites. For example, the necessity of transporting and pumping wet concrete on a congested construction site as well as on site cutting and welding costs of prefabricated steel sections along with associated hazards are completely avoided.

xii) Easy financing and return customers :

Most homes and buildings built in the modular fashion must be paid for up front which ensures that the construction teams receive payment in full right away. Again, if the building owner decides to move their prefabricated building, they may hire the construction company that assembled the structure to disassemble and rebuild the structure at a new location.

Disadvantages :

i) Lack of monolithic continuity :

In prefabricated construction, it is difficult to ensure monolithic continuity in the finished products. As a result of which, in concrete construction, the precast concrete members may often need to be made larger or more heavily reinforced than their instu equivalent because of the free and conditions involved. Again joining of prefabricated steel sections may require on site welding or riveting which is difficult to carry out.

ii) Weak and problematic joints :

In fact, prefabricated construction is bound to have more number of joints which are weak points in a structure contributing to the potential danger of failure. In addition, leaks can form at joints in prefabricated components. Therefore, sufficient care has to be taken for joining the components in prefabricated systems.

iii) Large initial capital investment :

Huge initial capital investment is required for establishment and operation of prefabrication shops, stock pilling of materials as well as in terms of heavy mechanization and employment of specialized work force or man power.

iv) Provision for extra stresses :

Prefabricated units are required to be transported from the factory or work shops to the construction site where final assembling or errection is done. Therefore, adequate care and provision for the extra stresses due to transporting, erecting and handling must be taken.

v) High transportation cost :

The cost of transporting voluminous prefabricated sections and lifting them into position may be higher as these will usually be larger, more fragile and more difficult to handle than the materials and components of which they are made, which can often be packed more efficiently.

vi) Need of sophisticated equipments :

Large prefabricated sections or huge material stocks usually require heavy duty cranes or similar heavy machinery and precision measuring equipments for their proper handling and placing in position.

vii) Poor aesthetics :

Actually, repeatation of a particular design i.e. larger groups of buildings from the same type of prefabricated elements tend to look drab and monotonous resulting in poor sense of aesthetic view.

viii) Loss of jobs :

Local jobs may be lost, if the work is done to fabricate the components that is located in a place far away from the place of construction. This means that there are less locals working on any construction project at any time, because the fabrication is mostly outsourced.

ix) Dilution of responsibility :

The major draw back to prefabrication is the dilution of responsibility. A unit that is designed in one area of the country may be prefabricated in another and shifted to yet a third area, which may or may not have adequate criteria for inspecting materials that are not locally produced. This fragmentation of control may increase the probability of structural failure.

x) Less flexibility :

Prefabricated construction is less flexible because working in a construction project that involves prefabricated structure creates an extremely structured time line which makes it harder for the construction teams to deal with unexpected obstacles. Again, it is also difficult to accomade any desired modification or deviation from the original design.

xi) Manufactures reliability :

In some case the manufacturer of the parts or components may not be reliable or fail to provide construction elements that are satisfactory. This may create complications for the construction company.

xii) Non-compliance to specifications :

The specification of the building's site may put restrictions on certain aspects of the structure which may be difficult to incorporate because the main components of the structure are put together in a different location.

xiii) Surplus project time :

Of course, the prefabricated buildings require a lot less extra time to build which means less time is spent on each project which may cut down the total profit of each project. This may lead to losses for some companies that are not prepared to fill the extra time with further assignments.

xiv) Increased dangers at site :

Most construction teams are familiar with the materials that they regularly work with, but prefabricated structures can create unique dangers since they are put together by a completely separate organization. Construction accidents can leave workers dealing with serious injuries and health complications. In some cases, victims have to work with a construction accident attorney to handle the legal complications of the accident.

xv) Lack of client popularly :

In spite of a lot of advantages of prefabricated buildings, the level of acceptance among the clients falls short of expectations till to day because of the age long mania towards the traditional on site construction methods.

Design principles of prefabricated systems :

Although the method of analysis and design of prefabricated structural components are normally the same as in the case of conventional construction, the following main points of system approach are further considered in the prefabricated construction.

i) Standardization :

Generally prefabrication calls for repeatation use of building elements and universal forms for speedy and easy construction. Standardization facilitates quicker construction of similar structures, avoid duplication of effort on individual planning, give a boost to ancillary industries for manufacturing a numbers of components on mass scale without fear of accumulation of stocks. The consumer also becomes sure of obtaining elements of certain minimum standards and so the expenditure on supervision and other over heads are avoided. Thus the standardization of prefabricated elements are very much essential.

As a matter of fact, to adopt prefabrication in actual practice, the main parameters of the whole building needs to be standardized. The dimensions which have proved to be most rational and useful in service are selected for the purpose. This facilitates the standardization of each and every component that forms the building. For each standard element, a limited number of types and sizes are established with a definite gradation in geometrical dimensions and reinforcement ratio.

The experience gained in standardization shows that it is good practice to retain the cross- sectional dimensions of the flexural elements while the section of reinforcement should be varied with changes in span and/or load. Similarly, in case of columns of multi-storeyed residential buildings, it is rational to retain constant cross sectional dimensions, and only the section of reinforcement or where necessary the grade of concrete is changed from storey to storey. In this case, although these is certain excessive consumption of concrete in the columns of upper storey but the overall cost of construction is reduced through the repeated use of forms and unification of reinforcement mats and cages. Moreover, another advantage that it offers is that with unchanging dimension of columns from storey to storey, one type of floor beam or girders supported by columns can be made.

However, standardization can be possible only by use of modular coordination in planning and design of building elements.

ii) Structural design :

The prefabricated units are structurally designed for the following two stages.

a) Stage I loading – At the time of laying out of the units, the loads to be considered are self weight, the weight of concrete in the joints between the units and the incidental live load. The units are to with-stand this loading as simply supposted beam. Further the units are checked for handling stresses considering the allowable stress in concrete at the time of handling. Also, the location of the points at which the components can be lifted should be analyzed technically and the members should be properly designed to withstand the extra stresses.

b) Stage II Loading :

The members or units are designed for the full load acting on it under appropriate end condition i.e. simply supported, partially fixed or continuous support as the case may be. Stress parameters like maximum positive bending moment, maximum negative bending moment and maximum shear force etc. are calculated and the elements are designed as per the provisions of relevant Indian standard codes.

iii) Connections :

In monolithic construction, the structural continuity is maintained i.e. all structural parts are rigidly joined together which facilitates easy transfer of forces. But in prefabricated construction, where the precast members are used, the transfer of forces is mainly achieved through connections. Thus, the connections determine wheather the structure acts as a unit or as a series of individual members.

Requirements of good connection :

Satisfactory transmission of load between the units with minimum relative difference in deflection among them is the criteria of a good connection. But in practice, there might be some difficulty while designing the connections. Very often the nature of structural joints is such that they can not be designed using conventional theories or established procedures. In such case, it becomes imperative to carry out load tests to establish the satisfactory structural and functional performance of the joints.

A good connection invariably fulfills the following criteria.

a) The joint should be capable of transmitting the design imposed loads with a known margin of safety.

b) It should withstand the loads without excessive displacement or rotation and avoid high local stresses.

c) It should normally accommodate acceptable tolerances.

d) It admits effective inspection and rectification.

e) It should not adversely affect the architectural appearance of the structure and should provide fire proof construction.

Types of connections :

For flexural units the following types of connections are adopted.

(A) – Scarf Joint

(B) – Tip to tip reinforcement facing joint.

(C) – Composite connection joint.

(D) – Lapping of reinforcing bars joint.

(E) – Welding of projecting bars joint.

The connection on type (A) is a very poor type of joint as the load carrying capacity of the assembly in this case is comparatively less than the other types. Connection type (B) is capable of carrying more ultimate load but the transfer of load from one unit to other is not satisfactory. Connection type (C) is considered to be a suitable one, because the ultimate load carrying capacity of the assembly may be more than that of the individual units. Again both the individual deflection as well as the relative deflection is also very less. Connection type (D) is regarded as superior to connection type (C) while connection type (E) is the best of all.

iv) Water proofing, insulation and finishing etc.

Dripping of rain water through the construction and expansion joints is a common defect even in the case of conventional construction. In this context, the importance of sealing the joints in prefabricated construction could be well under-stood. Hence, water proofing materials like tar-felt, bitumen or similar sealant products are used for making the joints leak proof. When prefabricated units are used for roofing, a layer of lime concrete or mud puska tile should be laid over it as a finishing coat. In addition, the flooring or roofing units should also provide thermal insulation as far as possible.

Types of prefabricated elements :

Several technical institutions and research organizations in our country have developed various types of prefabricated building elements to suit Indian conditions. Of them, the Central Building Research Institute, CBRI Roorkee has done some pioneering work in developing flooring and roofing units. Other organizations/ agencies all over the country have also substantially contributed in the development of various prefabricated elements. However, all these units developed in India can be grouped under the broad category of light prefabrication, which can be easily cast at site or factory and placed in position only with the help of manual labour with out employing heavy machineries/ equipments. These elements can be broadly categorized as follows.

Category I : Walling units.

Category II : Flooring / Roofing units.

Category III : Miscellaneous items.

Category I: Prefabricated walling units :

The following elements may be used for walling units.

a) Cellular Unit :

The cellular unit of walling system consists of un reinforced precast concrete element having trapezoidal hollows running along its length. The common sizes are 500x 1000 x 100 mm with three hollows weighing around 55 Kg/m and 600 x 1200 x 75 mm with four hollows weighing in the range of 80 Kg/m. These units are suitably placed side by side and one above the other to act as walls.

(Figure………..):

b) Hollow concrete block masonry unit

It is a very useful masonry unit available for building construction and its economy, strength, durability and attractive appearance has established it as a unique element in the prefabricated system. The additional features of advantage associated with this product are enumerated as follows:

i) Thermal insulation and acoustics

Due to the presence of hollow core, it is capable of providing effective insulation against heat and cold without incurring any extra expenditure on the special treatment for the purpose. Houses built with hollow concrete blocks gives comfort through out the year by keeping cool in summer and warm in winter. The sound absorption capacity of hollow concrete block walls made with concrete of dense aggregates absorbs more sound than the ordinary plastered walls. However it has been found that the blocks made with light weight aggregates have excellent sound absorbing properties.

ii) Fire resistance :

Hollow concrete blocks have excellent fire resistance. They have a substantial load carrying capacity and safety before, during and even after a severe five exposure. Blocks having fire ratings of 2hrs, 3 hrs and 4 hrs can be easily manufactured.

iii) Conventional size :

The hollow concrete blocks are generally available in standard nominal sizes of 40x20x20 cm which is equal to the volume of 8 bricks where as their actual size is 39x19x19 cm with 10mm mortar joints. These can be manufactured in various shapes and sizes and hence there is no necessity of wasting the labour force in cutting the blocks or adding small pieces to build walls of rooms with different sizes. Moreover, the projections and depressions on the block do the function of providing excellent shear keys in the walls.

Shape & size of hollow concrete blocks:

Hollow concrete blocks are usually manufactured in one of the following three nominal sizes.

Length (cm)	Width (cm)	Height (cm)	Weight(kg)
40	30	20	26
40	20	20	18
40	10	20	10

The actual dimensions are 10 cm scant to allow for the thickness of mortar joints.

iv) Economy in the use of mortar :

Due to their larger size and regular even shape, the joints in the hollow block masonry construction are generally fewer and thinner compared to the brick or stone masonry walls, which results in the substantial saving in mortar. For quantitative comparison, $100m^3$ of concrete block masonry requires only $5m^3$ of mortar where as $25m^3$ of brick masonry consumes same quantity of mortar with 10mm joints.

v) Sturdiness and elegant appearance – Tests have shown that hollow concrete blocks are very strong in comparison with a factor of safety of 4 to 6. It also presents an attractive appearance and lends itself to a variety of architectural expression by treatment on the surface.

vi) Lighter foundation – A hollow block wall is comparatively lighter in weight than a brick or stone masonry wall and consequently the load on the foundation is considerably reduced leading to lighter foundation.

vii) Low maintenance cost : Owing to less number of joints & better surface finish the maintenance cost of hollow concrete block masonry wall is negligible as compared to that of brick or stone masonry wall.

viii) Overall economy – The overall cost of a 20cm thick hollow concrete block wall may cost between 10 to 15% cheaper than the corresponding brick masonry wall.

c) Soil cement block unit :

For the construction of walls of low cost houses, a solid soil cement block may be economically used in place of hollow concrete block. Since locally available soil with only a small proportion of cement can be used to make these blocks in simple wooden moulds with the help of unskilled labour at a much lower cost than that is required for burnt clay bricks, these blocks are cheaper than conventional burnt bricks besides being strong and durable. In addition to it, soil cement block masonry requires less mortar and labour compared to the burnt clay brick masonry an account of their relatively shape and relating large size.

The soil cement blocks are actually manufactured in sizes of 29x19x9cm. Three quarter sizes and half unit sizes are also made according to the requirements. For manufacture of soil cement blocks, the soil cement mixture in placed in the mould in layers of 5cm which is continuously compacted with an iron hammer weighing 4 to 5 Kg.

(Figure ………….)

d) Fly ash bricks :

Fly ash bricks are precast cost effective building materials which can efficiently replace the burnt clay bricks that roughly constitute 22% of the cost of the building. these are lighter in weight leading to considerable reduction of load on the foundation.

Further the shape and the size of the bricks being exact, it consumes less mortar for joining and finishing. It indirectly saves the under utilization of the strength of burnt clay bricks. In a three storeyed building, the load bearing wall needs hardly 40 Kg/cm^2 strength to sustain normal loading at plinth level whereas the use of burnt clay bricks of 105 Kg/cm^2 in its place amounts to dumping of high strength bricks of no use. On the other hand, use of fly ash bricks helps in reducing environmental pollution, preservation of fertile land besides providing a solution of disposal problem.

e) Lime soil block :

Lime-soil blocks are exactly same as soil-cement blocks discussed earlier with the only difference that lime replaces the cement in the blocks.

f) Mud blocks :

Of course, the mud block buildings are well suited to the hot climate of developing countries like India. Compared to the buildings made of concrete, they are cooler in summer and warmer in winter. It has acquired importance in case of design of low cost houses. In this case, the earth free from pebbles and rubbish materials is well kneaded by mixing proper amount of water and made in blocks of 300 x 200 x 200 mm or 200 x 200 x 200 mm under high pressure of 150 to 250 Kg/cm^2 by a hydraulic press, which makes it highly impermeable. However, it is highly recommended to use rich cement mortar with water proofing materials to save the wall from erosion by the rain water.

Category II : (Prefabricated flooring / roofing units)

a) Channel Unit : The unit is an example of medium panel construction and has been developed by CBRI, Rourkee. Generally this unit is a precast RCC element, trough shaped with 300 mm width and 130 mm depth, having minimum flange/web thickness of 25 mm weighing about 36 Kg/m. The span is normally kept between 2.5 m to 4.2m and it does not requires any type of temporary support or propping arrangement during construction as well as deck concreting. During fixing, the corrugations on its sides are filled with in-situ concrete which helps to develop monolithi city and transfer of load in transverse direction. Where ever required, negative reinforcements can be provided at the support before filling with in-situ concrete. Overally, the scheme results in saving of 36% cement, 5% steel, 36% fine aggregate and 36% coarse aggregate when compared with 115 mm thick conventional RCC slab.

(Figure………..)

b) Cored Unit :

This unit is also another example of medium panel construction and has been developed by CBRI, Roorkee, It is a precast RCC structural component having two circular hollow cores through out its length and provides flush ceiling. In this case, too, these is no necessity of propping during construction and deck concrete. It is 300mm wide and 130 mm deep weighing about 46 Kg/m. Negative reinforcements, if required are placed in proper position and the joints are filled with concrete of grade M15. As compared to 115mm conventional RCC slab, in this case, these is a saving of 22% cement, 22% fine aggregate, 22% coarse aggregate and 5% steel.

(Figure………..):

c) Cellular unit :

This unit of flooring / roofing system, developed by CBRI, Rourkee, consists of cellular units supporting partially precast RCC joists and deck concrete. It is principally an unreinforced precast concrete slab element having trapezoidal hollows running along its length. The tensile strength of concrete is taken into account in the design of the element. These units are available in common sizes of 500 x 1000 x 100 mm with three hollows, weighing 55 Kg/m and 600 x 1200 x 75 mm with four hollows, weighing 80 Kg/m. In this case the supporting joints are propped at every one meter and the units are placed side by side. 6 mm dia steel rods are placed @ 30 cm c/c both ways as temperature reinforcement and 35 mm thick concrete of grade MI5 is laid over the deck. This system results in economy of 22% in concrete & 54% in steel as compared to that of 115 mm conventional RCC slab.

(Figure………..):

d) Ribbed Slab Unit :

These units are available in sizes of 1.20 m wide, 3.60 m long and 255 mm deep around the perimeter with two ribs of 150 mm in depth. The units are placed across the span and joints between the units are filled with M15 concrete with the reinforcements projected out from the units and welded. The saving of this system is 24% in concrete and 5% in steel, when compared to the traditional 115 mm slab.

e) Waffle unit :

This unit which is a scheme with precast called waffle unit has been developed by CBRI, Roorkee for the case of slabs spaning in two ways and having span length more than 6 meters. The units are open box type with nominal reinforcement and are available in sizes of 60cm x 120 cm squire. Of course, the depth varies according to the span. The precast waffle units are placed in position on shuttering in grid pattern and the reinforcements are provided in the joints between adjacent units at right angles to each other. The sailent features of the scheme are the elimination of structural deck concrete normally provided above other types of precast units and the monolithic behavior of these precast units along with insitu grid beams. Compared to the traditional T-beam slab construction, this system results in a saving of about 15% in concrete and 10% in steel.

f) Brick panel unit :

The prefabricated brick panel units used for flooring/ roofing system consists of three elements as given below.

i) Reinforced brick panel : - the size of the panel is 1040 mm long, 500 mm wide and 75 mm thick with 2 ms bars of 6 mm dia. It uses around 16 nos of bricks set in 1:4 cement sand mortar.

ii) Partially precast RCC Joist – Normally it is available in 130mm x100 mm section and the reinforcement is provided according to the structural design of particular span length. For example for a clear span of 3.3m, the main reinforcement consists of 3 nos.

of 12mm dia bars at bottam and 1 no of 6 mm dia bar at top and the transverse reinforcement consists of stirrups of 6mm dia bars.

iii) Deck concrete :The roof panels are supported on partially precast joist and joined together with 1:4 cement sand mortar. The steel bars 6 mm dia and 530 mm long are provided as negative reinforcement across the joints. Then 25 mm thick concrete of M15 grade is laid all over the panel.

The economy of the system results due to avsing of 30% in cement and 35% in steel as compaired to 115 mm thick conventional RCC slab.

(Figure………..):

g) Arched Brick panel Unit :

In contrast to the brick panel units in which the load is transferred by bending action, in case of arched brick panel units, the transfer of load in effected by the arch action. Here, although provision of reinforcement can be eliminated from consideration of strength, but is safer to provide 2 nos 6 mm dia. bars along the length of the panel, one bar in each outer row to take up transportation and handling stresses. Generally, they are available in common sizes of 1000 x 500 mm containing 16 nos of bricks set in 1:4 cement mortar, where in a rise of 70 mm is given for arching. The supporting beam of size 100 m x 125 m is reinforced with 2 bars of 12 mm dia. at bottom and one bar of 6 mm dia at tap along with 6 mm dia. stirrups. The hunch is filled with M15 grade of concrete for roofing. In addition 50 thick lime terracing is also laid over the surface. This system results in a saving of about 50% over the conventional system.

(Figure………..):

h) Doubly curved tile unit :

This system of roofing / flooring consists of doubly curved tiles upto size of 100 cm in square with partially precast cement concrete beams. The tiles are designed on the principles of simple shell with double curvature by taking the advantage of its property of resistance to static and shock loads. However, CBRI, Roorkee has suggested the tile size of 70 cm x 70 cm x 2 cm (without reinforcement) and partially precast beam of size 13cm wide x 9 cm deep reinforced according to the design requirement. In order to develop good bond between the precast and in situ concrete, stirrups are kept projecting by 5 cm above the precast portion. The haunches between the humps of tiles are filled with M15 grade of concrete. However, the beams must be supported by propping till the concrete in hunches has set. This system results in a saving of 28% in concrete and 40% in steel, over the conventional RCC floor or roof.

(Figure………..):

i) Doubly curved shell unit :

This system consists of a funicular shell in the form of thin doubly curved shell (25 mm minimum thickness) and an edge beam of 50m wide and 50 to 70 mm deep with minimum reinforcement of a 6 mm dia mild steel bar. The function of the edge beam provided along the periphery of the shell stiffers the shell which may be used in one of the following patterns.

i) Precast shell units supported on prefabricated beams: In this pattern of construction, the supporting beams and the shell units remain at different levels in two directions.

ii) Precast shell units forming waffles in two directions: In this pattern the precast shell units are kept supported on staging so as to form waffles in two directions. The hunches with reinforcements placed between the shell units are connected to a level of 2 to 5 cm above the crown of the shell. The ribs in both the directions remain at the same level and height offering an aesthetic sense of architectural treatment. The maximum size of the unit is kept between L/10 to L/15 where L is the size of the shell.

(Figure………..):

j) T-joist roofing unit :

There are two types of T-joist roofing units available either of which can be used as per requirement. These are :

i) The ordinary type and ii) The hollow type with ceiling tiles.

In the first category, the roof consists of precast reinforced concrete T-joists with flarges 30 cm wide placed side by side so that the ribs are at 30 cm on centers. Generally, the section of the joists is kept similar for all spans whereas only the depth of the ribs and the amount of reinforcement varying for different spans. Again, these are also similarly reinforced with mild or tor steel bars and fabricated in the same manner except that the main tension bars in the bottom of the ribs are of different dia suiting the span.

Thus, it is easy to build this type of roof. The T-joists are made in simple wooden moulds at the site of the house/building factory and are kept ready for use. After the construction of walls, the joists are lifted up by simple devices which are grouted and well compacted in place. This type of prefabricated roofing system takes much less time than any other type.

But, in the second category of the system, the hollow roof with cement sand ceiling tiles possesses better thermal insulation properties and mostly has plain ceiling without any projecting ribs being visible. This hollow roof can be advantageously adopted over living rooms to provide greater climatic comfort and aesthetics, where as ordinary T-joists roof can be used for verandahs, kitchen and bath rooms.

(Figure………..):

Category III (Miscellaneous Units)

a) Door and window frames :

The door and window frames may be made up of precast reinforced concrete of size 60 x 100 mm or 70 x 75 mm in cross section in case of single shutter and 60 x 120 mm for double shutter with minimum reinforcement of 3 bars of 6 mm dia steel rods. The concrete to be used for this purpose should not be weaker than M20 grade and for proper compaction of concrete free from voids and honey-combing, either a table vibrator or a form vibrator may be used. In addition to this, suitable arrangement for fixing of hinges is made.

Generally the mould for casting these frames are made of steel or of good quality timber suitably lined with iron sheet in order to ensure better surface finish. Further, provisions are made in the mould for accommodating fixing devices for hinges and hold fasts. Also suitable rebate may be provided to act as plaster groove wherever required. Either the entire frame may be cast complete in one piece or each of the vertical and horizontal members of the frame may be cast separately which are assembled into the complete frame at site. However, the former method has the advantage of reducing the work at site and offers monolithic property to the system. But side by side, it introduces difficulties in fabrication of the moulds as well as transportation and handling of the complete frame. Also there is risk of damage to the frame during transit. Again, since the damage to even one member leads to the rejection of the whole frame, the later method is relatively simpler and more economical.

When the frame is cast into separate parts, one of the reinforcing bars of the vertical members of the frame is kept projecting so as to tennon into the corresponding holes in the horizontal member. Normally, the holes in the horizontal member for taking the projecting reinforcement from the vertical member is made slightly larger than the bar dia for facilitating easy insection of the projecting bar. The holes are grouted with cement sand slurry of proportion 1:2 after assembly of the frame at site.

(Figure………..):

b) Precast RCC thin lintel :

The load carried by a lintel actually deperds upon the extent of arching action of the brick work on its top. Load tests conducted have established that such lintels mostly act as composite beams, tension being taken by the RCC portion and the compression by the brick work above. This approach makes it possible for economical flexure design of lintels resulting in thin sections. In this case, the deflections also remain within the permissible limits. Therefore, for normal loading conditions in buildings wheather single or multistoried, thin precast lintels of following specification may be used.

Concrete mix proportion – M20

Thickness of the lintel - 80 mm

Span of the lintel - (upto) 1.4m

Reinforcement = 2 nos of 10 mm # with 6 mm ∅distribution bars @ 300 mm c/c

Width of the lintel = equal to the width of the wall (250 mm)

Bearing of the lintel at the support = 12.5 cm

Minimum height of brick work over lintel =45cm.

Generally the top surface of the precast lintel is finished rough to provide key with the brick work on top and is required to be supported during the brick work over the lintel.

(Figure………..):

c) Precast RCC sun shade cum lintel

Normally, the sun-shade or chajja provided over the openings of the exterior walls in a building are monolithically cast with the lintels. But it is desirable that these units do not become too heavy for handling and lifting purposes. Whereas the lintel acts as a simply supported beam, the sun shade portion of the unit acts as a free cantilener where the main reinforcement bars are provided at the top face of the projection which is adequately anchored into the body of the lintel. Further, it is equally important to ensure that there is sufficient dead weight of the masonry over the lintel to ensure its stability against over turning. Of course, these are cast in wooden moulds and thoroughly compacted by suitable means, finished, cured preferably for 10 days and then dried for about 28 days after casting before they are laid into the wall.

(Figure………..):

d) Precast shelf slab :

Usually thin slabs made of precast concrete 40mm thick are used for cupboards, oven shelness, kitchen platforms and others which are properly fixed with nominal mix concrete of proportion 1:2:4. They are cast in wooden or metal moulds, thoroughly compacted by vibrator, finished smooth, cured for about 10 days ad adequately dried before placing them into the position.

(Figure………..):

e) Precast Jallies :

Generally the precast concrete jalleys of attractive designs are used in ventilator openings, parapet walls or partitions, compound walls etc. They are economical and more durable compared to the iron grills that suffer from corrosion and require periodical painting.

Modular coordination :

In the year 1930, and American Civil Engineer, Alfred Forwell Beams, initiated modern thinking in the field of modular coordination. His innovative idea of dimensioning of buildings by the use of a single module either in multiple or fractional form is called modular coordination and it is a prerequisite particularly for industrialized buildings. It is equally important, too, for rationalization of traditional buildings and may be regarded as the most effective mean for introducing and implementing standardization in buildings.

Of course, modular coordination is a form of dimensional coordination using a basic module. A basic module of 10 cm has been agreed upon internationally, designated as ‘M’. But his basic module is too small a dimension for planning a building. Therefore a multiple of the basic module, called a multi module, is adopted as the planning module (PM). Majority of the countries have adopted 30 cm as the planning module in the horizontal direction and 20 cm in the vertical direction. However, just as the basic module is too small for planning of a building, it is too large for deciding the dimensions of some other components of buildings such as cross-sectional dimensions of slabs, beams etc. For this purpose, a sub-multiple which is a fraction of the basic module (M/4 or 2.5 cm) is normally adopted for convenience.

In fact, the application of the principle of modular coordination by itself may not automatically result in full economy or desired efficiency. Rather, in order to achieve these objectives fully, reduction in the variety has to be made even in respect of those competents and units made to modular sizes which ultimately leads to the question of standardization by selection of prefered dimensions. Thus, a preferred dimension may be defined as a modular dimension adopted for planning of buildings and their components that permits considerable reduction in the number of standard sizes. It is, principally, a prefered multiple of the basic module.

However, full modular coordination implies that not only the components shall be modular but the buildings should also be designed in such a manner that the thickness of walls, floors etc. as well as the dimension of rooms, windows, doors etc. are modular. Thus, modular coordination serves the purpose of a dimensional guide both to the manufacturers by offering as set of coordinated prefered seizes and to the designers and architects by rendering a design module.

The module has three distinct functions:

i) It is a measurement upon which an architectural design is based.

ii) It determines the exact dimension of each building component.

iii) It determines the position of building components within the system and within the building itself.

Advantages of modular coordination :

The following are the important advantages of modular coordination:

i) The task of planning of the building is considerably simplified.

ii) The details of components and joints are given in a standard set of drawings and hence each building requires only a few drawings to show the location of components, thus considerably reducing the drafting time.

iii) It makes the estimation of quantities of materials and cost simpler.

iv)The site work of setting out the measurements and locating the components becomes pretty easier.

v) Elimination or avoidance of cutting of components to fit into construction and subsequent wastage.

vi) Reduction in the number of sizes of building components.

vii) Easy introduction of new scheme owing to use of standard components.

Indian standard recommendation for modular planning :

1. I.S. Codes have recommended a set of guide liens for modular planning of buildings as well as their components :

A) Modular planning of building as a whole :

The planning grid in both the directions of the horizontal plane are :

i) For residential building – 3 M

ii) For industrial buildings

15 M for spans upto 12 m

30 M for spans between 12 m and 18 m

60 M for spans over 18 m

The planning module in the vertical direction is to be 1 M upto and including a height of 2.8m and above the height of 2.8 m, it shall be 2 M.

The centre line of load bearing walls and columns are to concide with the grid lines.

B) Modular planning of building components :

The preferred dimensions of prefabricated elements are to be as follows:

a) Flooring Scheme:

i) Length – Nominal length is to be in multiples of 3 M.

ii) Width – Nominal width is to be in multiples of 1 M.

iii) Overall thickness – the thickness of structural flooring units including concrete decking is to be in the multiple of M/4.

b) Beams :

i) Length – Nominal length is to be multiple of 3 M

ii) Width – Nominal width is to be multiple of M/4

iii) Thickness – Overall thickness is to be multiple of M/4.

c) Columns :

i) Overall height – floor to floor clear heights are to be multiplies of 1 m upto 2.8 and 2m above 2.8 m.

ii) Lateral dimensions – Overall lateral dimension or dia meter are to be in multiples of M/4.

d) Walls :

Thickness – Nominal thickness in multiple of M/4.

e) Stair case :

Width – nominal width in multiple of 1M.

f) Lintels :

i) Length - Multiple of 1M.

ii) Width – Multiple of M./4.

iii) Depth – Multiple of M/4.

g) Sunshades:

i) Length – Multiple of 1 M.

ii) Projection – Multiple of 0.15 M.

CHAPTER-3

EARTQUAKE RESISTANT CONSTRUCTION

3.0- INTRODUCTION

Almost the entire Indian Territory is vulnerable to seismic risk and some specific zones are subjected to frequent earthquakes. Of the various hazards a building is likely to be subjected to, earthquake can be the most destructive or devastating. An earthquake is characterized by sudden and violent shaking of the earth's surface caused by the movement of the rocks underneath. This movement is primarily caused due to the release of built up stress within rocks along the geologic faults or by the movement of magma in volcanic areas. When an earthquake takes place, the ground motion may occur in a random fashion in all possible directions radiating from its point of origin within the earth's crust known as epicenter. Consequently, structures founded on ground are set into a kind of motion inducing inertia forces on them. Of course, an earthquake can bring about enormous damage to a building, as it makes the structure to vibrate, which leads the building to fall or sink into the soil. The earthquake motion could be resolved into two components; horizontal and vertical, of which the horizontal vibration is the most dangerous since it causes the foundation of a structure to move horizontally while the top of the structure tries to remain in its original position. Thus, the horizontal inertia that develops in the structure eventually leads to its failure or collapse.

In deed, it is rightly said that earthquake it self does not kill people rather the man made structures or vulnerable buildings do. Precautions against earthquake damage to the buildings are, therefore, essential with a view to afford reasonable degree of safety both to the occupants as well as to the surroundings in the event of occurrence of an earthquake; so also for the ultimate safety of the structure. Hence, it is imperative to make the building earthquake resistant, especially in earthquake prone areas. The important aspects or areas of building technology that are to be addressed to, in case of new construction, are building configuration, building characteristics, lateral load resisting systems, effect of structural irregularities etc. For the existing buildings as well as old monuments or in case of earthquake damaged structures, seismic retrofitting or seismic rehabilitation etc. strengthening measures are resorted to depending upon the need and importance of the structure.

3.1 BUILDING CONFIGURATION:-

The shape, size and proportion of the building form is referred to as building configuration. From earthquake point of view it may also include the location, shape and approximate size of structural elements. Very often this extended definition of configuration is significant because of the intricate relationship of seismic performance between these elements. The architectural configuration, in general, depends on architectural design, functional requirements, urban design parameters, planning considerations, aesthetic appearance and identity or distinctiveness.

Of course, the earthquake forces depend on mass and stiffness distribution. Whereas, the shape, size, and material of the building establish its mass, the stiffness is directly related with the type of configuration. However, for the same areal size and shape of the building, various configurations can provide a solution.

An important feature in building configuration is its regularity and symmetry in horizontal and vertical plane. Generally the codal provisions of earthquake resistant buildings are based on simple, symmetrical and uniform building configurations and their application to unusual/irregular building configurations may lead to unrealistic evaluation. Because the seismic behavior of irregular shaped plans differs from regular shapes as the forms can be subjected to their asymmetry and/ or can present local deformations due to the presence of re-entrant corners or excessive openings. Therefore, it is important to understand about regular and irregular configurations, before taking architectural design decisions. The building configurations has been described as regular or irregular in terms of size, and shape of the building, arrangement of structural elements and mass.

A) REGULAR CONFIGURATIONS :-

Regular building configurations are almost symmetrical (in plan and elevation) about the axis and have uniform distribution of the lateral force-resisting structure such that, it provides a continuous load path for both gravity and lateral loads. The configurations shown in fig. 3.1 come under regular configuration and are seismically ideal. These configurations have low height to base ratio, symmetrical plan, uniform section as well as elevation and thus have balanced resistance. These configurations possess maximum torsional resistant due to the presence of shear walls and bracings. Uniform floor heights, short spans and direct loads path play a significant role in seismic resistance of the building.

FIGURES

B) IRREGULAR CONFIGURATIONS:-

A building that lacks symmetry and has discontinuity in geometry, mass and load resisting elements is called irregular. This irregularity may cause interruption of force flow and stress concentrations. Asymmetrical arrangement of mass and stiffness of elements may cause a large torsional force (where the center of mass does not concide with the center of rigidity). A building is considered as irregular if it possesses either plan irregularities or vertical irregularities. Some of the common irregular building configurations are as shown in fig. 3.2(a) & (b)

FIGURES

Thus a building shaped like a box, such as, rectangular both in plan and elevation is inherently stronger than one that is L- shaped or U- shaped, i.e. a building with wings. Besides, building with abrupt changes in lateral resistance or lateral stiffness can be classified under irregular configuration. Also, highly torsional configurations as well as buildings with short column possess configuration problems. (fig. 3.3,3.4,3.5,3.6)

I.S 1893(part-1) : 2002has recommended building configuration systems in section 7 for better performance of buildings during earthquakes.

3.1.1-INFLUENCE OF CONFIGURATION ON SEISMIC PERFORMANCE:-

The influence of configuration on seismic performance depends upon the ways in which the building responds to the dynamic forces due to motion of the ground. Static vertical loads are directly transferred down to the ground through foundation. But the earthquake exerts fluctuating dynamic loads. It is imperative to know and understand the dynamic characteristic of building along with the behavior of different elements of building structure under dynamic loads in order to determine the seismic forces.

While deciding about the building configuration, the forces that are exerted on the building elements and the exact nature of their resultant behavior, which are quite complex, should be taken into account. These forces are shown in Fig. 3.7 below.

FIGURES

Such diagrams originate in the form of typical seismic design analysis in which the earthquake forces are separately applied to each of the main axis for a rectangular shape and for a circular shape, there would be more axes that are similar (more stable). However, in case of irregular shapes which are complicated, one has to look at along several axes as shown in the following fig. 3.8.

FIGURES

Although, the earthquake forces may act from any direction, but the forces perpendicular to the major axes of the walls or frames usually stimulates the worst direction. If the ground motion and its resulting forces occur diagonally, then the walls or frames along both longitudinal and transverse axes (X and Y axis) may participate in such a manner so as to negate the resistance and, the forces in each of the wall or frame are considerably reduced.

FIGURES

However, it may be noted that in reality the earthquake forces are much more complex than our diagrams would indicate. This is because the ground motion is random and the main direction of emphasis may only become axial by chance. In fact, in any particular event, the total ground motion will always include non-axial components also. Thus, fig. 3.10 shows a better diagram for visualizing building configuration related to reaction to the ground motion.

FIGURES

Of course, a building is not a homogeneous block but an assembly of parts; and each part is subjected to earthquake forces horizontally and vertically and from the adjoining parts through joints. In a large building, the ground motion affects different parts of the building differently. These forces can induce torsion or incompatible movement, even in a geometrically symmetrical building as shown in fig. 3.11

FIGURES

The building being made up of parts which are joined together by means of different connections will have different localized strengths and stiffness; some calculated and some inherently caused by interaction of non-structural elements or configuration influence. This further differentiates its behavior from that of a homogeneous building block.

FIGURES

3.2 Lateral Load Resisting Systems

When earth quake motion causes a building to move, energy is induced in the building structure. The function of lateral load resisting system is to absorb this energy by moving, or deforming without collapse such that even if the building will probably be damaged during a major earthquake, yet the damage is expected to be reparable.

All structural systems resist forces in three basic ways: by bending (Flexure), shear or axial tension and compression. In general, systems that resists forces by bending are more ductile than those that are stressed in shear or axial tension and compression.

There are three basic types of lateral load resisting systems; moment resisting frames, shear walls and braced frames. Generally, shear walls are the most rigid, that is, they deflect the least when subjected to a given load. Braced frames are usually less rigid than shear walls and moment resisting frames are the least rigid.

In seismoresistant building architectural planning building architectural planning, it is very important to select proper lateral load resisting system. Any configuration, whether regular or irregular, will have some resistant system to take the lateral forces, which acts in horizontal and vertical planes. In vertical plane there are shear walls, braced frames and moment resisting frames, whereas in horizontal plane, the lateral forces are resisted by diaphragms formed by floor and roof slabs of the building. The presence of these resistance systems is the result of schematic architectural design.

However, the load resisting system must be of closed loops, so that it is able to transfer all the forces acting either vertically or horizontally to the ground. Bureau of Indian standards (BIS) in the code IS-1893(part-1) 2002 has approved three major types of lateral force resisting systems, namely, moment resisting building frame system, bearing wall system and dual system. These systems are further sub divided based on types of construction material used.

Table-7 of IS -1893 (part-1): 2002 lists the different framing system and corresponding response reduction factors. Response reduction factor (R) is basically an indicator of the performance of the structure in earthquakes. A low value of R(=1.5) indicates an extremely earthquake prone building i.e. unreinforced masonry wall buildings and a high value of R(=5)indicates an earthquake- resistant type building like special moment resistant reinforced concrete frame or shear wall buildings.

3.2.1-MOMENT RESISTNG FRAME

In building frame system, the columns and beams along with the joints of the frames resist the earthquake forces primarily by flexure. This system is generally preferred by architects because they are relatively simple compared to shear walls or braced frames. But there may be poor economic risk unless special damage control measures are taken in this system. However, slab column frames are not recommended as a lateral load resisting system. Fig. 3.13 (a) shows schematic diagram of moment resisting frame.

3.2.2-BUILDING WITH SHEAR WALL/ BEARING WALL SYSTEM

This system supports all or most of the gravity loads as well as lateral loads. In general, a bearing wall system has a comparably lower value of 'R' since the system lacks redundancy and has a poor inelastic response capacity. In severe seismic zones, these bearing wall systems are required to be specially detailed as per the provision of I.S: 4326 (code of practice for Earthquake Resistant Design and Construction of Buildings). Therefore, this system is not much preferred by the architects. Fig. 3.13 (b)

3.2.3 –BUILDINGS WITH DUAL SYSTEM

This system consists of shear walls (or braced frames) and moment resisting frames such that

i) The two systems are designed to resist the total design force in proportion to their lateral stiffness considering the interaction of dual system at all floor levels; and

ii) The moment resisting frames are designed to independently resist at least 25% of design seismic base shear.

In general, a dual system has a higher value of 'R' as compared to aforesaid systems since a secondary lateral support system is available to assist the primary non-bearing lateral support system as shown in fig.3.13 (c). This system is somewhat less restrictive architecturally.

- *Rigid frames or moment resisting frames-* They are principally composed of reinforced concrete portal frames with the lateral load being mainly resisted by flexure. They resist lateral loads by beams and columns and they tend to have large drift or lateral deflection. They are used in low/ medium rise buildings (up to 20 storeys)
- *Shear walls* – Eccentrically a shear wall is a rigid vertical plate that is oriented parallel with the direction of force that act like a vertical cantilever beam. Thus, they act like deep cantilever beams supported at the ground. They can resist both gravity (load bearing) and lateral loads transmitted to them by the floors. Shear walled buildings are very stiff structure against lateral loads. They are often used up to 30-40 storeys.
- *Braced frames* – A frame strengthen with diagonal bracing members mostly used in steel buildings. Diagonal bracings resist tension. Columns and beams carry gravity loads, bracings carry lateral loads.

3.3 – EFFECT OF STRUCTURAL IRREGULARITIES

Very often, it has been seen that geometrically the building may appear to be regular and symmetrical, but it may have irregularity due to uneven distribution of mass and stiffness. Therefore, it is always better to distribute the lateral load resisting elements near the perimeter of the building rather than concentrate these, near the centre of the building. (fig. 3.14). As a general rule, buildings with irregular configuration perform poorly in earthquakes even when good engineering has been carried out.

NOTE: - Heavy lines indicate shear walls and/ or braced frames.

Fig. 3.14 (a) - Arrangement of shear walls and braced frames – not recommended

Fig. 3.14 (b) - Arrangement of shear walls and braced frames – recommended

The section 7 of I.S. 1893 (part-1): 2002 enlists the irregularity in building configuration system. These irregularities are categorized into two types.

i) Vertical irregularities referring to sudden change of strength, stiffness, geometry and mass resulting in irregular distribution of forces and/ or deformation over the height of the building, and
ii) Horizontal irregularities which refer to asymmetrical plan shapes (e.g. L-, T-, U-, F-) or discontinuities in the horizontal resisting elements (diaphragms) such as cut-outs, large openings, re- entrant corners and other abrupt changes resulting in torsion, diaphragm deformations and stress concentration.

3.3.1-VERTICAL IRREGULARITIES:

3.3.1.1-*Vertical discontinuities in load path:* - One of the major causes to structural damage in structures during strong earthquake is the discontinuities or irregularities in the load path or load transfer. It is desirable that the structure should contain a continuous load path for transfer of the seismic forces, that develops due to acceleration of individual elements, to the ground. Failure to provide adequate strength and toughness of individual elements in the system or failure to tie individual elements together can result in distress or complete collapse of the system. Therefore, all structural and non- structural elements must be adequately tied to the structural system to act as a unit. The load path must be complete and sufficiently strong. The sequence of general load path is as follows:-

* Earthquake forces, which originate in all elements of the building are delivered through structural connections to horizontal diaphragms.

* The diaphragms distribute these forces to vertical resisting components such as columns, shear walls, frames and other vertical elements in the structural system which ultimately transfer these forces into the foundation.

FIGURES

The examples of load path irregularities are discontinuous columns, shear walls, bracings, frames that arise in a floating box type situation (fig. 3.16 a & b). In case of columns or shear walls that do not continue up to the ground but end at an upper floor level, shear is induced due to overturning forces to another resisting element of a lower level. This imposition of overturning forces over whelms the columns of lower level through connecting elements. Thus, the most critical region of damage is the connecting elements (link between discontinuous columns to lower level columns) and the lower level columns.

Therefore, the primary concern in load path irregularities is regarding the strength of lower level columns and strength of the connecting beams that support the load of discontinuous frames. Experience has shown that the failure due to discontinuity of vertical elements of the lateral load resisting system has been among the most notable and spectacular.

FIGURES

3.3.1.2-*Irregularity in strength and stiffness:-* The presence of a weak or soft storey in a building contributes to irregularity in either strength or stiffness. A weak storey may be defined as one in which the storey's lateral strength is less than 80% of that in the storey above, where as a soft storey is one in which the lateral stiffness is less than 70% of that in the storey immediately above or less than 80% of the combined stiffness of the three storeys above.

FIGURES

Here the storey's lateral strength is the total strength of all seismic resisting elements sharing the storey shear for the direction under consideration i.e. the shear capacity of the column or the shear walls or the horizontal components of the axial capacity of the diagonal braces. The deficiency that usually makes a storey weak is inadequate strength of frame columns. Thus, the essential characteristic of a 'weak' or 'soft' storey consists of a discontinuity of strength or stiffness, which generally occurs at the second storey connections. Of course, this discontinuity caused by lesser strength or increased flexibility of the structure results in extreme deflections in the first storey of the structure which in turn results in concentration of forces at the second storey connections. The result is a concentration of inelastic action.

FIGURES

However, the soft storey concept has technical and functional advantages over the conventional construction.

i) First, is the reduction in spectral acceleration and base shear due to increase of natural period of vibration of the structure as in a base isolated structure. But the advantage of this force reduction is nullified by an increase in structural displacement and inter-storey drift, which is a threat to stability of the structure.
ii) Secondly, a taller first storey is sometimes necessitated for parking of vehicles and/ or retail shopping, large space for meeting room or a banking hall. Due to this functional requirement, the first storey has lesser stiffness of columns as compared to stiffness of upper floor frames, which are generally constructed with masonry infill walls.

The failure of reinforced concrete buildings due to soft storeys have remained the main reason in past earthquakes. Undoubtedly, it is recognized that this type of failure results from the combination of several other unfavorable reasons, such as torsion, excessive mass on upper floors, P-Δ effect and lack of ductility in the bottom storey. These factors lead to local stress concentration accompanied by large plastic deformations. Therefore, the soft storeys deserve a special consideration in analysis and design and it is not always necessary that all the first storeys of the buildings are soft storeys, if the columns of the first storey have been designed on the basis of the first storey have been designed on the basis of capacity or ductility.

3.3.1.3-*Mass irregularity;-* Mass irregularity is induced by the presence of a heavy mass on a floor like a swimming pool. As per I.S 1893, mass irregularities are considered to exist where the effective mass of any storey or floor is more than twice the effective mass of adjacent storey or floor. However, NEHRP defines it when the weight exceeds 150% of that of the adjacent floor/ storey.

FIGURES

Here the effective mass is the real mass consisting of the dead weight of the floor plus the actual weight of the partitions and equipments. Excess mass can lead to increase in lateral inertial forces, reduced ductility of vertical load resisting elements and increased tendency towards collapse due to P-Δ effect.

Irregularity of mass distribution in vertical and horizontal planes can results in irregular responses and complex dynamics. The characteristic swaying mode of a building during an earthquake implies that masses placed in the upper storey of the building produce considerably more unfavorable effects than masses placed lower down. The center of gravity of lateral forces is shifted above the base in the cases of heavy masses in upper floors resulting in large bending moments. Massive roofs and heavy plant rooms at high level are therefore to be discouraged wherever possible. When mass irregularity exists, the lateral-force resisting elements to be checked using a dynamic analysis for a more realistic lateral load distribution of the base shear.

3.3.1.4-*Vertical geometric irregularity* :- All buildings with vertical offsets fall in this category. Also, a building may have no apparent offset, but its lateral load carrying elements may have irregularity. It is considered, when the horizontal dimension of the lateral force resisting system in any storey is more than 150 % of that in an adjacent storey. For instance, shear wall length may be suddenly reduced. Also when a building is such that larger dimension is above the smaller dimension; it acts as an inverted pyramid and is undesirable.

FIGURES

The set back can also be visualized as a vertical re-entrant corner. The general solution of a set back problem is the total seismic separation in plan through separation section, so that the portions of the building are free to vibrate independently. When the building is not separated, the lateral force resisting elements are checked using a dynamic analysis.

3.3.1.5-*Out of plane offsets:-* This is a very serious irregularity wherein , there is an out of plane offset of vertical element that carries the lateral loads. Such an offset imposes vertical and lateral load effects on horizontal elements, which are difficult to design for adequately. In this case, shear walls are not obvious.

FIGURES

3.3.1.6-*Proximity of adjacent buildings;-* Pounding damage is likely to be caused by mutual hitting of two buildings constructed in close proximity with each other. Pounding may result in irregular response of adjacent buildings of different heights due to different dynamic characteristics. Several examples of building failure have been observed due to pounding during earthquakes.

FIGURES

This problem arises when buildings are built without separation right up to property lines in order to make maximum use of the space. When floor of these buildings are constructed of the same height, the damage due to pounding usually is not serious. If this is not the case, there may be two problems. When the floors of adjacent buildings are at different elevations, the floor of each structure can act like rams, battering the columns of the other buildings. When one of the buildings is higher than the other, the lower building can act as a base for the upper part of the higher building and the lower building receives an expected large lateral load while the higher building suffers from a major stiffness discontinuity at the level of the top of the lower building. Damage due to pounding can be minimized by drift control, building separation and aligning floors in adjacent buildings.

3.3.2 PLAN IRREGULARITY OR PLAN CONFIGURATION PROBLEMS

3.3.2.1 *Torsion irregularities:* -Torsion irregularity is considered when floor diaphragms are rigid in their own plan in relation to vertical structural elements that resist the lateral forces. Torsion irregularity is considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structure transverse to the axis is more than 1.2 times of the average of the storey drifts at two ends of the structure.

FIGURES

The lateral force resisting elements should be a well-balanced system that is not subjected to significant torsion. Significant torsion is taken as the condition where the distance between the storey's centre of rigidity and storey's center of mass is greater than 20% of the width of the structure in either major plan dimension. Torsion or excessive lateral deflection is generated in asymmetrical buildings, or eccentric and asymmetrical layout of the bracing system that may result in permanent set or even partial collapse. Torsion is most effectively resisted at point farthest away from the centre of twist, such as the corner and perimeter of the buildings.

3.3.2.2*Diaphragm discontinuity;-* Discontinuity in diaphragm stiffness leads to plan irregularity. The diaphragm is a horizontal resistant element that is responsible for transferring forces between vertical resistance elements. The diaphragm discontinuity may occur with abrupt variation in stiffness including those having cut-out or open areas greater than 50% of the gross enclosed diaphragm area, or change in effective diaphragm stiffness of more than 50% from one storey to the next.

FIGURES

The diaphragm acts as a horizontal beam and its edges act as flanges. It is obvious that openings cut in the tension flanges of a beam seriously weaken its load carrying capacity. In a number of buildings, there have been evidence of roof failures which is caused by tearing of diaphragms.

3.3.2.3*Re-entrant corners:-* The re-entrant or inward cutting corner is a common irregularity in overall building configurations that, in plan, assume the shape of an L, T, H, + or combination of these shapes resulting in lack of tensile capacity and force concentration. When an other -wisely regular building has a large re-entrant corner, wings of the building tend to vibrate in a manner different from that of the entire building and hence a building is treated as irregular when offset dimensions exceeds certain limits. According to I.S.1893 (part-1):2002, plan configuration of a structure and its lateral force resisting system contain re-entrant corners, where both projections of the structure beyond the re-entrant corners are greater than 15% of its plan dimensions in the given direction.

FIGURES

The re-entrant corners of the buildings are subjected to two types of problems. The first is that they tend to produce variations of rigidity and hence differential motions between different parts of the building, resulting in a local stress concentration at the notch of the re-entrant corners. The second problem is torsion. The magnitude of the induced forces depends upon mass of the building, structural system, length of the wings and their aspect ratios, height of the wings and their height- depth ratios. Examples of damage to re-entrant corner buildings are common and to avoid this type of damage, either a separation joint between two wings of the building are provided or the buildings are tied together strongly in the region of stress concentration and locate resistant elements so as to increase tensile capacity at re-entrant corners.

3.3.2.4 ***Projections:-*** All projections (vertical and horizontal) are most vulnerable to damage during earthquakes. As they are basically cantilevers, there is no redundancy and hardly any ductility at their junctions with the main structure. Design of such structures is to be made taking five times the seismic coefficient in line with the international practice.

FIGURES

3.3.2.5 ***Non-parallel systems: -***_In this case, the vertical load resisting elements are not parallel or symmetrical about the major orthogonal axis of the lateral force resisting system. Such situations are often faced by architects and these lead to high probability of torsional forces under a ground motion because the center of mass and center of resistance do not coincide. This problem is often exaggerated in the triangular or wedge shaped buildings resulting from street inter- sections at an acute angle. The narrower portion of the building will tend to be more flexible than the wider ones, which increases the tendency of torsion. In the design of such type of buildings, special care must be exercised to reduce the effect of torsion or to increase torsional resistance of the narrow parts of the building.

FIGURES

3.3.3GENERAL DISCUSSIONS AND RECOMMENDATIONS

The multi-storeyed reinforced concrete buildings with vertical irregularities, where the load distribution with building height is variable, should be designed on the basis of dynamic analysis and inelastic design. In buildings with plan irregularity, load distribution to different vertical elements becomes complex. In such cases, floor diaphragm plays an important role and needs to be modeled carefully. The proper effect of these irregularities can be accounted by 3-D mathematical modeling of the building and dynamic analysis.

In irregular buildings, there may be concentration of stresses and the ductility provisions and special care in detailing are most important in such situations. Therefore, more care is necessary at the time of planning of such buildings for reducing the irregularities and just dynamic analysis may not solve the problem. The torsional effect in a building can be minimized by proper location of vertical resisting elements and mass distribution. Shear walls should be employed for increasing the stiffness where necessary and be uniformly distributed in both the principal directions.

3.4 BUILDING (RESPONCE) CHARACTORISTICS

Different individual buildings shaken by the same earthquake respond differently. In fact earthquake response of a building is very much dependant upon its various characteristics because the seismic forces exerted on a building are not entirely externally imposed forces like wind forces , rather these are the response of cyclic motion at the base of a building causing acceleration and hence inertia forces. Several important features of buildings affect their performance during an earthquake. Buildings of different construction materials or configuration respond in different ways to the same ground motion; some may collapse while others are able to survive. The effect of earthquake ground shaking depends up on the specific response characteristic of the type of structural system used.

The knowledge of how the buildings respond in an earthquake helps the architects, engineers and builders to design and construct the buildings so as to withstand ground motion without collapsing. The response being essentially dynamic in nature, the dynamic properties of structures such as natural period, damping and mode shapes play a crucial role in determining the response of a building. Besides, the other characteristics of building system, such as ductility, foundation system, response of non-structural elements etc. also affect the seismic response.

The effect of building characteristics on its seismic performance may be discussed under following heads:

3.4.1 ***Fundamental period and mode shapes****:* -When a building is subjected to dynamic action like earthquakes, a vibratory motion is set up owing to elastic properties and mass of the building. In this context, one important building characteristic is the fundamental period of vibration of the building (measured in seconds), which depends in a complex way on the stiffness of the structural system, its mass and total height or distribution of mass. The seismic waves with periods similar to that of the building are likely to cause resonance and amplify the intensity of earthquake forces that the building has to resist.

Structural systems using concrete or masonry shear walls are stiff and result in buildings with short periods, whereas more flexible moment- frame systems have longer periods. On the basis of time period, the buildings may be classified as rigid ($T<0.3$ secs), Semi rigid (0.3 secs$<T<1.0$ secs), and flexible structure ($T>1.0$ secs). Buildings with higher natural frequencies and a short natural period, tend to suffer higher acceleration but smaller displacement. In the case of buildings with lower natural frequencies and a long natural period, this is reversed; the buildings will experience lower accelerations but larger displacements. Therefore, short period buildings with stiff structural systems are designed for larger forces than long period flexible buildings. This concept is also applicable to the amount of force the individual structural seismic elements and their components must resist. Stiff elements must be made stronger because they will attempt to resist larger earthquake forces than flexible elements in the same structural system.

This vibration is similar to the vibration of a violin string, which consists of a fundamental tone and the additional contribution of various harmonics. The vibration of a building likewise, consists of a fundamental mode of vibration and the additional contribution of various modes, which vibrates at higher frequencies. In low rise buildings, (say less than 5 storeys high), the seismic response depends primarily on the fundamental mode of vibration and accordingly the period of vibration of this mode (expressed in seconds), is one of the most representative characteristic of the dynamic response of a building as discussed above.

Fundamental periods of vibration can be determined by the code based empirical formulae and the fundamental modes of the building may be determined by any of the several methods developed for the dynamic analysis of structures.

3.4.2 ***Building frequency and ground period: -*** During an earthquake, the inertial forces generated in a building depend upon the frequency of the ground on which the building is standing as well as the building's natural frequency. When these are nearly equal to one another, the building response reaches a peak level. In some situations, this dynamic amplification effect can increase the buildings acceleration to a value, which may be double or more than that of the ground acceleration at the base of the building.

Past studies have shown that the predominant period at a firm ground site is typically in the range of 0.2-0.4 sec while the period can reach up to 2 sec or more on soft ground. Since most building structures have fundamental periods of approximately 0.1N (where N is the number of the storeys), it can be concluded that if the foundation soil is firm, rigid structures will have more unfavorable seismic response than flexible structures, where as the seismic response of flexible structures on soft foundation sites will be less favorable than that of rigid structure.

3.4.3 ***Damping: -*** One way of decreasing the effects of structural amplification of ground motion by constructing the building so that the vibration of a building is quickly reduced, as an earthquake set it in motion, is by damping. The damping is the ability of a structural system to terminate or retard the motion or vibration of a system by dispatching energy of the earthquake. In fact, the building response being inversely proportional to damping, the more damping a building possesses, the sooner it will stop vibrating, which is highly desirable from the earthquake performance point of view.

In a structure, damping is due to internal friction and the absorption of energy takes place by the buildings structural and non-structural elements. Therefore, connections of non- structural elements such as partitions, ceilings and exterior walls, can dampen a building's vibration, and modern office buildings, with open flooring and a few partitions, tends to be deficient in damping and suffer more damage in an earthquake. It is most advantageous for a building to have a high level of damping characteristic - in effect to be an inefficient vibrator. Today some of the more advanced techniques of earthquake resistant designs and constructions employ added damping devices like shock absorbers to increase artificially the intrinsic damping of a building so as to improve its earthquake performance. With damping design, a building is less likely to resonate in tune with the ground.

There is no numerical method available for determining damping of a building and it is only obtained by experiments.

3.4.4 ***Ductility: -***Ductility is another factor that can affect the performance of a building during an earthquake. Ductility is the property of certain materials, systems or structures to absorb energy by deforming in the elastic range so that failure takes place only after large stresses and strains have occurred. The safety of the building against collapse is on the basis of the energy, which must be imparted to the structure in order to make it fail and in such instance, consideration must be given to structure's capacity to absorb energy rather than to its resistance. We can rely on ductile materials to absorb energy and prevent collapse when earthquake forces over whelm a building.

The primary task of an engineer designing a building to be earthquake resistant is to ensure that the building possesses enough ductility. Although there are as yet no clearly defined methods for determining the ductility of a structure, it is useful to clarify the concept, so that at least a relative appreciation of its importance can be attained.

The greater the energy is required for causing a structure to fail, the greater is its ductility and the ductility of a structure depends on the types of material used as well as the structural characteristic of the assembly. It is possible to build ductile structures with reinforced concrete if care is taken during design and detailing to provide the joints with sufficient abutments that can adequately confine the concrete, thereby permitting it to deform plastically without breaking. It is also important for this purpose to ensure that the tension edges of the structures are adequately reinforced and that there are sufficient stirrups to ensure that concrete is properly confined along the compression edge. In case of columns, the combined effect of flexure and axial stress produces a flexural compression failure mode in which the failure takes place near the column ends or beam column junctions and by buckling of longitudinal reinforcement. This can be eliminated by ductile detailing of the structural elements by providing the lateral reinforcements in the region of plastic deformation.

3.4.5 ***Seismic weight****:* -In fact, earthquake induced forces in a building are proportional to weight of the components and increases along the height of the building. However, weight reduction can be achieved by using lighter materials or by relocation of heavy masses such as file racks, libraries, swimming pools etc. at lower levels. Thus, the overturning moment caused by a certain weight placed at the 5^{th} level will be 25 times greater than that when the same weight is placed at the 1^{st} level. In addition to it, in case of former the seismic shear affects from level 1 to 5, where as in the later case, only the first level is affected but to a lesser extent.

3.4.6 ***Hyperstaticity / Redundancy:-*** In earthquake resistant construction, generally hyper- static (statically indeterminate) structures have advantage over statically determinate structures, because in this case if the primary system yields or fails, the lateral forces can be redistributed to secondary elements or systems to prevent progressive failure (by providing an alternate load path). Also redundancy (indeterminacy/ hyperstaicity) of the structure causes the formation of plastic hinges that absorb considerable energy without hampering the stability of the structure. Therefore, the redundancy of hyperstatic structure is highly desirable structural characteristic in view of earthquake resistant design.

3.4.7 ***Non- structural elements:-*** In an earthquake like situation, it is practically difficult to deal with the non-structural damage problem, because non-structural components that are subjected to seismic forces do not come under the purview of structural engineer, whose sole responsibility is to provide the seismic safety of the building. Moreover, non-structural components such as partition walls are often added after the initial building design and the original architect, or an architect at all, is rarely involved. Thus, although non-structural components remain uninvolved in the building design yet they became the source of damage.

In general, non structural damage is caused in two ways. The component may be directly affected by ground motion transmitted through the main structure of the building and be subjected to accelerations and consequent inertial forces similar to the main building structure. Alternatively, the non structural components may be affected by the movement or distortion in the structural elements, that support or abet the element. These two causes can be called as acceleration or drift related damage.

However, the methods of mitigating the damage to the non-structural components must take into account the probable mode of failure, whether through inertial forces or movement of failure in backing or abetting structures. In the former case, non-structural components must be designed and detailed in a similar way to the building structure, using an analysis of forces to determine bracing support requirements. For the latter, separation from back up or abetting structures is necessary. Therefore, mechanical, electrical and plumbing distribution system must be secured to the building structure, with allowance for differential movement where applicable.

3.4.8 ***Foundation soil and Liquefaction****:* -_For proper earthquake resistant design the knowledge of foundation soil is essential. In certain situations, a soil having good resistance against static loads may pose serious problem under dynamic condition of seismic loads. However, the problems related to foundation soil may be classified mainly into two groups:-

i) Influence of sub-soil on the characteristics of seismic movement, landslides and loss of soil resistance (liquefaction), these problems are not significantly affected by the structures and their foundations, and

ii)Problems caused by the load transmitted to the soil by the foundations and the setting of foundation under static and seismic loads. This problem generally arises in loose unsaturated granular soils, which may be compacted as a result of earthquake.

The liquefaction of soil is the most common adverse feature in an earthquake. This phenomenon is characterized by loss of soil resistance that generally occurs in saturated fine granular soil leading to damage of building by severe undermining or in extreme cases, completes toppling.

3.4.9 ***Foundation system: -*** In earthquakes, the foundation system of buildings are subjected to increased stresses, that may lead to differential settlement and consequential damage to the super structure. To avoid such failures the following recommendations may be given due weightage during planning and design.

i) Foundation may be preferably designed as a continuous (mat or raft) in order to avoid relative horizontal displacement.

ii) In case of isolated footings, these are to be connected to each other by means of tie beams and such ties are to be designed to take up both tensile and compressive forces arising in case of stress reversal.

iii) Parts of building foundations, which rests on soils of different types or are sunk to different depths should be designed as separate units. In such cases, there should also be structural independence in the super structure.

iv)When different parts of the buildings are to be structurally independent because of the shape of their ground plan, their foundations should also be independent.

3.5 ADDITIONAL STRENGTHENING MEASURES IN MASONRY BUILDINGS

Masonry buildings have large mass owing to which they attract large horizontal forces during earthquakes shaking. As a result of which they develop numerous cracks under both compressive and tensile stresses that often finally leads to their severe damage or collapse. In view of universal use of such buildings, it is necessary to increase their earthquake performance. Besides appropriate choice of structural configuration of buildings, some additional features or strategic measures are taken to make them earthquake resistant by developing good box (integral) action between different elements of the buildings i.e. between roof, wall and foundation etc. These earthquake resistant measures are intended to increase the seismic resistance in terms of strength and ductility and are mainly provided in the form of horizontal bands or vertical reinforcements. The horizontal bands or bond beams are provided at critical levels of masonry buildings and vertical reinforcing bars at corners and junctions of walls. The horizontal bands constitute the most important earthquake resistant feature in a building which in combination with vertical reinforcement considerably improves the strength, ductility and energy dispassion capacity of masonry walls. The strengthening arrangement varies with the type of construction and seismic zone.

3.5.1 ***Horizontal seismic bands****:* - The horizontal bands hold a masonry building as a single unit by tying all the walls together to improve their integral action. There are five types of bands in a typical masonry building, namely- gable band, roof band, lintel band, sill band and plinth band, named after their location in the building.

Fig. 3.28(a & b)

<u>Gable band</u>:-The gable band is employed only in buildings with pitched or sloped roofs. It is provided at the top of the gable masonry below the purlins. This band is made continuous with the roof band at the eaves level. It restricts the out of plane failure of gable wall, which is susceptible to earthquake forces.

<u>Roof band</u>: - Roof band is similar to lintel band but it is provided below the roof or floors. It improves the in plane rigidity of horizontal floor diaphragms. Such band need not be provided in buildings with flat reinforced concrete or reinforced brick roofs, since the roof slab itself plays the role of a band. However, in buildings with flat timber or C.G.I sheet roof, roof band is very much required. In buildings with pitched or sloped roof, the roof band is essential.

<u>Lintel band</u>: - The lintel band is most important of all and needs to be provided in all most all buildings. This band is provided at lintel level on all internal and external longitudinal as well as cross walls except partition walls. It provides integrity to the structure and resistance to out of plane wall bending by tying the walls together and creating a support for walls loaded along weak directions from walls loaded in strong

directions. This band also reduces the unsupported height of the walls and there by improves their stability in the weak direction. So lintel bands if provided in partition walls will also enhance their stability. Thus lintel band along with the roof band prevents collapse of spandrel masonry as well as roof.

Sill band: - This band is similar to lintel band but is provided at sill level. It is intended to reduce the effective height of masonry piers between the openings and is expected to reduce shear cracking in piers. Also it bridges over the upward traveling cracks from above the plinth level.

Plinth band: - This band is provided at the plinth level of walls on the top of the foundation substructure. Plinth bands are primarily used to arrest differential settlements particularly when the foundation soil is soft or has uneven properties.

3.5.2 ***Vertical reinforcement**:* -Generally, steel bars are provided as vertical reinforcements at corners and junctions of the walls as well as around jambs of doors and windows.

Fig. 3.29

Corner reinforcement:- Despite provision of horizontal seismic bands masonry buildings are weakened by the openings in their walls and during earthquake shakings, the masonry walls get grouped into subunits that rock back and forth leading to crushing or diagonal shear cracks (X- cracking). Embedding vertical reinforcement bars in the edges of the wall piers and anchoring them to the foundation at the bottom and to the roof band at the top, forces the slender masonry piers to undergo bending instead of rocking. In wider wall piers, the vertical bars enhance their capability to resist horizontal earthquake forces and delay the X- cracking. Adequate cross sectional area of these vertical bars prevents the bar from yielding in tension. Further, the vertical bars also help protect the wall from sliding as well as from collapsing in the weak direction.

Fig. 3.30

Reinforcement around openings:- However, the most common damage due to an earthquake in diagonal X-cracking of wall piers and also inclined cracks at the corners of door and window openings. Steel bars are provided in the wall masonry all around the openings restricts these cracks at the corners. In summery, lintel and sill bands above and below openings and vertical reinforcement adjacent to the vertical edges, provide protection against this type of damage.

In multi- storeyed buildings, the corner reinforcement should pass through the lintel bands and floor slabs in all storeys. The diameter of steel bar varies from 10mm to 16mm depending upon the wall thickness and storey height. For providing vertical steel in stone masonry, a casing pipe is recommended around which masonry is built up to a height of 600mm; then the pipe is raised and the cavity is filled by 1:2:4 grade of concrete mix around the steel bar.

3.6 SAFETY CONSIDERATIONS DURING ADDITIONAL CONSTRUCTION AND ALTERATION OF EXISTING BUILDINGS:-

The following safety and security measures are to be adopted during additional construction and alteration of existing buildings.

1) **Errection of side hoardings**: - No additional construction or alteration work on a site abutting a street shall be started without having first provided hoardings or barriers along the whole length of such site so as to prevent the danger or injury to the public or the persons employed in the work.

2) **Occupant's safety**: - Where repairs or alterations are conducted in occupied buildings, barricades, signs, drop clothes and other protective means are to be erected as required to provide reasonable protection for the occupants against hazard and nuisance.

3) **Neighbor's safety**:- During construction or excavation for foundation or basement, adequate safety measures are taken against damage of neighboring compound walls, foundations and structures etc. A safety distance of 1.5m is to be left while excavating the basements.

4) **Caution lights/ signs for obstruction**: - Adequate red lights or flags are to be fixed upon or near the hazardous site.

5) **Stability of adjacent buildings:-** No excavation, dewatering, earthwork or demolition of a building which is likely to affect the stability of adjacent buildings is not done unless adequate steps are taken before and during the work to prevent the collapse or damage of any adjacent building or the fall on any part of it.

6) **Safety measures at excavated site:**-Adequate safety measures where necessary is provided and used to protect any person from falling on earth, rock, other material or adjacent to any excavation or earthwork. Material should not be placed or stocked near the edge of any excavation so as to endanger persons working below. No load shall be placed or moved near the edge or any excavation carried out where it is likely to cause a collapse of the side of excavation and endanger any person. Where vehicles or machinery is used close to any excavation, there shall be measures to prevent the vehicles and machinery from over-running and falling into excavation or causing collapse of any side of the excavation. In high rise buildings, temporary rails, scaffoldings or barriers shall be installed during construction at the edge of the slabs and around all openings such as lift or stair well etc.

7) The demolition of a building and the operations incidental there to shall only be carried out under the direct supervision of a professional.

8) **Safe loading: -** Roofs, floors or other parts of the building shall not be over loaded during demolition and construction with debris or materials so as to render it unsafe.

9) **Provision of scaffolds:** - Suitable and sufficient scaffolds are to be provided for all work that cannot be safely done from the ground or from part of the building or from a ladder or other available means of support and sufficient safe means of access are to be provided to every place at which any person has to work at any time. Every scaffold, means of access and every part thereof, shall be adequately fabricated with suitable and sound materials and of required strength to ensure stability. All scaffolds, working platforms, gang ways, runs and stairs shall be maintained to ensure safety and security. All vertical members of scaffolds on ground level facing road side should be adequately wrapped with spongy material up to a height of at least 2.1m and for any horizontal member, if used, up to a height of 2.1m from ground, should be wrapped all along its length with such material.

10) **Road side protection:**- To ensure adequate safety of the pedestrian and other road users, all construction and repair activities at a height up to three storeys should have adequate arrangement by way of providing protective covering of suitable material. Adequate provision of safe passage for pedestrians shall be ensured, incase the scaffolding covers part of the road or footpath.

11) **Safety of working platform:**- Every working platform from which a person is liable to fall and which is more than 2.1m height shall be at least two feet wide provided the platform is used as a working platform only and not for the deposit of any material. A clear passage-way of at least 45cm wide shall be left between one side of any working platform and any fixed obstruction or deposited materials.

12) **Guard rails and ladders:** - Every side of a working platform, gangway and stair shall be provided with suitable guard rail of adequate strength, up to at least one meter above the platform, gangway or steps.

Every ladder shall be of good construction, sound material and adequate strength for the purpose for which it is used. It shall be securely fixed when in use and shall not have any missing or defective rungs.

13) **Work on slopping roofs: -** Where work is to be done on the sloping surface of a roof, suitable precautions are taken to prevent the persons employed from falling off. Hence, suitable and sufficient ladders or boards, securely supported shall be provided and used to avoid concentration of loads leading to unsafe conditions. Where persons are employed in a position below the edge of slopping roof and where they are in a position of being endangered by work done on the roof, suitable precautions shall be taken to prevent tools and/ or materials falling from such roofs so as to endanger such persons or passerby.

14) **Precautions for raising and lowering of loads:**- For raising or lowering loads or for suspending them by either hand or power operation, the following precautions are observed;

a) Broken wires shall never be used.

b) No chain, which has been shortened or joined to another chain by means of bolts and nuts shall be used.

c) Chain or wire ropes which have a knot tied in any part shall not be used when under direct tension.

d) Safe and efficient devices to prevent the displacement of the sling or load from the hook or of such shape as to reduce the risk of such displacement shall be used.

e) All debris and waste materials during construction shall be deposited off through well designed chutes from each level of building over three storeys height or more.

f) The vertical hoist platforms used are to be enclosed or protected by proper barrier. Every opening of lift, shaft or other such vertical voids or openings in slab etc., where a person is likely to fall shall be protected by safety barrier and properly lit. Any area including basement, where natural light is not available or which is dark, shall be so illuminated as to eliminate any risk of life or hazard to the users.

15) **Machinery and equipments:-** All exposed, electrically charged, moving or otherwise dangerous parts of the machines and construction or demolition equipments shall be located, guarded, shielded or barricaded so as to prevent contact by public.

16) **Fencing:** - If any construction or demolition operation is abandoned, discontinued or interrupted, a solid fence shall be provided to protect the public from the potential hazards on the site.

17) **Protection of sides of excavation:**-

a) Shoring, Bracing and sheeting – The sides of excavation including related or resulting embankments that are 1.5m or greater in depth or height measured from the level of adjacent ground surface to the present point of excavation shall be protected and maintained by shoring, bracing, sheeting, sheet piling or by other retaining structures as may be necessary to prevent the sides of excavation from caving in before permanent supports are provided. Alternatively, the excavation sides may be slopped not steeper than 45° or stepped so as not to endanger any structure including sub-surface structures.

b) Guard rail – A standard guard rail or a solid enclosure shall be provided along the open sides of the excavations.

c) Placing of excavation equipment and excavated materials – Excavated materials and superimposed loads such as equipment and trucks shall not be placed closer to the edge of the excavation than a distance equal to one and half times the depth of such excavations, unless the excavation is in rock or the sides of excavation have been sloped, sheet piled (sheeted) and shored to withstand the lateral force imposed by such loads.

18) **Safety measures during demolition:-**

a) Demolition of weakened structure – Where a partially wrecked or weakened structure is to be demolished, it shall be shored or braced to the extent necessary to permit orderly full demolition or partial demolition without collapse.

b) Full or partial demolition of structures – Steel, RCC or heavy timber construction shall be demolished column length- by -column length and tier-by-tier. Any structural member that is being dismembered shall not support any load other than its own weight and such member shall be chained or lashed in place to prevent any uncontrolled swing or drop. Structural members shall not be thrown or dropped from the building, but shall be slowly and carefully lowered by hoists equipped with adequate breaks and non-reversing safety devices.

c) Hazards removal – Before commencement of actual demolition, all glass windows, doors, skylights and fixtures shall be removed. Any window or exterior wall opening of a floor near the passage of debris shall be solidly boarded up or otherwise substantially covered to prelude any person being injured by material that may fall through such windows or openings. Before demolition, the portion shall be thoroughly cleaned of combustible material and debris.

d) Demolition of walls – Demolition of walls or partitions shall proceed in a symmetric manner and all work above each tire of floor beams shall be completed before any of the supporting structural members are disturbed. Sections of masonry walls shall not be loosened or permitted to fall in such masses as to affect the carrying capacity of floors or the stability of structural supports. No wall, chimney or other structural part shall be left in such condition that it may collapse or be toppled by wind, vibration or any other cause.

e) Storage of materials – Materials shall not be stored on catch platforms, working platforms, floors or stairways of any structure beyond its capacity and storage spaces shall not interface with access to any stairway or passageway, and suitable barricades shall be provided so as to prevent materials from sliding or rebounding into any space accessible to public. All materials shall be safely piled in such storage locations in a manner that will not overload any part of the structure or create any hazard.

f) Removal of material – Debris, bricks and similar materials to be removed through openings in floors of a structure shall be solidly planked over.

19) **Safety netting and tarpaulin:-** Both horizontal and vertical safety netting are to be provided for work above 4 storeys height.

PROBLEMS AND SOLUTIONS OF BUILDING CONFIGURATION:-

1) **Extreme height/ depth ratio –** It causes high over turning forces, large drift causing non-structural damage and foundation instability. In that case, the height depth proportion is to be revised or special structural system is to be adopted.

2) **Extreme plan area -** It builds up large diaphragm forces. Here the remedy is to sub divide the building by seismic joints.

3) **Extreme length to depth ratio –** It builds up large lateral forces in perimeter and large axial differences in resistance is created. In this case, also the remedy is to subdivide the building by seismic joints.

4) **Variation in perimeter strength stiffness -** Due to this torsion is caused which can be remedied by adding frames, disconnecting walls or using frames and light weight walls.

5) **False symmetry –** In this case torsion is caused by stiff asymmetric core and the remedial measure is to disconnect the core or use frame with non structural core walls.

6) **Re-entrant corners –** It causes torsion and stress concentration at the notches which can be avoided by separate walls, uniform box, centre box, architectural relief and diagonal reinforcement.

7) **Mass eccentricity –** It also results in torsion and stress concentration. Here the remedy is to re-organize the structure or add resistance around the mass to balance resistance and mass.

8) **Vertical and Reverse setbacks –** It leads to stress concentration at notch, different periods for different parts of the building and transfer of high diaphragm forces at setback. This can be controlled by employing special structural systems and detailed 3-D dynamic analysis.

9) **Soft storey frame –** It causes abrupt change of stiffness at points of discontinuity and can be controlled by adding bracings or braced columns.

10) **Variation in column stiffness –** It leads to abrupt changes of stiffness and much higher forces in stiffer columns. This will require redesign of structural system to balance stiffness.

11) **Discontinuous shear wall –** It results in discontinuities in load path and stress concentration for most heavily loaded elements. Here primary concern is to be placed over the strength of lower level columns and connecting beams that supports the load of discontinuous frame.

12) **Weak column – Strong beam construction –** Here failure of columns occurs before beam as short column tries to accommodate storey height displacement. In this case, full walls are added to reduce column forces, spandrels are dispatched from the columns or light weight curtain walls with frame is used.

13) **Modification of primary structure –** It is most serious when masonry infill modifies structural concept and creation of short stiff columns results in stress concentration.

14) **Building separation (insufficient) –** There is possibility of pounding depending on building period, height, drift and distance. This can be avoided by ensuring adequate separation.

15) **Coupled structures –** It may lead to incompatible deformation between walls and links, which can be taken care of by designing adequate link.

16) **Random openings –** It seriously degrade capacity at the point of maximum force transfer. It needs careful designing and adequate provision of reinforcing the openings.

CHAPTER-4
RETROFITTING OF STRUCTURES

4.0 SEISMIC RETROFITING OF REINFORCED CONCRETE BUILDINGS:-

Retrofitting means up gradation of earthquake resistance of a structure up to the desired level by appropriate techniques. The concept of retrofitting includes strengthening, repairing and remoulding so as to increase the seismic resistance by up-grading certain building systems such as mechanical, electrical or structural to improve the performance, function or appearance.

NECESSITY: - The necessity of seismic retrofitting of buildings arises under two circumstances: i) Earthquake damaged buildings and ii) Earthquake vulnerable buildings that have not yet experienced severe earthquakes.

i) Earthquake damaged buildings: - The aftermath of an earthquake manifests great devastation due to unpredicted seismic motion causing extensive damage to innumerable buildings of varying degree, i.e. full, partial or slight. Such damage to structures causes irreparable loss of property and life with a large number of casualties, as a result of which the frightened occupants hesitate to enter the building unless assured of the safety of the structure from future earthquakes. In fact, the majority of such earthquake damaged buildings may be safely reused, if they can be converted into seismically resistant structures by employing a few retrofitting measures. In comparison to replacement of the buildings, this proves to be a better option catering to the economic considerations and immediate shelter problems. Of course, it has been observed that retrofitting of buildings is generally more economical rather than demolition and re-construction even in the case of severe structural damage.

ii) **Earthquake vulnerable buildings: -** The need of retrofitting of existing earthquake vulnerable buildings may arise due to one or more than one of the following reasons.

a) Buildings have not been designed in accordance with seismic codes.
b) Buildings may be designed according to a seismic code, but the code has been upgraded later on.
c) Buildings may be designed to meet the requirements of modern seismic codes, but some deficiencies exist either in the design or in construction.
d) Essential buildings like hospitals, historical monuments and architectural buildings are to be strengthened.
e) Important buildings catering to the life line of public whose services are very much required even just after an earthquake.
f) Buildings, the use of which has changed through years.
g) Buildings that are to be expanded, renovated or rebuilt.

BASIC CONCEPTS OF RETROFITTING:-

The seismic retrofitting of building structures is one of the most important aspects for mitigating seismic hazards especially in earthquake prone countries. Various techniques of seismic retrofitting have been developed and used in practice. The basic concepts of these techniques aim at

a) Up-gradation of lateral strength of the structure.
b) Increase in the ductility of the structure.
c) Increase in the strength and ductility of the structure.

However, the decision to repair or strengthen a structure depends not only on technical considerations as mentioned above but also on the cost/benefit analysis of the different possible alternatives. It is suggested that the cost of retrofitting of a structure should remain below 25% of the replacement cost as a major justification for retrofitting.

PROBLEMS OF RETROFITTING:-

The problems faced by a structural engineer in retrofitting earthquake damaged buildings are**(a)** lack of standards for methods of retrofitting, (**b)** ambiguity regarding effectiveness of retrofitting techniques (since there is considerable dearth of experience and data on retrofitted structures, **(c)** absence of consensus on appropriate methods of the wide range of parameters like type of structures, conditions of materials, types of damage, amount of damage, location of damage, significance of damage, conditions under which a damaged elements can be retrofitted etc.

The problems faced by the structural engineer in case of earthquake vulnerable buildings are to obtain sufficient records of buildings such as architectural and structural drawings, structural design calculations, material properties, details of foundation and geo-technical reports, records of at least natural periods of buildings in order to evaluate the increased stiffness of buildings since strengthening techniques most often stiffen the structure reducing its natural period.

Retrofitting of buildings and issues of their structural safety has not yet received adequate attention in our country. There are at present no guide lines or codes of practice available in the country for retrofitting. The methods of seismic assessment of existing buildings are not adequately developed. Therefore, a catalogue of available options regarding feasible and practical retrofitting methods is needed by a structural engineer due to great variability of retrofitting requirements differing from building to building. In addition to this, experimental and analytical research is urgently required to strengthen different techniques of retrofitting.

CONSIDERATIONS IN RETROFITTING OF STRUCTURES:-

The method of retrofitting primarily takes into account the vertical and horizontal load resisting system of the structure and the type of materials used for parent construction. It also relies on the technology that is feasible and economical. The selection of retrofitting methods of buildings is considerably influenced by the understanding of mode of failure, structural behavior as well as weak and strong design aspects as derived from the earthquake damage surveys.

Usually, the retrofitting method aims at increasing the lateral resistance of the structure. The lateral resistance includes the lateral strength or stiffness and lateral displacement or ductility of the structures. The lateral resistance is often provided through modification or addition of retrofitting elements of an existing structure in certain areas only. The remaining elements in the structure are usually not strengthened and are assumed to carry vertical load only. However, in an earthquake, all components at each floor, retrofitted or not, will undergo essentially the same lateral displacements. While modified or added elements can be designed to sustain these lateral deformations, the remaining non-strengthened elements could still suffer substantial damage unless lateral drifts are controlled. Therefore, caution must be taken to avoid an irregular stiffness distribution in the strengthened structure.

Thus, the ability to predict initial and final stiffness of the retrofitted structure need classification and quantification. Consequently, it is suggested that the design of retrofitted schemes should be based on drift control rather than on strength consideration alone. The use of three-dimensional analysis is recommended to identify and locate the potential weakness of the retrofitted building.

4.1 SOURCES OF WEAKNESS IN RC FRAME BUILDINGS:-

In fact, earthquake engineering is not a pure science; rather it has been developed through the observation of failure of structures during earthquakes. However, the experience in damage survey of past earthquakes reveals the following main sources of weakness in reinforced concrete moment resisting frame building.

a) Discontinuous/ interrupted/ irregular load path
b) Lack of deformation compatibility of structural members
c) Quality of workmanship and poor quality of materials

4.1.1**Structural damage due to discontinuous load path:-**

In general, every structure has two load resisting systems; a) Vertical load resisting system for transferring gravity load to the ground and b) Horizontal load resisting system for transferring the lateral load to the vertical load resisting system. It is imperative that the seismic forces should be properly arrested by the horizontal framing system and subsequently transferred to vertical load resisting system. Any discontinuity /irregularity in this load path or load transfer may cause structural damage during strong earthquakes. Further it must be ensured that each member both of horizontal or vertical load resisting system must be strong enough not to fail during an earthquake. Therefore, all structural and non-structural elements must have sufficient strength and ductility and should be well connected to the structural system so that the load path must be complete and sufficiently strong.

4.1.2 **Structural damage due to lack of deformation:-**

The major problems in the structural members of moment resisting frame building are the limited amount of ductility and the inability to redistribute load in order to safely withstand the deformations caused by the seismic loads. The most common regions of failure in an existing reinforced concrete frame are as shown in the Fig. 4.1. The regions of failure may be in columns, beams, walls and beam-column joints. It is also pertinent to consider the consequence of member failure or structural performance. Inadequate strength and ductility of a structural member leads to local or complete failure of the system. The different modes of failure in various structural members are reviewed.

FIGURE 4.1

Columns: - The lateral load behavior of reinforced concrete columns is influenced by several interaction mechanisms. The main actions are associated with axial, flexure, shear and bond as shown in Fig. 4.2

FIGURE 4.2

Beams:- In reinforced concrete beams, the major problem exist at the right end, considering seismic forces left to right as shown in Fig.4.3. A brittle shear failure may take place due to superposing of shear forces caused by vertical loading and seismic loading.

FIGURE 4.3

Beam-column joints:- In beam-column joints, the situation of exterior joints is more critical if there is inadequate lateral reinforcement. In case of strong column-weak beam behavior, the joint may be heavily stressed after beam yielding and diagonal cracking may be formed in the connection. Wide flexural cracks may develop at the beam end which may be partially attributable to the slip of beam reinforcement within the connection. Such shear cracking may reduce the stiffness of a building.

Slab :- Shear failure has been observed in case of slabs resting directly on columns capital without having any beam. The critical part of the flat plate slab system is the vertical shear transfer between the slab and column.

4.1.3 Quality of workmanship and materials:-

There are numerous instances where faulty construction practices and lack of quality control have contributed to the damage. The faulty construction practices may be like, lack of amount and detailing of reinforcement as per requirement of code particularly when the end of lateral reinforcement is not bend by 135 degrees or required development length is not provided. Many buildings have suffered damage due to poor quality control of design material strength as specified, spalling of concrete by corrosion of embedded reinforcing bars, porous concrete, aging of concrete, improper maintenance etc.

4.2CLASSIFICATION OF RETROFITTING TECHNIQUES:-

Broadly two methods are employed to enhance the seismic capacity of existing structures. The first is a structural-level approach of retrofitting involving global modifications to the structural system. The second is a member-level approach of retrofitting or local retrofitting which deals with an increase of the ductility of components with adequate capacities to satisfy their specific limit states.

FIGURE 4.4

Generally, structural level retrofitting is applied when the entire structural lateral load resisting system is deemed to be deficient. Common approaches in this regard are employed to increase stiffness and strength with limited ductility. The very art of seismic retrofitting aims at achieving desired ratio between the additional stiffening and strengthening. Based on this concept, retrofitting techniques like addition of shear walls, steel bracings, infill walls, wing walls or buttresses as well as member thickening, mass reduction, supplemental damping and base- isolation comes under the per view of global retrofitting.

1) The addition of new reinforced concrete shear walls is the most widely used device which proves to be effective for controlling global lateral drifts and for reducing damage in frame members.
2) Steel braces are used to make the existing buildings stiffen. Either concentric or eccentric bracing system may be used in the selected bays of an RC frame contributing to increase in the lateral resistance of the structure.
3) Infill walls may be employed for strengthening of reinforced concrete buildings which has been effective in the case of one to three storey buildings that may be extended up to five storeys.
4) The lateral strength of existing columns can be increased by adding wing walls (side walls) or buttresses similar to infilling. However, these techniques are not so popular because of requirements of vacant site around the building and enough resistance from piles or foundations of the buttresses.
5) In some cases, it might be possible to achieve the retrofitting objectives by means of global mass reduction, which can be accomplished by removal of upper storeys, heavy claddings, partitions, and stored goods.
6) Increasing the strength or stiffness of structural members such as slabs and shear walls can be achieved by thickening of members.
7) The concept of seismic base isolation is based on decoupling of structure by introducing low horizontal stiffness bearings between the structure and the foundation. This method is found to be effective for seismic protection of historical buildings where the super structure has limited seismic resistance and intervention is required only at foundation level.
8) The supplemental damping device such as addition of viscous damper, visco-elastic damper and frictional damper in diagonal bays of frames substantially reduces the earthquake response by dissipation of energy.

Local retrofitting is typically used either when the retrofit objectives are limited or the direct treatment of the vulnerable components are needed. The most common modifications include jacketing of beams, columns, beam-column junctions and strengthening of individual footings. The jacketing or confinement by the jackets of reinforced concrete, steel, fibre reinforced polymer, carbon fibre etc. is the frequently used techniques in local retrofitting. Jacketing around the existing members increases the lateral load capacity of the structure in a uniformly distributed way with minimal increase in loading on foundations as well as with no alteration in the basic geometry of the building. Strengthening of individual footings may be done by under- pinning.

4.3 STRATEGY FOR RETROFITTING METHODS:-

4.3.1 Structural level/ global retrofit methods:-

Generally two approaches are used for structural level retrofitting I) Conventional method - based on increasing the seismic resistance of existing structures and II) Non-conventional methods - based on reduction of seismic demands.

Conventional methods

Conventional methods of retrofitting are mainly used to enhance the seismic resistance of existing structures by eliminating or reducing the adverse effects of design or construction. The methods include addition of shear walls, infill walls, steel braces etc.

A) *Addition of new shear walls :-*

Provision of additional shear walls increases the lateral strength of the reinforced concrete buildings and this technique of adding or infilling is regarded as the simplest yet the best solution for improving seismic performance. It is mostly used for retrofitting of non-ductile reinforced concrete framed buildings. Both cast-in-situ or precast concrete elements can be employed for the purpose. However, the new elements are preferably placed at the exterior of the building, although it may cause alteration in the appearance and window layouts. Placing of shear walls in the interior of the structure is not preferred in order to avoid interior mouldings.

FIGURE 4.5

Technical considerations:-

The following are the technical considerations for addition of new shear walls.

1) Determination of adequacy of existing floor and roof slabs to carry seismic forces.
2) Transfer of diaphragm shear into new shear walls with dowels.
3) Addition of new collector and drag members to the diaphragms.
4) Increase in the weight and concentration of shear by addition of walls which may affect the foundations.

Constructional considerations:-

The following constructional considerations are taken into account for addition of new shear walls.

1) Finding location where walls can be added and well located which may align to the full height of the building to minimize torsion. It is often desirable to locate walls adjacent to the beam between columns so that only minimum slab demolition is required with connections made to beam at the sides of columns.
2) The design of shear wall may be similar to new construction. A reasonable structural ductility may be achieved if the wall is properly designed with good detailing. The connection to the existing structure has to be carefully designed to guarantee shear transfer.
3) The longitudinal reinforcement must be placed at the ends of the wall running continuously through the entire height. In order to realize this, the reinforcement has to pass through holes in slabs and around the beams to avoid interference. To achieve both conditions, boundary elements can be used.
4) There should be continuous shear reinforcement but in its absence, the walls must be adequately connected to the beams, slabs and columns ensuring proper shear transfer through shear connectors.
5) Wall thickness may vary between 15cm to 25 cm and is normally placed externally.

This retrofitting system is only adequate for concrete structures, which brings forth a big increase in lateral capacity and stiffness.

Limitations:-

The main limitations of this method are:-

1) Increase in lateral resistance is concentrated only at a few places.
2) Increased overturning moments at foundation may cause very high uplift that needs either new foundations or strengthening of the existing foundations.
3) Increased dead load of the structure.
4) Excessive destruction at each floor level may result in functional disability of the buildings.
5) Possibility of inadequate attachment between the new walls and the existing structure.
6) Closing of formerly open spaces may have major negative impact on the interior of the building or exterior appearance.

B) Addition of infill walls:-

Addition of infill walls often serves the purpose of strengthening of existing reinforced moment resisting frames. It is also an effective and economical method for improving strength and reducing drift of existing frames. But a relatively stronger masonry infill may result in the failure of the columns of existing frame. By proper selection of infill masonry strength along with prevention of its premature separation from the columns, a more desirable failure mode can be achieved. However, the anchorage of masonry to the frame is a critical factor in determining an overall performance. With proper anchorage, it should be possible to force failure in the masonry and prevent premature shear/ flexure failure of the column.

FIGURE 4.6

Technical considerations:-

Performance of frames is highly sensitive to the relative values of infill strength, column strength, and stiffness and beam strength. Three basic failure modes of masonry in-filled frames may be considered:

Mode: 1 – Corner crossing of the infill at least at one of its loaded corners - associated with strong infill surrounded by a strong frame.

Mode:2 – Diagonal shear cracking in the form of a crack connecting the two loaded corners - associated with strong infill surrounded by a weak frame or a frame with weak joints and strong members.

Mode: 3 – Frame failure in the form of plastic hinges in the columns or the beam-column connection - also associated with a strong infill surrounded by a weak frame or a frame with weak joints and strong members.

Constructional considerations:-

i) The capacity of the infill wall is usually governed by dead load column to resist overturning uplift.
ii) Number of infill wall depends on the building seismic loads along with shear and uplift from single bay full height.

iii) Determination of number of bays of infill walls is needed in both directions to prevent uplift and locate walls in appropriate bays.

iv) The design forces are transferred to new infill panels using shear friction.

v) If columns have compression splices that are weak in tension, strengthening of column splices will be necessary for which there are generally two approaches:

a) The first consists of making spliced bars continuous so that forces could lie transferred directly without relying on the bond strength between spliced bars and surrounding concrete.

b) The other is to involve the region to improve bond along the spliced bars. External reinforcement around the splice region significantly improves confinement and spice strength must be grouted in order to permit it to effectively confine the concrete.

vi) Addition of internal ties on the splice region has not been an effective method for strengthening column splices, because removal of concrete reduces the effectiveness of concrete cover and the splice strength more than additional ties improve it.

*Limitations:-*The main limitations of this method are:

1) The benefit of retrofitting by infill walls is often limited by failure of splices in existing columns, which act as boundary elements for new infill walls.

2) Consequently, some columns in the frame are subjected to large axial tensile forces, which may exceed the capacity of the column splices that were originally been designed both for little or no flexure and only for either compression prior to seismic code or only for gravity loads without consideration of seismic loads.

C) Addition of steel bracings:-

Use of steel bracings is another method of strengthening RC buildings, which has also similar advantages as shear walls. The structural details of connection between the bracing and column are as shown in the fig. 4.7. The installation of steel bracing members can be an effective solution when large openings are required.

However, the scheme of the use of steel bracings has potential advantage over other schemes for the following reasons:

1) Higher strength and stiffness can be proved.
2) Opening for natural light can be made easily.
3) Amount of work is less since foundation cost may be minimized.
4) The bracing system adds much less weight to the existing structure.
5) Most of the retrofitting work can be performed with prefabricated elements and disturbance to the occupants may be minimized.

FIGURE 4.7

Technical considerations:-

1) The steel bracing system can be used for RCC as well as steel structures to upgrade their strength and stiffness.

2) It performs well exhibited linear behavior even up to twice the design code force.

3) The effective slenderness ratio of brace should be kept relatively low so that braces are effective in compression as well as tension, suggested *l/r* ratio 80 to 60 or even lower.

4) Collectors' members are recommended for transferring forces between the frame and bracing system. Careful considerations of connections of strengthening elements to the existing structures and to the foundations have to be consciously designed to ensure proper shear transfer.

5) Column shear failure is not specifically prevented; hence close alteration must be given to limit drifts of the strengthened frame.

6) Local reinforcement to the columns may be needed to bear the increased load generated on them. The epoxies threaded rods have proved to be quite effective in connecting the bracing system to the concrete frame and in transferring the forces.

Constructional considerations:-

1) The available dead load of the structure has to be considered to determine the amount or number of bays of bracings that can be mobilized to resist over turning uplift, as steel bracing is relatively light.

2) Bracing bays usually requires vertical columns at ends to resist over turning forces to work vertically, as chords of a cantilever truss are arranged horizontally at each floor level.

3) It is to be collected to the horizontal diaphragms by collectors members or an opposite system of diagonals can be added to complete the truss network.

4) Tension in braces should be avoided except in the case of light, simple buildings.

5) Braces should have relatively slow slenderness ratio so that they can function effectively during compression. Members are to be selected to provide acceptable slenderness ratio and to make simple connection, which in turn develops the strength of the member.

Limitations:-

1) Some inconveniency may be experienced with steel bracing; e.g. lack of information about the seismic behavior of the added bracing, undesirable changes that take place regarding the original architectural features of the building.

2) Lack of cost efficiency and field experience may also cause inconvenience.

3) Steel bracing system may be sensitive to construction errors or omissions, which may cause reduction in member capacity at a section and section failure, can impact the overall performance of the system.

4) A moderate to high level of skilled labor is necessary for construction, due to the necessity for member fit up adjustment and welding.

5) Close quality control particularly with respect to welding is essential.

Non-conventional methods:-

Now -a-days, several alternative approaches are being used in the retrofitting of structures. Among them, the seismic base isolation and addition of supplemental damping devices are most popular. These techniques are fundamentally conceived to reduce the horizontal seismic forces rather than augmenting their structural resistance.

A) <u>Seismic base isolation:-</u>

It is a powerful and relatively cheaper method of seismic rehabilitation of buildings. Its main advantages are: (a) better protection against earthquake due to decrease of shears (b) superstructure needs no reinforcement (c) foundation system does not need any reinforcement to resist overturning moments, which are much smaller than those of initial design. (d) Least interruption of building activities, since the work is carried out in the basement with no loss of income during the rehabilitation programme. (e) Requirement of least temporary work.

A typical base isolation system makes use of rubber bearing located at the base of the building, most often just below the first floor, under columns or shear walls. Rubber bearing consists of laminated layers of rubber and steel plates strongly bound together during the vulcanizing process of rubber. They are designed with a vertical stiffness, which is usually 300 to 1000 times higher than the horizontal stiffness. Such a system increases the first natural period in both the horizontal direction in between the range of 1 to 2.5 seconds and the response acceleration decreases accordingly (except for buildings on soft soils for which the natural period should be increased up to 3 seconds or more). Damping usually comprised between 5% and 10% critical but can jump to as high as 20% with the addition of damper. A building fitted with well designed base isolation behaves like one degree of freedom system. Fig. 4.8 and fig. 4.9 depict step by step process of base isolation retrofit of building supported by column and pile respectively.

FIGURE 4.8 and 4.9

B) <u>Supplemental damping devices:-</u>

Use of supplemental damping devices is an effective method to resist seismic force. The most commonly used approaches to add supplemental dampers to a structure are installing of viscous damper or visco-elastic damper, frictional damper and hysteretic damper as components of braced frames.

FIGURE 4.10

4.3.2**<u>Member level/ local retrofit methods:-</u>**

The member level retrofit or local retrofit approach aims at to upgrade the strength of members, which are seismically deficient. This approach is more cost effective as compared to the structural level retrofit. The most common method of enhancing the individual member strength is jacketing. It includes the addition of concrete, steel or fiber reinforced polymer (FRP) jackets for use in confining reinforced concrete columns, beams, joints and foundations.

<u>Jacketing/ confinement:-</u> The main purpose of jacketing are:-

1) To increase concrete confinement by transverse fibre/ reinforcement, especially for circular cross-sectional columns.
2) To increase the shear strength by transverse fibre/ reinforcement.

3) To increase flexural strength by longitudinal fibre/ reinforcement, provided they are well anchored at critical sections.

Transverse fibre should be wrapped all round the entire circumference of the members possessing close loops sufficiently overlapped or welded in border to increase concrete confinement and shear strength. This is how members with circular cross sections will get better confinement than members with rectangular cross-sections. Where square or rectangular cross sections are to be jacketed, circular/ oval/ elliptical jackets are most often used and the space between the jacket and the column is filled with concrete. Such type of multi-shaped jackets provide a high degree of confinement by virtue of their shape to the splice region proving to be more effective. The rectangular jackets typically lack the flexural stiffness needed to fully confine the concrete. However, circular and oval jackets are less desirable due to i) requirement of large space in the building, potential difficulties of fitting in the jackets with existing partition walls, exterior cladding and non-structural elements and ii) Where an oval or elliptical jacket has sufficient stiffness to confine the concrete along the long dimension of the cross section is questionable. The longitudinal fibres similar to the longitudinal reinforcement can be effective in increasing the flexural strength of the member although they cannot effectively increase the flexural capacity of building frames because the critical moments are located at beam-column ends where most of the longitudinal fibres are difficult to pierce through to get sufficient anchorage.

FIGURE 4.11

Technical considerations:-

In almost every case, the columns as well as beams of the existing structure are jacketed. In comparison to the jacketing of reinforced concrete columns, jacketing of reinforced concrete beams with slabs is difficult. It is because slab causes hindrance in the jacket to achieve good confinement. In structures with waffle slab, the increase in stiffness obtained by jacketing columns and some of the ribs, improves the efficiency of structures. Also, in some cases, foundation grids are strengthened and stiffened by jacketing their beams. An increases in strength, stiffness and ductility or a combination of these properties are obtained. There are several options for the jacketing of members as shown in fig. 4.11.

FIGURE 4.11

Usually the existing member is wrapped with a jacket of concrete reinforced with longitudinal steel and ties or with welded wire fibre, steel plate, similar to other strengthening schemes, the design of jackets should also include the probable redistribution of loads in the structure. A change in the dynamic properties of the structure may lead to a change in the lateral forces induced by an earthquake. Jacketing serves to improve the lateral strength and ductility by confinement of compression concrete. It should be noted that retrofitting of a few members with jacketing or some other enclosing techniques may not be effective enough to improve the overall behavior of the structure, if the remaining members are not ductile.

(A) **Jacketing of columns**:-

Jacketing of columns constitutes addition of concrete with longitudinal and transverse reinforcement around the existing columns. This type of strengthening improves the axial and shear strength of column while flexural strength of columns and the strength of beam-column joints remain the same. However, the jacketing of columns is not very effective in improving the ductility.

A major advantage of column jacketing is that it improves the lateral capacity of the building in a reasonably uniform and distributed way and hence the concentration of stiffness is avoided as in the case of shear walls. This is how major strengthening of foundations may be avoided. However, the original function of the building can be maintained, as there are no major changes in the original geometry of the building with this technique. The jacketing of columns is generally carried out by the following three methods: i) Reinforced concrete jacketing ii) Steel jacketing.iii) FRP jacketing.

Reinforced concrete jacketing:-

Reinforced concrete jacketing can be employed as a repair or strengthening scheme. Damaged regions of the existing members are to repaired prior to jacketing. There are two main purposes of jacketing of columns: (a) increase in shear capacity of columns in order to accomplish a strong column-weak beam design and (b) to improve the column's flexural strength by the longitudinal steel of the jacket made continuous through the slab system and anchored with the foundation. It is achieved by passing the new longitudinal reinforcement through the holes drilled in the slab and by placing new concrete in the beam column joints as illustrated in the fig. 4.12

FIGURE 4.12

Rehabilitated sections are designed in this way so that the flexural strength of the columns should be greater than that of the beams. Transverse steel above and below the joints is provided, which consists of two L-shaped ties that overlap diagonally in opposite corners. The longitudinal reinforcement usually is concentrated in the column corners because of the existence of beams where bar bundles used as shown in fig. 4.13.

FIGURE 4.13

It is recommended that not more than 3 bars be bundled together. Windows (holes) are usually bored through the slabs to allow the steel to go through as well as to enable the concrete casting process. Fig. 4.14 shows the options for detailing of the longitudinal reinforcement to avoid excessive use of the bundles. In some cases jacketing has been applied only within the storey as a local strengthening measure as shown in fig. 4.15.

FIURE 4.14 AND 4.15

Details of reinforced concrete jacketing are given in table 4.1.

TABLE 4.1

Steel jacketing:- Local strengthening of columns are frequently accomplished by jacketing with steel plates. A general feature of steel jacketing is mentioned in table 4.2

TABLE 4.2

FRP Jacketing:-Fibre reinforced polymer composite jackets are used for seismic strengthening of columns winding them with high strength carbon fibres around column surface to act as spiral hoops. The merits of this method are:

1) Carbon fibre is flexible and can be made to contact the surface tightly for a high degree of confinement.
2) Confinement is of high degree because carbon fibres of high strength and high modulus of elasticity are used.
3) Carbon fibre has light weight and it is rust free.

FIGURE 4.16

Limitations of column jacketing: - There are some disadvantages associated with the column jacketing techniques such as:

1) In some cases, the presence of beams may require majority of new longitudinal bars to be bundled into the corners of the jacket.
2) With the presence of existing columns it is difficult to provide cross ties for new longitudinal bars which are not at the corners of the jackets.
3) Jacketing is based mostly on engineering judgment as there is dearth of definite guidelines.

(B) Jacketing of beams:-

Jacketing of beams is required for several purposes as it gives continuity to the columns and increases the strength and stiffness of the structure. While jacketing a beam, its flexural resistance must be carefully computed to avoid the creation of a strong beam-weak column system. In the retrofitted structure, there is a strong possibility of change of mode of failure and redistribution of forces as a result of jacketing of columns, which consequently causes beam hinging. The location of the beam critical section and the participation of the existing reinforcement are taken into consideration. Jacketing of beams may be carried out under different ways namely one sided, or 3- and 4- sided jacketing. (Fig. 4.17)

FIGURE 4.17

At several occasions the slab is perforated to allow the ties to go through and to enable the casting of concrete. The beam is jacketed to its whole length. The reinforcement is added to increase the beam flexural capacity moderately and to produce high joint shear stresses. Top bars crossing the orthogonal beams are put through the holes and the bottom bars are placed under the soffit of the existing beams, at each side of the existing column. The transverse reinforcement of the beam consists of sets of U-shaped ties fixed to the top jacket bars and of inverted U-shaped ties placed through perforations in the slabs. Also closely spaced ties are placed near the joint region where beam hinging is expected to occur.(fig. 4.18) The main features of reinforcement details of beam jacketing are given in table 4.3

FIGURE 4.18

TABLE 4.3

(C) Beam-column jacketing :-

Theoretically, a joint may be defined as the part of the column that is located through the depth of the beams and which intersect that column. This critical region should have enough confinement and shear capacity. However, due to lack of space in the joint region it is difficult to provide adequate confinement. Jacketing is effective in rehabilitating the joint, with improvement of strength, stiffness and energy dissipation characteristics of the existing joint. In these specimens, the dissipation of energy has been mainly concentrated at the beam's end. It is also very important to point out the need to have a very strong column as compared to the beam to avoid driving of the column or joint into significant inelastic behavior.

FIGURE 4.19

(D) Slab-column connection:-

The most critical type of structural damage is the slab-column connections which results in the punching shear failure due to transfer of unbalanced moments. The retrofitting of slab-column connection is beneficial for the prevention of punching shear failures. Research has shown that adding concrete capitals or steel plates on both the sides of slab can prevent punching shear failures.

(E) Foundations:-

The repair or retrofitting of foundations is mainly required due to two types of problems: i) the change of loads on the foundation by strengthening the structure and ii) the failure of foundation itself.

In the first case, the most common practice has been the reinforced concrete jacketing of basement beams and the addition of new piles. Generally, segmented concrete piles are used for retrofitting.

CHAPTER-5

BUILDING SERVICES

Water supply requirements for residences: - In respect of requirements regarding water supply, drainage and sanitation for residential buildings, it is assumed that a minimum water supply of 200 liters per head per day must be provided for a full flushing system. However, this minimum value of water supply may be reduced to 135 liters/capita/day for houses of lower income groups and economically weaker sections of society depending up on prevailing conditions. Out of the total requirement of 200 liters per capita per day 45 ltrs may be taken for flushing requirements and the remaining quantity for other domestic purposes. Taking requirements for animals and vehicles @ 45 ltrs, the total requirement of residential building comes out = 135 + 45 = 180 ltrs.

Water supply requirement for buildings other than residences: - Minimum requirement of water supply for buildings other than residences are as given in the following table

Sl. No.	Types of building	Consumption/ Head/ Day (ltrs)
1	Factories where bath rooms are required to be provided	45
2	Factories where no bath rooms are required to be provided	30
3	Hospitals (including laundry) per bed a) No. of beds not exceeding 100 b) No. of beds exceeding 100	 340 450
4	Nurse's homes and medical quarters	135
5	Hostels	135
6	Hostels per bed	180
7	Offices	45
8	Restaurants per seat	70
9	Cinemas and theaters per seat	15
10	Schools a) Day schools b) Boarding schools	 45 135

The design of the pipe system from the point of off-take of the street mains to the point of delivery at the fixture is based on the total daily requirement of the building. For design purposes, generally the daily requirement of residential buildings is calculated on the basis of 5 members per family and per capita water supply of 135 liters/ capita/ day

Systems of water supply: - All premises intended for human habitation or occupancy or use shall be provided with the supply of pure and whole sum water, neither connected with unsafe water supply nor subjected to the hazards of back flow or back syphonage. The water supply in a building may be through one of the following two or their combination, depending up on the height of the building, the pressure available in the municipal service main and the hours of supply.

a) Direct supply system or upward distribution system
b) Down take or down feed supply with or without sump or pump.
c) Combined system

a) **Direct Supply system: -** If the pressure near the premises are adequate to supply water to the water fittings at the highest part of the building for sufficient number of hours, then suitable connections are taken to deliver the required water supply to the buildings directly. In this system only one connection is granted for the whole building to deliver the total requirement of the day in a suction tank and then pumped to the overhead tank. Sometimes direct supply to the third floor is considered, if the pressure in the main is sufficient to deliver the required discharge. The quantity allowed for the direct supply is deducted from the total requirements of the building, if combined system is adopted. Of course, the quantity of direct supply is generally restricted to 45 ltrs per head per day.

b) **Down-take supply system:** - At places, where the water supply is either intermittent or the pressure is not sufficient to deliver water supply directly, then the down take supply system with ground level storage and boosting is adopted. In this system, the supply may be delivered directly to the overhead storage tanks or the ground level storage tanks (suction tank or sump). In this case supply to all the fixtures is effective only for the overhead tank under gravity.

Storage tanks are to be provided for the total daily requirements of the whole building based on its population after deducting the quantity of water allowed for direct supply. The quantity of water thus stored is then pumped to the overhead tank for equal distribution. The capacity of the suction tank is kept half the total requirement i.e. at the rate of about 90 ltrs per head per day. Overhead storage may be either flushing storage tank or domestic storage tank. The capacity of flushing storage tank is taken at the rate of 55ltrs per head per day for residential buildings and 25 ltrs per capita per day for office/ factory/ school buildings. On the other hand, the capacity of the domestic storage tank is taken at 75% of the total daily requirement after deducting flushing requirements and direct supply requirements up to 3rd floor. Thus the daily requirement of the storage tank comes out to be (180 – 55 = 125 X0.75) 90 ltrs per capita per day for residential buildings and 20 ltrs per capita per day for office/ factory/ school buildings.

Pressure requirements and size of connections: - A water supply system should be designed to distribute water to the consumers at adequate quantity and at adequate pressure. The piped water supply are designed for continuous 24 hour supply and intermitted supplies are not desirable from the public health point of view. There should be at least a residual head of 0.018 N/mm^2 at the consumer's tap, the residual head being taken at the highest/ farthest outlet in the building. The minimum recommended pressure head at the ferrule points of one storey building is 7m, two storey building is 12m and three storey building is 17m. However, a distribution system should not be designed for pressure heads greater than 22m. For high rise buildings, water should be supplied by pumps from ground level reservoir to terrace level tanks.

In general, the sizes of pipes (which is based on a pressure of 1.5 kg/sq. cm in the main and a total length of about 30 meters up to the suction tank) given in the following table are to be used.

Discharge Through Various Diameters Of Pipes

Internal dia. of the pipe (mm) →	15	20	25	30	40	50
	Discharge in liters per hour (LPH)					
Ground floor direct supply to suction tank	560	1700	3500	7000	11,200	23,600
First floor direct supply	450	1450	3000	6000	9800	20,400
Second floor direct supply	400	1250	2500	5000	7800	17,700
Third floor direct supply	300	800	2150	3500	5700	12,500

Distribution system in multistoryed buildings: - Generally the multistoried buildings are classified into the following three categories for the sake of convenience depending up on their height, which is measured from the plinth level to the top of terrace.

Sl. No.	Building storeys	Height limit	Classification
1	Buildings up to 10 storeys	Ht up to 30m.	Low
2	Buildings with 10 to20 storeys	Ht up to 60m.	Medium
3	Buildings above 20 storeys	Ht above 60m.	High rise

Various water supply systems practised in multi-storeyed buildings or high rise buildings may be one or a combination of the following systems:

I) Overhead storage system – This system can be divided into two types a) Pressure reducer valve system b) Multiple storage system.

a) *Pressure reducer valve system* - In this system, the tanks are provided on the terrace. From the storage tank, a manifold down take may be taken out which is laid out horizontally in a loop on the terrace to carry a designed peak load demand. Of course, the pressure in the loop at the peak demand should not become negative. However, the vertical down takes are taken out from the loop as per the requirement and each down take is linked for a zone of four storeys at a time and designed for the peak demand it has to serve. Ideally, a pressure reducing valve is provided in the down takes to limit the head to a maximum of 25m and located in easily accessible places like ducts, catwalks etc.

FIGURE

b) *Multiple storage system* - In this system the entire building is divided into subzones of 8 to 10 floors and domestic and flushing tanks are provided for such zones independently on the service floors. Of course, the suction tank capacity is to be taken as one days requirement. However, the connection to the individual zones is done either combinedly or separately depending upon the situation.

FIGURE

c) *Break pressure tank system* – In this system, the entire building is conveniently divided into suitable zones of 5 to 8 storeys each. For each such zone, a break pressure tank of capacity of at least 15 minutes supply depending upon the number of floors it has to feed is provided. However, its capacity should not be less than 2000 ltrs capacity each for flushing and other domestic purposes separately. In this case, the down take from the master overhead tank feeds into the break pressure tanks.

FIGURE

Generally, the break pressure tanks of 3600 liters capacity for domestic as well as for flushing purposes are provided separately for the zones of 6 to 8 floors. The building is commonly divided into zones comprising of 6 to 8 floors and down take arrangement is made to provide supply to the lower floors. Preferably two down take branches are taken for 8 floors, each branch serving 4 floors. Down take for the upper tank serves as an inlet to the lower tank. This also helps in limiting the pressure head in the pipe to 25m.

d) Hydro-Pneumatic system – In this system, the water supply is made through a hydro-pneumatic pressure vessel fitted with accessories like non-return valves, pressure relief valves etc. For operating convenience, in this type of system, each zone of supply is restricted to about seven storeys or 20m which ever less is. In this case, three numbers of pumps with an air compressor and air vessel are provided. The capacity of the pump should be such as to cope with the peak demand. Of the three pumps, one pump is a stand by pump preferably driven by a diesel engine, for operation at the time of power failure. The other two pumps are the lead pump and supplementary pump respectively.

The hydro-pneumatic pressure vessel is normally an air tight vessel, cylindrical in shape being fabricated from mild steel plates as per fabrication code of pressure tanks; its capacity is equivalent to three minutes requirements. The air compressor is required to feed the air into the vessel so as to maintain the required air-water ratio in the vessel. As soon as the demand exceeds the capacity of the lead pump, the supplementary pump must start automatically. However, the disadvantages of such tanks are that only about ¾ to 2/3 of the tank's capacity is available for storing water, the reminder of the capacity being occupied by the compressed air. Air is lost by dissolving in water, the rate of solution increasing with the pressure. But, tall, narrow tanks minimize the air loss by exposing a relatively small water surface to air. Also air may be drawn into the system by such means as an air inlet or snifter valve on the pump suction.

The tanks are so designed that, at the desired maximum pressure, the air occupies about 1/3rd of the volume of the tank. A pressure relief or safety valve is to be provided on the top of the tank to prevent the development of a dangerously high pressure and also a vacuum relief valve is necessary to avoid collapse of the tank or back flow into the water system. Of course, wide variations in pressure are undesirable and also uneconomical but they are sometimes unavoidable in this type of storage. The capacity of a pneumatic tank is generally not less than 135 liters for a small household and is about 270 liters for a large house hold. In any installation, care is taken to see that , the pump should not be thrown on and off more often than once in about 15 to 30 minutes.

In this case, the underground storage should be 100% of the days total requirement; the hydro-pneumatic vessel being provided separately for each zone of supply. Here, a small tank of 2700 liter capacity may be provided for flushing supply. Of course, this is an automatic system and works on air vessel and hence, the moment some water is drawn on the floors, the pressure in the vessel drops down. Thus, when it drops down to a particular point to which the vessel is adjusted, the pump starts working and builds up the pressure in the vessel again. However, this is not a very common system used in high rise buildings.

Cold water supply in buildings

There could be two types of cold water supply to the buildings i.e. Direct system and Indirect system of cold water installation.

I) Direct system of Cold water supply: In this system, the pipe work is minimal and the storage system need only have small capacity (115 liters). The system may be located within the airing cup board or may be combined with the hot water cylinder. For efficient operation of this system, a high pressure water supply is essential particularly at periods of peak demand. Drinking water is available at every draw off point and maintenance valves are fitted to isolate each section of pipe work. However, the possibility of back siphonage must be considered with every outlet supplied from the main. Of course, back siphonage occurs, when there is a high demand on the main. Negative pressure can then draw water back into the main from a submerged outlet; e.g. a rubber tube attached to a tap or a shower fitting without a check valve facility left lying in the dirty bath water.

FIGURE

II) Indirect system of cold water supply: The indirect system of cold water supply has only one drinking water out let at the sink, i.e. in this case cold water is supplied to all out lets from a cold water storage cistern except for the cold water supply to the sink where the drinking water tap is directly connected to the incoming supply from the main. The cold water storage cistern has a minimum capacity of 230 liters, for the location in roof space. In addition to its normal supply function, it provides an adequate emergency storage in the event of water mains failure. The system requires more pipe work than the direct system and is therefore more expensive to install, but it ensures uniform pressure at all cistern supplied outlets. However, the water authorities prefer this system as it imposes less demand on the main. Also, with fewer fittings attached to the main, there is less chance of back siphonage. Other advantages of lower pressure include less noise and wear on fittings and the opportunity to install a balanced pressure shower from the cistern.

HOT WATER SUPPLY IN BUILDIGS

Introduction: - Hot water supply in buildings are required for cooking, cleaning and ablution purposes starting from small domestic houses to large establishments such as hospitals, hotels and industrial premises. In hot water system, the water is heated as a result of which it expands, became less dense and rises up being displaced by heavier water that sinks to the bottom. This is known as the process of convection and the hot water systems are so designed that convection currents are set in as the heavier cold water continues to displace upwards the lighter warm water and this continues until all the water in the system is heated. Generally the heating source or fuels used for hot water system are electricity, gas, oil and solid fuel.

Demand and storage capacity: - The hot water requirement of a building depends upon the location, climate and standard of living of the occupants. Keeping the total per capita demand of water supply constant, the hot water fraction is calculated in terms of fixture units similar to cold water. For combined systems, separate demands are taken as 3/4th of the total demands. The size of the storage vessel is governed by the maximum short time demand of the domestic premises. Depending on local conditions, this may be 50 to 75 liters at 60°C in a dwelling with a bath tub and 25 liters at 60°C for a shower or a tap. However, the capacity of the storage vessel shall not be less than 20 percent in excess of the required maximum short time demand. In larger houses, where a single hot water heater is intended to supply hot water to more than one bath room or kitchen or both, the maximum short time demand is estimated and the capacity is decided accordingly.

Storage temperature and rate of flow: - The design of hot water supply systems and its appliances are based on the temperatures at which water is normally required for various uses, namely

Sink	60°C
Hot bath	43°C as run, for use at 41°C
Warm bath	37°C
Tepid bath	29.5°C

In order to minimize the danger of scalding, precipitation of scale from hard water, standing heat losses, risk of steam formation and the possibility of damage to porcelain and other fittings and to surface finishes, a storage temperature of 60°C is recommended. In case the storage capacity is limited, a higher temperature up to 65°C may be adopted when soft water is used. With storage type installation, the recommended minimum rates of flow for different types of fixtures are as given below.

Fixtures	Rate of flow of hot water (ltrs/ min)
Bath tub	22.5
Kitchen sink	18
Wash basin	7
Shower (spray type)	7

Heating elements or heaters: - These may be of either storage tank or tank-less type irrespective of whether they are heated by direct methods like combustion of fuel, electric heaters etc. or by an indirect method consisting of copper coils, live steam system etc. Again storage type heaters may be either pressure type or non-pressure type.

Storage tank heaters are economical for small capacities where direct method of heating is applied and these are designed to store hot water. On the other hand, the tank less heaters are used for large installations where indirect method of heating is applied and are designed to heat cold water to standard hot water supply temperature in a single pass through the heater so that hot water may be directly piped to the fixtures. Besides instant water heaters, called geysers are used where small quantities of water are required for long duration of time and at any time.

Systems of hot water installation: - There could be direct systems for small establishments or central hot water system in major projects like hotels, hospitals etc, where, now a days, piped hot water supply is considered as essential.

A) ***Direct system: -*** This is the simplest and least expensive system of hot water installation. In this case, the water is heated in the boiler where the hot water rises by convection to the hot water storage tank or cylinder which is replaced by the cooler water from the bottom of the storage vessel. Thus hot water drawn from the storage is replaced with cold water from the cold water storage cistern. Direct systems are suitable for soft water areas and for installations which are not supplying a central heating circuit.

FIGURE: - *(lay out of typical direct hot water supply system)*

B) ***Central hot water systems: -*** While designing and installation of central hot water system, the following points are considered to be important.

1) Fuel to be used.
2) Location and dimensions of boiler house (calorifier chambers), fuel supply, storage and chimney.
3) Means of ash disposal in case of solid fuels.
4) Location of cold water cistern, pipe runs, size of main ducts, trenches etc.
5) Location and sizes of sleeves/openings provided for pipes in the structures or buildings.
6) Drainage facilities for emptying the installations.
7) Quantity of water supply.

8) Provision of air for combustion and ventilation.

Layout of piping system: - Generally hot water piping may be laid out as a pressure system where either the pressure is provided from a source outside the building or the pressure may come from a tank open to the atmosphere and located at a high point in the building. However, in each of these systems, the piping may be laid on non-continuous circulation or continuous circulation system which may be actuated either by gravity or by (forced) pumping. Depending on the hot water storage capacity, the following sizes of pipes may be provided.

Storage capacity	Dia of pipe for flow and return
140 ltr	25mm
180 ltr	32mm
225 ltr	40mm

The above system is characterized by the following salient features.

i) In the tank system, there is no chance of pressure built up to cause bursting.
ii) The pumping system is simple and requires fewer pipes than the tank system.
iii) Although non-continuous circulation requires least amount of piping, this layout should not be used where the hot water pipes are long and there are numerous fixtures to be served. Because, here the cold water may be drawn for sometime before hot water reaches the faucet and the heat is lost from the hot water standing in the pipe. But it is satisfactory only for short pipes between the heater and a hot water faucet.
iv) Continuous forced circulation can be satisfactorily used for large installations.
v) Continuous gravity circulation is used where non continuous circulation is not available. But it is not suitable for more than two or three storyed buildings or for more than two or three apartments.

Principles of design: - In the layout of hot water piping systems, it is essential to have equal pressures of hot water and cold water at each fixture especially so where mixing faucets are to be used. This is because; other wisely there is every possibility that the water at higher pressure will force itself into the lower pressure supply when the mixing faucet is opened to both the supplies. Of course, the pressure in hot water supply is always lower than that of the cold water on account of more circuitous path followed by the former. However, this drawback can be partly overcome by the use of larger dia and smoother pipes and long radius fittings on hot water lines. On the other hand, sudden demand for cold water, as by flush-o-meter valves, may so reduce the cold water pressure as to draw hot water into the cold water, pipes and such conditions can be avoided by an appropriate analysis of the system to balance the head losses in each supply.

In gravity circulation systems, the following principles are generally adopted.

i) Hot water pipes should rise continuously from the heater to faucets and only return circulating water should descend. However, exception to this rule sometimes permit a short, descending spur from a riser to a single fixture and in a multi-storey buildings a few fixtures on each floor may be supplied from the descending return pipe.

ii) The riser pipe should preferably have two to three times the cross sectional area of the return pipe and no riser should have diameter less than 20mm in case of galvanized iron.

iii) Riser pipes should rise continuously to the highest point in the system and return pipes should descend continuously to the bottom of the heater or into the storage tank.

iv) It is essential that multiple circulating loops connected to the same heater have approximately equal head differential from all causes to avoid uneven flow of hot water among the loops. This can be achieved by proper adjustment of valves at the base of each riser by trial or it can be taken care of at the design stage before installation of pipes.

v) Air relief provision should invariably be provided at the high point or points in the form of an air relief valve, a faucet or in a tank system, it can be done by a pipe connected at the high point or points and terminating with an open end above the highest water level in the tank.

vi) It is desirable to make provision for draining water that escapes from the air relief valve in the form of an indirect waste.

vii) In a return circulating type of hot water supply, the difference in head existing in hot water supply and return lines at the source of hot water supply provides the force causing circulation.

viii) The velocity of flow in circulating pipes depends up on the difference in the weight of water in the riser and the return pipes.

The head of water causing flow, $H = \frac{H_1S_1 - H_2S_2}{W_T}$

Where H_1, H_2 = Height of water in supply and return pipes respectively.

S_1, S_2 = Specific gravity of water columns in riser and return pipes respectively.

W_T = Weight of 1m of water column at average temperature in two pipes in kg.

Then, the velocity of flow in the pipe $v = \sqrt{2gH}$

where g = acceleration due to gravity

In the gravity system, the temperature in the return pipe is assumed to be 20°C cooler than the riser pipe where as in pumped system that is about 10°C . The pressure head in hot water due to pumping is generally taken to be $0.1 kg/cm^2$ greater than the cold water pressure.

The recommended limiting lengths of gravity hot water circulating pipes are as given below.

Table: - Maximum permissible lengths of hot water draw off pipes. (IS: 7558)

Largest internal diameter of pipe	Length
Not exceeding 20mm	12m
Between 20mm to 25mm	8m

Exceeding 25mm	3m

NOTE: -*In case of composite pipe of different diameters, the largest diameter is to be taken.*

The storage capacity of a cold water tank should be at least twice the capacity of the hot water heater. The capacity of the storage tank may, however, be 1.5 times when the number of heaters connected to one common tank exceeds 10.

The storage tank for supply of cold water to hot water heaters should be separate wherever practicable. In case of a common tank which also supplies cold water to the fixtures, this cold water supply connection shall be so arranged that 50% of the net capacity is available for supply to the hot water heaters.

Return circulation system: - There is a definite loss of heat from the hot water supply piping system to the lower temperature surroundings by different means of heat transmission (by convection, radiation or conduction) resulting in unsuitability of hot water supply which may necessitate a return circulation system for buildings more than four storeys in height and where the length of the farthest fixture is at least 30m from the point of hot water source.

Figure: - (Arrangement of hot water storage generator)

For large extensive hot water supply systems, a return circulation type of system is a definite necessity. In case these are not designed to re-circulate hot water continuously, it would result in delays in obtaining hot water at normal service temperatures and possibility of excessive wastage of water of unsuitable temperature.

The return circulation system may be classified into two broad types a) Conventional, b) Inverted type. Again these may be divided into three general types of hot water supply:- return circulation systems, namely, the up-feed system; the down- feed system and a combination of up-feed-down-feed system. These names are basically derived from the direction of flow in hot water risers supplying branches to fixtures but are unrelated to the direction of flow in return piping. However, in each type, the return piping is connected to the end or near end of hot water supply risers so that it circulates water back to the hot water source.

A) Conventional system: -

i) Conventional return circulation system: - Generally, the hot water heaters and tanks are located in cellar and basements for various reasons such as economy in building design, convenience in locating such equipments in proximity of heating boilers and the source of fuel supply as well as availability of convenient means for ash disposal. Of course, the heaters and tanks are located at the lowest part of the hot water supply systems. Under such circumstances the circulation of hot water may be achieved by gravity due to the head induced by the difference in temperatures of water in hot water supply and return pipes located above the hot water source. But where the systems are extensive or have little effective circulation height, pumps may be used to provide greater circulation.

ii) *Conventional up-feed system: -* In this system, the main hot water supply line is extended from the source of hot water supply and is located in the lowest part of the building from where hot water is supplied to the bottom of all the hot water supply risers. The flow is upward in all the risers supplying branches to fixtures and a hot water return pipe is provided for each of the hot water supply risers. The top of the return pipe is connected to the supply riser just below the top most supply branch to fixtures. The return pipes generally extend down to the lowest part of the building where these are connected to a main hot water return line through which water circulates back to the source of hot water supply. Here, the air accumulated in the uppermost part of each riser, is drawn off when a hot water faucet is opened at a fixture supplied from the top of the supply riser, thereby eliminating air accumulation which would have other-wisely restricted the circulation.

Figure: -

iii) *Conventional down-feed system: -* This system is characterized by the extension of the main hot water supply line from the source of hot water supply to the highest part of the building. From that location, hot water is supplied to the tops of all hot water supply risers. The flow is downward in all the risers supplying branches to fixtures, where the base of each down-feed riser is connected to a main hot water return line so as to circulate the cooled water back to the source of hot water supply. At the top of the main hot water supply line, which is the highest point in the system, provision for elimination of air should be made so that air pockets do not develope and restrict the circulation of hot water. This is accomplished by connecting a fixture supply branch to the highest point of the system so that air may be drawn off when the hot water faucet is opened at the fixture.

Figure: -

An alternative method is to install an approved type of air-relief vent valve at the highest point with a relief pipe discharging into a approved fixture at which the discharge of air and water is not objectionable but where leakage will be evident to indicate a need for valve maintenance.

iv) *Conventional combined up-feed and down-feed system: -* This system is a combination of the two systems discussed earlier. In this system, some hot water supply risers have upward flow while others have downward flow. Here, each down feed riser is supplied from the top of an up-feed riser and the base of each down-feed riser is connected to a main hot water return line through which water circulates back to the source of hot water supply. But, in this case some means for preventing air accumulation at high points of the system are necessary and this provision is preferably made according to the site conditions.

B) Inverted system: -

i) *Inverted return circulation system: -* Here the hot water heaters and tanks are located at the highest part of the hot water supply system where the supply and return risers are below the level of the hot water source. In this case, hot water circulation by gravity is not possible as cooled part of the hot water settles in to the lowest part of the circulation system to remain there. Therefore, an inverted system of circulation of hot water can be achieved only by means of pumps. However, such inverted design of hot water supply return circulation system has been advantageously applied in many tall buildings.

ii) *Inverted up-feed system: -* In this system, the main hot water supply line is extended from the source of hot water supply to the lowest part of the system, from where, hot water is supplied to the bottom of all the hot water supply risers. The flow is upward in all the risers supplying branches to fixtures. The top of each up-feed riser is connected to a main hot water return line through which water is pumped back to the source of hot water supply. Here, the air vent valve is provided at the highest point for the purpose of air release.

Figure: -

iii) *Inverted down feed system: -* In this case, the main hot water supply line is extended from the source of hot water supply and is located at the highest part of the system. From that point, hot water is supplied to the taps of all the hot water supply risers. Here the flow is down ward in all the risers supplying branches to fixtures and a hot water return riser is provided for each of the hot water supply risers. The bottom of the return riser is connected to the supply risers just above the lowest supply branch to fixtures. The return risers extend upward to the highest part of the system where they are connected to a main hot water return line through which water is pumped back to the source of hot water supply. Of course, air accumulated in the uppermost part of this system is discharged by means of an automatic air vent valve located at the highest point of the system, thereby eliminating the accumulation of air which might tend to restrict circulation, provide noise in the piping or be objectionable when discharged to a fixture.

Figure- 6.8

However, where hot water storage tanks are installed at the highest part of the system, such as is the case in an inverted hot water supply system, it is advisable to provide a tank vacuum breaker or vacuum relief valve at the top of the tank. This permits air to enter the tank whenever a vacuum occurs and thereby prevent collapse of the tank. In such locations, the tanks may be subjected to very severe vacuums in the event of cold water supply failure or when the supply to the tank is shut off and hot water is drawn at a lower floor outlet.

iv) *Inverted combined down-feed and up-feed system: -* This system is a combination of the two inverted systems discussed earlier. In this system, some hot water risers have downward flow while others have upward flow. Each up-feed riser is supplied from the bottom of a downward riser and the top of the up-feed riser is connected to a main hot water return line through which water is pumped back to the source of hot water supply. Here, air relief valve should invariably be provided at the highest point to release air accumulated in the system.

However, it is not desirable to connect the main hot water return line to a vertical section of the lower circulation piping between the bottom of a tank and a heater. Water in the main return line is generally hotter than water in the lower circulation piping between the tank and the heater and the hotter return line water tends to rise into the tank while the tank water descends to the heater. These two opposing flows cause retardation of circulation in both the main return line and in the piping between the tank and the heater.

Figure- 6.9

Hot water supply system in high rise buildings: -

The principles of layout of hot water supply systems in tall buildings may be either gravity or forced circulation system. Of course, a non-circulatory supply is unsatisfactory in tall buildings because of the length of piping involved. It is necessary to provide a well balanced gravity or forced circulating systems to cater to the needs of faucets. The following salient points may be taken as a guideline.

a) The water pressure may be divided into zones with separate heaters for each zone or one heater may serve two or more zones with pressure tank for each zone.
b) Equal distribution of hot water among the risers is difficult when there are a number of risers in which case valves must be provided at the bottom of each riser to adjust the flow by trial and error.
c) Provision of check valves prevents the back flow of cold water into return circulating pipes.
d) While designing pipe system, the longitudinal expansion of pipes must be taken into account and expansion joints provided when the length of pipe is more than 20 meters.
e) Air relief valves should invariably be provided at the highest point to avoid any air locking in the system.
f) Drain valves must be provided at the lowest point, so that the entire system can be emptied.
g) In case of multistoried buildings, where a common overhead tank over the stair/ lift well is generally installed, it is advisable to have one or more local tanks for supply to the hot water heaters. This arrangement helps in reducing the length of the vent pipes.

Figure – 6.10

h) In tall multistoried buildings where the static pressure increases with the height the total static pressure on the hot water heaters on the lowest floor shall not exceed the rated working pressure of the hot water heater installed. Where the height of the building so requires, additional tanks are provided on the intermediate floors to restrict the static head to the permissible limits.

Figure – 6.11

i) As an alternative to the above arrangements, an individual storage tank in each flat may be provided for supply to hot water heaters.

Figure

Cold water feed: -

The feed pipe connecting the cold water tank with the hot water heater should not be of less than 20mm bore and should leave the cold water tank at a point not less than 5cm above the bottom of the tank being connected into the hot water heater near its bottom. Thus, the feed pipe shall not deliver cold water to any other connection but into the hot water cylinders only.

In case of multistoried buildings, a common cold water feed pipe may be installed, but each hot water heater is to be provided with a check valve. Generally horizontal type of check valve is preferred to vertical type for easy maintenance.

In additional to this, care is taken in installing the piping to prevent air locks in the piping and negative pressure in the hot water heater. However, cold water feed pipe are not to be cross connected with any other source of supply under pressure.

Expansion pipe or vent pipe: - The very purpose of providing vent pipe is to allow free movement of air to and fro from the system. Since the hot water systems now being considered are low pressure hot water systems, they are generally designed to operate at atmospheric pressure so that their water contact in normal circumstances are not heated to a higher temperature than 100°C. Under the circumstances, the provision of vent pipe becomes quite essential, if the system is to work properly and safely.

The followings are the salient features in respect of vent pipes: -

a) Each pressure type hot water heater or cylinder is to be provided with a vent pipe of not less than 20mm bore. Usually vent pipes of 25mm dia for small installations and 32mm dia for large installations are used. It rises from the crown or the highest point of the hot water storage to terminate with its open end above the feed cistern.
b) The vent pipe should rise above the water line of the cold water tank by at least 15cm plus 1cm for every 30cm height of the water line above the bottom of the heater.
c) The vent pipe should discharge at a level higher than the cold water tank and preferably in the cold water tank supplying the hot water heaters. Care is taken to ensure that any accidental discharge from the vent does not hurt or scald any passerby or persons in the vicinity.

d) The vent pipe should be connected to the highest point of the heater vessel and it shall not project downwards inside it, as otherwise air may be trapped inside, resulting in surging and consequent noises.
e) At no point after leaving the vessel, the vent pipe should dip below the level of its connection with the vessel.
f) However, a vent pipe may be used for supply of hot water to any point between the cold water tank and the hot water heaters.
g) The vent pipe shall not be provided with any valve or check valves.

Sizing of pipes: - The hot water supply and return circulation system aims at maintaining the hot water temperature within suitable limits in the supply mains and risers. This is achieved by re-circulating the hot water through the mains and risers from a storage tank or heater, so that hot water is immediately available at fixtures far remote from the hot water source. The following points must be considered for a simple and rational method for determining the rate of circulation and the sizes of return piping economically and accurately.

a) The rate of heat loss of the piping in which circulation occurs.
b) The temperature differential at which the system is to operate
c) The pressure or head available for circulation.
d) Hot water demand of individual fixtures.

The following procedure may be followed in designing the hot water re-circulation system.

1) A systematic layout sketch of the hot water supply system from the source to the sanitary fixtures where supply is required is drawn.
2) For each section of the system, the total load in terms of fixture units is marked on the drawing.
3) Adjacent to each fixture units, the demand in liters per minute corresponding to each fixture unit is marked on the drawing.
4) The rate of heat loss of the entire hot water supply piping through which hot water is to circulate is calculated on the basis of the following table.

Rate of heat loss for insulated pipes

Nominal dia. of pipe in mm	15	20	25	32	40	50	65	80	100
Rate of heat loss in hot water supply piping in cal/hour/Rm	49	56	62	69	79	95	105	125	151

5) The rate of heat loss of the return mains and risers is determined assuming 2/3rd of the heat loss rate of the supply piping in return lines.
6) The calculated and assumed heat losses are summed up for the entire supply and return piping through which hot water circulates in the system so as to establish its tentative rate of total heat loss.

7) The circulation rates required for the main and branch circuits are calculated in accordance with their assigned heat loss loads and with the temperature differential at which the system is to operate. Generally a differential of 11°C is recommended for use in designing the systems equipped with circulation pumps whereas a 22°C differential is recommended for the systems having gravity induced circulation.
8) The pressure or heat available for establishing the circulation (either by gravity or by pumping) is determined.
9) The particular run of return piping which has the maximum developed length in the system by measurement is determined. The maximum run of the return piping will have the most frictional losses and requires largest size which can be called as basic circuit for design purposes.
10) The pressure drop due to frictional resistance of the water flowing at required circulation rates in the hot water supply piping extending from the hot water tank or heater, along the supply main and up to the supply riser to the point at which the basic return circuit connects there to is calculated.

    The pressure drop may be calculated by the following formulae: -

    a) For copper piping, $h = 461q^2(L/d^5)$
    b) For wrought iron piping, $h = 922q^2(L/d^5)$

       (Where h = m, q = lpm, L = m, d = mm)
11) The maximum permissible uniform pressure drop for the basic circuit is determined by dividing the pressure drop by the total developed length.
12) The rate of flow of various pipe sizes is calculated and the type of pipe selected / assumed for the system is tabulated.

    The flow can be worked out by the following formulae: -

    a) For copper piping, $q = 0.0466d^{2.5}(h/L)^{1/2}$
    b) For wrought iron piping, $q = 0.33d^{2.5}(h/L)^{1/2}$
13) Using the tabulated values of flow rates producing a pressure drop corresponding to the maximum permissible uniform pressure drop for the circuit, the sizes of all parts of basic circuit, is determined.
14) After establishing the sizes of all return pipes, these sizes are applied in checking the assumptions and calculations made in steps 5 to 12.
15) The sizes are finalized accordingly after due adjustment.

SANITARY INSTALLATION IN BUILDINGS

INTRODUCTION: - The elements of a drainage system, which are its principal parts, consists of soil pipe, waste pipe, rain water gutters, leaders, the traps, vents etc. A soil pipe in the plumbing system is a drainage pipe that carries or is designed to carry human excrement. The soil appliances which collect and discharge excretory matter discharge through the traps into a soil pipe. A waste pipe carries liquid wastes that do not include human excrement. The waste appliances collect and discharge waste water through the traps into a waste pipe.

The traps are ventilated by anti-siphonage or ventilating pipes. The vent pipes, barring a few exceptions, are attached to the drainage pipes near the traps, and between the trap and the sewer for the purpose of admitting air or taking air away from the drainage pipes. The ventilating pipes provide a safe outlet into the atmosphere for the foul gases in the drain or sewer. These vent pipes preferably lead to the outside air at some distance from any other opening into the building. Ventilating and drainage pipes at point near the trap assist in preventing the trap seal from being broken by air pressure in the drainage pipes.

The rain water collected in the premises is carried down the rain water gutters and pipes. The soil pipes discharge into the building drain or sewer. The waste pipes discharge into a building drain directly or through a trapped gulley. However, in a partially separate system, where a portion of the drain or storm water is mixed with the sewage, the building sewer carries rain water also. The vertical main of soil, waste or vent piping is called a stack and when laid horizontally, it is called a branch.

SYSTEMS OF PLUMBING: - Generally there are four systems of plumbing for building waste water drainage as follows: -

1) Two pipe system
2) One pipe system
3) Single stack system
4) Singe stack (Partially ventilated system)

Although IS: 5329 recommends the use of first three systems only, yet the fourth system which is the slight modification of third system, is also much used in practice. However, in all these cases, the storm or rain water system is separate.

1) ***Two pipe system***: - In this system of plumbing , two pipes are provided; the soil and waste pipes being distinct and separate. Soil pipe collects the foul soil and lavatory wastes whereas the waste pipe collects the unfoul water from the kitchens, bath rooms, house washings, rain water etc. The soil pipes are directly connected to the man hole/sewer, whereas the waste pipes are connected through trapped gulley. All the traps used in this system are fully ventilated.

This is the most common system used in India which provides an ideal solution where it is not possible fix the fixtures closely.

FUGURE:

Fig. ----- illustrate the system and it is characterized by the following features: -

i) The entire system is properly ventilated on the house side and all the inspection chambers should be provided with fresh air inlets.

ii) The main soil vent pipe rises to above the level of eves and is so placed that gases leaving it can not be a nuisance or a danger to health.

iii) All the rain water pipes, bath, basin and sink wastes discharge over gully traps which ensure aerial disconnection of these wastes from the drain air.

iv) All the soil pipes are carried direct to the man holes without gully traps.

v) All the drains are to be laid in such a way as to ensure their easy future extension and safety.

vi) If the quantity of sewage flowing in a pipe is small, an automatic flushing tank may be provided on its top for flushing it.

2) ***One pipe system***: - In this system only one main pipe is provided which collects both the foul soil waste as well as unfoul waste from the buildings and is directly connected to the building sewer/ manhole. The provision of waste pipes and gully traps are completely eliminated. All the traps of soil and waste appliances are completely ventilated through a single ventilating pipe. Thus, it contains one soil-cum-waste pipe and one ventilating pipe for both soil and waste appliances. Fig._____ shows this system.

FIGURE:

3) ***Single stack system***: - This system of plumbing is the same as one pipe system with the only difference being that no ventilation is provided even in the traps too. i.e. without any trap ventilation pipe work. Thus it contains only one soil cum waste pipe and no ventilating pipe.

FIGURE:

4) ***Single stack (partially ventilated) system***: - This system of plumbing is the same as one pipe system but partially ventilated and may be regarded as a combination of one pipe and single stack system. In this case, only one pipe is provided to collect all types of waste water foul or unfoul and only the traps of soil appliances or water closets are ventilated through a single vent pipe called relief vent pipe. Thus it contains soil-cum-waste pipe and one ventilating pipe for the soil appliances only.

FIGURE:

Choice of Plumbing System: - The two pipe system is an age-old and safe system especially suitable where the sullage (waste water) from waste appliances can be dealt with separately for use in gardening or any other such purposes. The reasoning behind using this system has been to segregate what has been regarded as the more objectionable discharges from water closets and to discharge them into the soil stack which in effect, a direct extension of building drain or sewer. On the other hand, the waste stack is not directly connected to the building drain but to the trapped gully that discharges to the building drain and forms a barrier to the passage of air from the drain into the waste pipe. The two pipe system is a proper system to adopt where the conditions are not suitable for the adoption of one of the more modern simplified systems, as for instance, where the fitments are scattered with water-closets, baths and basins widely separated. But this two pipe system is costly as it requires much labour and material with anti-siphonage pipe compared to the single stack system of plumbing.

In case the planning of a building provides for a suitable grouping of all soils and waste appliances and where all types of waste water are taken in a common sewer to the place of disposal or treatment, one pipe system is to be preferred. Again, in this system the traps of all appliances, soil and waste are fully ventilated. Thus the term one pipe system is a misnomer since actually there are two stacks, one soil-cum-waste stack and the other, vent stack. The reasoning behind this system of plumbing in the past is based on the fact that there is no second line of defense in the form of a trapped gulley against the passage of sewer air into the building at the waste appliances. The trap at the appliances must not fail and to eliminate any risk or failure, every appliance is vented. Of course, in this case, 40mm water seal trap is sufficient for waste appliances and 50mm water seal for soil appliances. Additionally following safeguards are taken.

a) Each waste pipe is directly connected to the common stack above the soil branch at each floor.
b) All traps are ventilated by 'loop vents' by means of pipe of not less than 50mm dia for preserving their seal.
c) C.I. fittings and branches for waste pipes should be of the same quality as for the soil pipe and all waste pipe joints are to be made gas tight.

In single stack system, no antisiphonage pipe is required and this system is adopted where the cost reduction is of prime importance. Now-a-days this system is becoming popular in modern building construction. The tests done by CBRI, Roorkee on five storied building shows that in this case there are no break of water seals. Thus single stack system aims at economising on the pipe work and taking sufficient safeguards. Here the stack itself is made to serve the vent requirements by restricting the flow in the stack. As it is the common practice in India to discharge the waste water from the sinks and wash basin to the floor trap, sanitary appliances carrying unfoul waste water do not require deeper seals. This system may be recommended up to 4 storey buildings with 100mm dia. stack and not more than two toilet units discharging to the single stack at each floor level. However, the single stack partially ventilated system is an improvement or modification over this system, where some of the drawbacks of the single stack system is done away with.

The safeguards for the single stack system and the partially ventilated one pipe or single stack system are as follows: -

a) The vertical distance between the waste branch (from floor trap or from the individual appliance) and the soil branch connections when soil pipe is connected to stack above the waste pipe, shall be not less than 20cm.
b) If the appliances, like wash basin and sinks are directly connected to the stack (branch waste pipe less than 75mm dia), they are to have a 75mm deep water seal traps. However, if they are connected through the floor trap to the stack, the individual appliances need not have any water seal trap. The floor trap should have at least 56mm water seal. However, the conventional 50mm water seal traps in soil appliances are satisfactory. The branches from the soil appliances and floor traps are to be of 10 and 7.5 cm dia. respectively.
c) The branch pipes from all appliances should fall gradually and continuously in the direction of flow and should have a slope of 1 in 10 to 1 in 50.

SOIL AND WASTE WATER INSTALATION IN HIGH RISE BUILDINGS: -

Now-a-days, in multi storey or high rise buildings, the modern trend is to go in for a partially ventilated one pipe or single stack system, where the vent stack is connected to the drainage stack or the soil appliances at each or alternate floors. Use of one pipe system is becoming popular due to its low cost. The central building research institute (CBRI), Roorkee after extensive research on this system, has recommended it in modern buildings. An analysis of this system has shown that the flow from the appliance to the stack through the branch is momentarily halted at the point where a sharp change of flow direction takes place. In fact, a plug of water is some-times formed immediately at the junction, which depends up on the rate change of discharge and the size of branch. This gives rise to unequal pressures at the seals for the lower floors of the building which sometimes leads to breakage of the water seals of the sanitary appliances. In this situation, C.B.R.I has recommended the use of aerator and deaerator in the stack with a view to increase its capacity.

The function of the aerator is to prevent the formation of the plugs of water in the vertical stack and to make a mixture of water and air of low specific gravity. The aerators are to be provided at every floor.

a) For supply of water to various sanitary fittings.
b) For collection of waste water from the sanitary fittings.
c) For collection of rain water from the roofs, house and courtyard washings.

However, the fixing of sanitary appliances in the walls, floors and other places and their connected pipe works are to be done carefully for the proper functioning of the system. De-aerators are provided at the foot of the stack to separate air and water to avoid excessive pressure. Studies carried out by the C.B.R.I, Roorkee have revealed that 100mm dia. stack with these fittings can be used only up to 15 storeys, where as a single stack system without these fittings can be used only up to 5 storeys.

Fig. ___ shows the sketch explaining the water supply, drainage and sanitation in high rise buildings.

FIGURE:

ELECTRICAL SERVICES IN BUILDINGS

INTRODUCTION: - From the day of invention of electricity, a lot of developments in the field of electrical engineering have taken place and survival in the present world without electricity is unthinkable. Electrical power is generated at far off places and is transmitted through overhead lines at a very high voltage and finally distributed to the consumers. Since the supply is received by the consumer from a long distance consumer line, it is subjected to a number of disturbances caused either due to over loading of grid, switching of large loads etc. or due to weather condition due to lightening etc. Thus the supply generally is not pure and totally reliable. Hence for critical installations, the reliable power supply should be planned without much disturbances. The safe and economical use of electricity is of paramount importance to the user of the building as well as the world as it is the most highly refined form of energy available to the civilization. In fact, production of electricity consumes as much as up to three times its own energy value in fossil fuel and the electricity in its distributed form is potentially lethal which gives rise to accidents leading to loss of human life or property if the system is not designed, executed or maintained properly. Due to scarcity of fossil fuel used for power generation and increase in the cost of such fuel so also the cost of production, more emphasis is now being given to energy conservation by well designed and well maintained electrical service system.

PLANNING OF ELECTRICAL SERVICE SYSTEM: - The electrical service system to a building or house consists of drawing supply from the public supply systems and distributing it for various outlets and electrical appliances used in buildings. The design and planning of an electrical installation involve consideration of all prevailing conditions and is usually influenced by the type and requirements of the consumer. For an electrical installation to be efficient, strong coordination between the architect, civil engineer and electrical engineer is essential right from the planning stage for providing an installation that will prove adequate for its intended purpose with reasonabe safety as well as takes care of any future increase in demand. Therefore, the planning and design of electrical installation should take into consideration, some or all of the following.

1) The types of supply, occupancy, envisaged load and the earthing arrangement available.
2) The atmospheric conditions, such as cooling air temperature, moisture or such other conditions which are likely to affect the installation adversely.
3) The possible presence of inflammable or explosive dust, vapour or gas.
4) The degree of electrical and mechanical protection necessary.
5) The importance of continuity of service including the possible need for stand by supply.
6) The probability of need for modification or future extension.

7) The probable operation and maintenance cost taking into account the electricity supply tariffs available.
8) The relative cost of various alternative methods.
9) The need for radio and telecommunication interface suppression.
10) Ease of maintenance, safety aspects and energy conservation.

In general, electrical installation system consists of wiring, earthing including provision of circuit breakers, energy consuming devices and fuses etc.

WIRING :- A network of wires connecting various accessories for distribution of electrical energy from the supplier meter board to the numerous electrical energy consuming devices such as lamps, fans and other domestic appliances through some sort of controlling and safety devices is known as wiring system. The wiring system of a building should be capable of carrying the maximum current that normally flows through it without its rating being exceeded. While estimating the current to be carried through the wiring, the following power ratings may be taken into account, unless actual values are known or specified for these elements.

Table: - Power rating s of various electrical fixtures or elements.

Name of the fixture / element	Power rating in watts
Incandescent lamps	60
Ceiling and table fans	60
Fluorescent tubes of length 600mm 1200mm 1500mm	 25 50 90
Power outlet sockets	1000

As per recommendation of Indian standards, the maximum number of points of lights, fans and 5-A socket outlets that can be connected in one circuit is 10 and the maximum load that can be connected in such a circuit is 800 watts; in case of more load or more points are required to be connected to the supply, then it is to be done by having more than one circuit.

Table: - Recommended schedule of socket outlets.

Location	No. of 5-A sockets	No. of 15-A sockets
Bed room	2-3	1
Living room	2-3	2
Kitchen	1	2
Dining hall	2	1
Garage	1	1
For refrigerator	-	1
For A/C	-	1 for each
Verandah	1 for $10m^2$	1
Bath room	1	1

The electrical installation in a new building should normally begin immediately on completion of the main structural building work but before the commencement of finishing work such as plastering etc. except in case of surface wiring which can be carried out after the plaster work. In that case, the conductors should be passed through galvanized rigid conduits. Of course, no installation work should start until the building is reasonably water proof but where the electric wiring is to be concealed within the structures as may be the case with a R.C.C building, the necessary conduits or ducts are positioned firmly by tying the conduit to the reinforcement before concreting. However, when the shutters are removed after concreting, the conduit ends are given suitable anti-corrosive treatment and the holes blocked off by putties or caps to protect the conduits from getting blocked.

LAYOUT OF WIRING: - The electrical wiring layout should be finalized after proper location of all outlets for lamps, fans, both fixed and transferable appliances, motors etc. have been selected and best methods of wiring determined. All runs of wiring as well as the exact position of all point or switch boxes and other outlets are first marked on the plans of the building using red colour for live, black for neutral and green for earth wires, which must be approved by the engineer-in-charge or the owner before actual commencement of the work. Industrial layout drawings should indicate the relative civil and mechanical details. The layout should be designed to minimize the wiring length keeping in view the disposition of the lighting system to meet the illumination levels. Power and heating sub-circuits are to be kept separate and distinct from the lighting and fan sub-circuits. All the wiring is to be done on the distribution system with the main and branch distribution boards at convenient physical and electrical load centers. All types of wiring, whether concealed or un-concealed should be as near to the ceiling as possible. However, in all types of wiring, due consideration is to be given for neatness and good appearance.

FIGURE

MATERIALS AND DEVICES FOR WIRING: - The following materials and devices are used in the wiring of a building.

Cables/ wires: - These consists of conductors surrounded by the insulating materials. Generally, copper or aluminum conductors are used; the copper conductors are superior but aluminum conductors are used, as they are cheap, but the later suffer from the defect of brittleness due to oxidation and may create problems in the long run.

Circuit breakers: - Commonly the following three types of circuit breakers are used.

- **i.** *Miniature circuit breakers (MCB): -* They automatically switch off the power supply when excess current flows through the circuit, which may occur due to the over-loading or short-circuit. It is preferable to fuse but more expensive.
- **ii.** *Earth leakage circuit breaker (ELCB):* **-** If there is fault in an electric appliance, when it is connected to the power supply, the metal parts of the appliance may become live without blowing of the fuse, which may result in an electric shock accident to the person touching it.

In order to avoid this, the metal parts of the body must be earthed and ELCB is a tripping device connected to the earth wire, which trips in the event of current passing through the earth. This switch is connected to the neutral line of the electric supply in the main distribution board and before the main switch**.** When it trips, the electric supply of the main building is cut off.

iii. *Residual current circuit breaker (RCCB): -* It is a better device than the ELCB and is connected to all three phase and the neutral. It also gives good protection against minor defects in the wiring. It generally trips and remains dis-connected until the defect is rectified. However, it is more expensive than ELCB.

iv. *Fuse:* **-** A fuse protects appliances and cables from the electrical faults. The current ratings of fuses are to be lower than that of the cable or the appliances it has to protect.

v. *Plug fuse: -* These are the fuses provided at the plug outlets used for expensive electrical equipments such as television, refrigerators, air conditioners and laboratory equipments.

METHODS OF WIRING

There are two methods of wiring such as joint box system (or Tee system) and loop-in- system.

I) **Joint box or Tee- system** – In this system, the connections to the lamps are made through the joints within joint boxes by means of suitable connectors or joint cut-outs. Although there is a saving in the quantity of wire or cable required in this case, but the same is offset by the extra cost of joint boxes. Again, another draw back of this system is that the number of Tee connections made in wiring system results in weakness, if not properly done. Hence, the use of this system is limited to temporary installations only as its cost is low.

II) **Loop-in-system** – Here the connections of various lamps or other appliances are made in parallel. In this system, when a connection is required at a light or switch, the feed conductor is looped in by bringing it direct to the terminal and then carrying it forward again to the next point to be fed. The switch and light feeds are carried round the circuit in a series of loops from one point to another until the last point on the circuit is reached. The phase or line conductors are looped either in switch board or box but should never be looped either in switch board or from light or fan. In no case, joint is made in the run of wire or cable. In this case the fault location is easy since no joints are concealed beneath the floors or in roof spaces but only at out lets so that they are accessible for inspection. But this system suffers from the disadvantage that it requires more wire or cable length resulting in increased voltage drops and copper losses. Also loop-in within switches or lamp holders is usually difficult. However, this system is usually employed.

TYPES OR SYSTEMS OF WIRING

Different types of wiring are followed for extending the supply to various electrical equipments and the systems of internal wiring usually employed in our country are the following :

1) Cleat wiring: - In this type of wiring, PVC insulated or VIR insulated wires are run on porcelain cleats which are fixed at a distance of 600mm apart and are fixed to the wall by using wooden

plugs previously connected to the wall or ceiling so that the cables are held by about 6mm above the surface. It is a very cheap and trust worthy system for certain circumstances being more suitable for construction sites and temporary house wiring. All cleated wirings possess the important advantage that the wires are always visible except in positions where they would be liable to mechanical injury and run above 1.5m from floor level. Hence they can be easily inspected and are less likely to be damaged by over sight. Further, as the wires are better ventilated than other systems, it can allow a slightly greater current density.

This system is not adopted on damp walls or ceilings and is suitable for circuits up to 250V. The cleats are arranged in such a way that the distance between wires is 25mm and in case of sub-mains, the same shall be minimum 40mm. However, where cleated conductors cross each other, they are separated by an insulating bridge piece. The cleated wirings are not taken through the floors and at the time of laying and drawing of wires, care is taken to keep the wires straight, tight and rigid without any twist. This type of wiring has become outdated and is not in vogue.

2) <u>Wood casing wiring: -</u> This type of wiring is suitable for low voltage installations where vulcanized rubber insulated cables or plastic insulated cables are used in wiring work. All casings are made with seasoned teak wood or any other suitable hard wood, free from knots, shakes or other defects. The casing generally has grooved body with beaded or plain moulded cover.

All casings are fixed by means of suitable wooden screws to plugs at an interval not exceeding 900mm for sizes up to 64mm casing and not exceeding 600mm for sizes above 64mm. Casings are provided only on dry walls / ceiling and shall not be fixed near gas/ steam appliances. Again all casings are to be provided with porcelain insulators of not less than 6.5mm thick from the wall and never to be buried in flooring or plastering. However, when the wires are to be taken through walls of floors, only a heavy conduit properly bushed at both the ends shall be used. The most serious limitations to the use of wood casings are its inflammable nature and its inability to resist dampness. This type of wiring was extensively used two to three decades ago, but is not done now-a- days.

3) <u>CTS/TRS/PVC Sheathed wiring: -</u> In this system, the cables are insulated with rubber as usual but have an outer protective covering of a tough rubber compound. The use of these cables usually known as cab tyre sheathed (CTS) or tough rubber sheathed (TRS) cables is now very common. Such covering is unaffected by paint, moisture, acid fumes or wet plaster but is quite flexible and being a non-conductor, is entirely free from attack by electrolysis. Thus this system of wiring is suitable for places where acids or alkalis are likely to be present. These types of wiring are also suitable for low voltage installations and are not used in places exposed to sun and rain or in damp places.

All TRS wiring is run on well seasoned and varnished straight teak wood battens of not less than 10mm finished thickness and width suitable to run all the wires. All the wirings are fixed using link clips to minimize sweating or condensation inside the conduit. The outer surface of the conduit and other conduit accessories in all cases, wherever exposed to weather are to be protected against rust. Link clips are so arranged that one single clip does not hold more than two twin core TRS or PVC sheathed cables up to 1.5 sq.mm above which single clip holds single cable. The wiring should not under any circumstances be bent so as to form a right angle but should be rounded off at corners to a radious not less than six times the overall diameter of the cable. The cable shall not be buried in floor or in plaster. This system of wiring looks neat and clean. Besides it is not very costly.

4) Metal sheathed wiring / Lead sheathed wiring: - In this case, the cables used are insulated wires, TRS or PVC with an outer covering sheath of lead-aluminum alloy containing about 95% lead. This metal sheath gives protection to the cable from mechanical injury, dampness and atmospheric corrosion. The whole metal sheathing is made electrically continuous and is properly earthed to protect against leakage current ensuring optimum safety. These types of wiring system is suitable for low voltage installations and are not used in places where acids or alkalis are present, but is used in places exposed to sun and rain provided no joint is exposed. The wires are fixed on walls similar to TRS cables. The link clips are arranged similar to TRS cables fixing. However, when the cables are laid in places exposed to weather, the link clips shall be made for outdoor use. It is costlier than TRS wiring.

5) Conduit wiring system: - This system provides better mechanical protection and is fire proof. It is broadly divided into rigid steel conduits and rigid non-metallic conduits. Again, rigid steel conduits may be classified as surface conduit wiring and recessed conduit wiring.

a) *Rigid steel conduits:* - Here, the steel tubes, known as conduits are installed either on the surface of the walls (surface conduit wiring) or are buried under plaster (recessed conduit wiring).

i. *Surface conduit wiring system with rigid steel conduits: -* The diameter of the conduit depends on the number of cables which passes through it. The minimum size of the conduit shall be of 16mm diameter and of 16 SWG thicknesses. All conduit pipes should be finished with galvanized or stove enameled surface. All conduit accessories like junction boxes, couplings etc. are of threaded type and in no case clamp type accessories should be used. Conduit pipes are joined by means of screwed couples and screwed accessories only. The inside of the conduit is reamered to clear the burns as otherwise it may damage the insulation of the wire.

The conduit pipes are fixed using heavy gauge (minimum 18 SWG) saddles secured to suitable wooden plugs or any other screws at an interval not more than one meter. The bends in conduits including diversions are done by bending pipes or by using solid or inspection type bends, elbows etc. and the radius of such bends in conduits are not to be less than 75mm. All bends/ junctions/ inspection boxes must be accessible for maintenance/ repair.

The insulated conductors of AC and DC supplies are not bundled in the same conduit. The lighting and power outlet wires and wires of different phases are run in different conduits. All conduits are properly drained and ventilated. The wires used in the conduits are to be with standard conductors. The conduits are permanently connected to earth by means of earthing clamp for a perfect continuity between the earth and the conduit. The conduit is to be tested for mechanical and electrical continuity after erection.

ii. *Recessed conduit wiring system with rigid steel conduits: -* In multi storeyed construction, generally the recessed system of conduits is universally adopted in buildings and this work is carried out along side with the building construction. The recessed conduit wiring system should comply with all the requirements of surface conduit wiring system for fixing of conduit. A neat chase of ample dimensions must be made in the wall so as to permit the conduit to be fixed in the manner desired, which is filled up neatly after erection of conduit and brought to the original finish of the wall.

The conduits in the chase are fixed by staples/ saddles not more than 600mm apart. Fixing of standard bends and elbows are avoided as far as practicable and all curves are maintained by bending the conduit pipe itself with a long radius which permits easy drawing in of conductors. Suitable inspection boxes of size 75 X75 mm are provided at required places to enable periodical inspections and to facilitate removal of wires. All threaded joints of rigid steel conduit is treated with some approved preservative compound to secure protection against rust. When conduit is to run across the expansion joints, the conduit section across the joint is to be with flexible conduits of same size as the rigid conduit.

b) *Conduit wiring system with rigid non-metallic conduits*: - Rigid non-metallic (PVC) conduits are used for surface and concealed conduit wiring. The conduit may be either threaded type or plain type and are used with corresponding accessories.

The other factors applicable to metallic conduits are valid for non-metallic conduits also. Non-metallic conduit system are used only where it is ensured that they are

i. Suitable for extremes of ambient temperature.
ii. Resistant to moisture and chemical absorptions.
iii. Resistant to low temperature and sunlight effects.

PVC conduits are cheaper in cost and the labour time saved may be as much as 25% compared to steel conduit. The main drawback of PVC cable is its movement due to variations in temperature. Also PVC conduits are not suitable for use in locations prone to fire hazards.

CHOICE OF WIRING SYSTEMS

The efficacy of a wiring installation largely depends up on the proper selection of the type of wiring, size and position of light/ fan points. The choice of any wiring system for a particular installation should be based on technical and economic considerations, both in the context of wiring system itself and the installation for which it is proposed. In general, the following factors are to be considered.

1) Safety: - It is one of the most important factors to be considered while deciding the type of wiring system to be employed. The first and foremost consideration is to protect the person using electricity against any leakage or shock. For instance, in industrial establishments where lots of fumes are produced, cleat or casing-capping wiring cannot be adopted. In places prone to fire hazard, conduit wiring must be resorted to. Sometimes, poor workmanship may also lead to dangerous results which must be guarded against.

2) Durability: - The type of wiring to be adopted must be durable and of proper specifications in accordance with the accessed life and type of building. For example, cleat wiring that is suitable for temporary buildings are definitely not acceptable for a permanent building. The wiring should also be able to withstand wear and tear in addition to the effects of weather and must be capable of carrying maximum current without overheating.
3) Appearance: - The wiring must present a good look after its installation. The cleat or casing-capping system of wiring will not definitely suit a modern beautiful house. From aesthetic point of view; the concealed wiring system provides the most elegant appearance but is costly. Also PVC wiring system renders a good appearance and is very popular now-a-days.
4) Mechanical protection: - The wiring must be protected against mechanical damage during its use.
5) Initial cost: - The initial cost of the wiring system to be selected is of prime importance since in addition to being safe it must be economical.
6) Cost of maintenance: - The wiring system selected should have as far as possible low maintenance cost.
7) Accessibility and amenability: - The wiring system should be amenable to future extension, renewal or alteration in addition to being accestible for repair and maintenance.
8) Miscellaneous factors: - The other factors that must be kept in view while making the choice of wiring system are load, voltage to be employed and the type of building etc.

FUSE: - Fuse is a weak point deliberately placed in circuit to ensure safety of the appliances. It is a device that by the fusion of one or more of its specially designed and proportioned components opens the circuit in which it is inserted when the current through it exceeds a given value for a sufficient time. The fuse comprises all the parts that form the complete device. It can be provided in the form of a fuse element or a fuse switch. A fuse element is that part of a fuse which is designed to melt and thus open a circuit, where as a fuse-switch is a composite unit, comprising a switch with the fuse contained in or mounted on the moving member of the switch. A fuse link is that part of fuse which needs replacement when the fuse blows out.

NECESSITY OF FUSE IN AN ELECTRIC CIRCUIT: -

The main functions of a fuse are to blow out under a fault and isolate the faulty section from the live side or section. If no fuse or other similar device is provided in the circuit, then a hazardous situation may be created on developing of faults such as over-load, short circuit or earth faults. In case of over-load, short circuit and heavy earth faults, a heavy current will continue to flow through the consuming apparatus, current carrying cables or wires and other current carrying equipments. Due to the continuous flow of heavy current through the cables or wires, apparatus etc., these might get heated up leading to its damage. Even fire may also break out in some cases. However, in case of earth leakage faults (i.e. the body of the electrical apparatus becoming alive),the body of the electrical apparatus continues to remain alive and at much higher potential above that of the earth. Under such circumstances, any person coming in contact with the metal body of the apparatus is laible to get an electric shock, even if it is earthed. Aforesaid case necessitates the use of fuse as a safety device.

WORKING OF A FUSE AND FUSE RATING: -

Generally, during normal operations, the current flows from the 240V line through the appliance and along the neutral conductor back to the power station alternator. Thus the nominal drop of voltage across the appliance is 240V. If either the line or the neutral conductor come into contact with a conducting material that is earthed, due to a wiring fault, the current automatically chooses the lower-resistance path to earth on its return journey to the earthed alternator. Then, immediately a higher current will flow and the appliance becomes a shock hazard.

This increased heating effect of the fault current can be used to melt a rewirable or cartridge fuse at the appliance, its fault current being 60% above the stated continuous rating. But high rupturing capacity (HRC) cartridge fuses, that allow for the high starting current required for electric motors, have silver elements in a ceramic tube which is packed with granulated silica. Of course, the correct fuse rating is to be used for each appliances to avoid damage to cables and buildings from overheating through the use of too high a fuse capacity. Fuse ratings can be calculated from the following formula

Fuse current rating = $\mathbf{1.6} \times \frac{\textbf{Appliance input VA}}{\textbf{Circuit voltage}}$

This can be given in a tabular form as follows: -

Table _____ Fuse ratings for 240V single phase and unity power factor

Power consumption in watts (W)	Fuse required in amperes (A)
120	0.8
240	1.6
720	4.8
1200	8
3120	20.8
3600	24
7200	48

In normal lighting circuits, the fuse of current rating 3 amperes and minimum fusing current of 5 amperes is used as the cables used are capable of carrying 5 amperes current safely. In circuits, where the current is fluctuating, as in the case of electric motors, the fuse wire should be of such size that it can carry momentary overloads without blowing. However, if advantage is taken of the diversity factor in deciding the size of the cables and the cables of a smaller size are used, then the size of the fuse must be decided according to the rating of the cable and not according to the total load of the circuit. On the other hand, if cable of higher size is used, in order to keep the voltage drop in the circuit within permissible limits, the size of the fuse must be decided as per the circuit load and not according to the rating of the cable.

Fuse is always provided on the live pole or in phase, never on the neutral pole.

TYPES OF FUSES: - The following types of fuses depending up on their location are normally used.

1) **<u>Supply main fuse: -</u>** This fuse is provided by the supply agency and is fixed just after the service meter and sealed by the agency. The seal can be broken only by the authorized person of the supply agency in case of blowing out of the fuse for the purpose of replacement. The rating of supply main fuse is always as per the load current of the consumer.
2) **<u>Consumer main fuse:</u>** - This is another fuse of rating slightly less than that of supply main fuse provided by the supplier which is placed after the consumer's main switch. The rating of the consumer fuse is kept slightly lower than that of the supply main fuse so that in case the current exceeds the normal current which may occur due to overload, short circuit or earth fault, the consumer fuse blows first that can be replaced by him, the supply main fuse remaining intact.
3) **<u>Sub-circuit fuses: -</u>** In this case, the total wiring system is divided into a number of sub-circuits or branch circuits and a separate fuse is provided for each branch circuit, known as sub-circuit or branch circuit fuse.
4) **<u>Point fuses:</u>** - In good quality indoor wiring of buildings, every light and plug point is provided with its individual fuse known as point fuse.

FUSE UNITS: - A fuse unit essentially comprises of the metal fuse element or link, a set of contacts between which it is fixed and a body to support and isolate them. In majority of cases, they also have some means for extinguishing the arc which appears when the fuse element melts. Various types of fuse units most commonly used are:

a) Round type
b) Kit-Kat type
c) Catridge type
d) High rupturing capacity (HRC) fuse units
e) Semi conductor fuse units

a) **<u>Round type fuse unit: -</u>** This type of fuse unit consists of a porcelain or bakelite box and two separated wire terminals for holding the fuse wire between them. In this case, one of the terminals remains always energized and therefore, for the replacement of the fuse, either the worker will have to touch the live mains or open the main switch. Also appreciable arching takes place at the instant of blowing off of the fuse and has every chance of damaging the terminals. Hence, after two or three arching, the fuse unit becomes unusable. Due to the above disadvantages, this type of fuse is not in common use.

b) **<u>Kit-Kat or rewirable type:</u>** - This is a semi enclosed or rewirable fuse most commonly used in house wiring and small current circuits. It consists of a porcelain base carrying the fixed contacts to which the incoming and outgoing live or phase wires are connected and a porcelain fuse carrier holds the fuse element that consists of one or more stands of fuse wire stretched between its terminals. Here the fuse carrier is a separate part and can be taken out or inserted in the base without risk, even without opening the main switch. If the fuse holder or carrier gets damaged during use, it may be replaced without replacing the complete unit. The fuse wire may be of lead, tinned copper, aluminum or an alloy of tin-lead. The actual fusing current is about twice the rated current. However, when two or more fuse wires are used, the wires are to be kept apart and a derating factor of 0.7 to 0.8 is used to arrive at the total fuse rating. On occurrence of fault, the fuse element blows off and the circuit is interrupted. The fuse carrier is pulled out, the blown out fuse element is replaced by new one and the supply is resorted by re-inserting the fuse carrier in the base. Although they have the advantages of easy removal or replacement and negligible replacement cost, they suffer from unreliable operation, small time lag, low rupturing capacity, no current limiting feature, slow speed of operation as well as the risk of flame and fire.

c) **Catridge type fuse:** - This is a totally enclosed type fuse unit. It essentially consists of an insulating container of bulb or tube shape and sealed at its ends with metallic cap known as catridge enclosing the fuse element and filled up with granular material known as filler. There are various types of materials used as filler like sand, calcium carbonate, quartz etc. Sometimes there is a blow out device beside the tube to indicate when the fuse is blown. On overload and short circuits, the fusible element is heated to a high temperature causing it to vaporize. The powder in the fuse catridge cools and condenses the vapor and quenches the arc thereby interrupting the flow of current.

   As this type of fuse is totally enclosed, it is not possible to rewire it and therefore the whole unit is to be replaced, once it blows out. But it provides complete securing against the risk of fire. This type of fuse is available up to 660V and the current rating up to 800A.

d) **High rupturing capacity (HRC) fuses: -** Where very heavy current flows into the fault as in case of modern power stations of heavy generating capacities, the fuse has to withstand very high stresses. A rewirable fuse may not be useful in this case and therefore high rupturing capacity fuses commonly known as HRC fuses for use in medium and high voltage installations are used for such duties. Their rupturing capacity is as high as 500MVA up to 66KV and above. Their main advantages are that they are cheap, requiring little maintenance, their operation is quick and sure, and they do not deteriorate with time, have inverse time current characteristics, high degree of reliability and can be selected for proper discrimination. But they are required to be replaced after each operation, inter-locking is not possible and they lack relays in complete discrimination. However, as the advantages outweigh the disadvantages to a very large extent, HRC fuses are extensively used. There are two types of HRC fuses that are commonly used namely i) Catridge type and ii) Tetra-chloride type.

e) **Semi-conductor type: -** These are very fast acting fuses for protection of thyristor and other electronic circuits.

EARTHING: - Earthing or grounding means electrical connection to the general mass of earth or it pertains to the conduction of electricity through the earth. More precisely earthing is a term used for connection of the neutral point of a supply system or the non-current carrying parts of electrical apparatus, such as metallic frame work, metallic covering of cables, earth terminal of socket outlet, stay wires etc. to the general mass of earth in such a manner that all times an immediate discharge of electrical energy takes place without danger. Thus earth connection improves service continuity and avoids damage to equipments and danger to human life.

The object of an earthing system is to provide as nearly as possible a system of conductors at a uniform potential and as nearly zero or absolute earth potential as possible. The very purpose of earthing is to ensure that in general all parts of apparatus other than live parts shall be at earth potential as well as to ensure that persons coming in contact with it shall also be at earth potential at all times. Also by providing such an earth surface of uniform potential under and surrounding the station, there can exist no difference of potential in a short distance big enough to shock or injure an attendant when short-circuits or other abnormal occurrences takes place.

Earthing systems are basically classified into two categories: -

System earthing: - Earthing associated with current carrying conductors is normally essential to the security of the system and is generally known as system earthing.

Equipment earthing: - Earthing of non-current carrying metal work and conductors is essential to the safety of human life, animals and property and it is generally known as equipment earthing.

As far as possible, all earth connections should be visible for inspection and should be carefully made. But, if they are poorly made or inadequate for the purpose for which they are intended, loss of life and property or serious personal injury may result.

Except for the equipments provided with double insulation, all the non-current carrying metal parts of electrical installations are to be earthed properly. All metal conduits, trunking, cable sheaths, switch gear, distribution fuse boards, lighting fittings and all other parts made of metal are to be bended together and connected by means of two separate and distinct conductors to an efficient earth electrode.

Earthing of metallic parts should not be effected through any structural metal work which houses the installation. Rather, where metallic parts of the installation are not required to be earthed and are liable to become alive if the insulations of conductors become defective, such metallic parts are to be separated by durable non-conducting material from any structural work.

However, the equipment and portions of installations are deemed to be earthed only if earthed in accordance with either the direct earthing system, the multiple earthed neutral system or the earth leakage circuit-breaker system.

EARTHING CONDUCTORS: - Earthing conductors are generally of high conductivity copper and is of either stranded, flat strips or circular or rectangular bar, which is protected against mechanical injury. Galvanized solid iron or steel wire or rod or any other suitable approved material can be used provided their conductivity is not less than the copper earthing conductor. However, bare conductor is to be protected against corrosion.

Earthing conductors are so placed and connected that they may not get accidentally damaged or cut. They are fixed over their entire length by clamps, clips, saddles, stapples, clouts etc. which in no way causes damage to the conductor. Of course, aerial earthing conductor is supported on suitable insulators and is clearly identified. It is to be protected against mechanical damage when burried. Joints in earthing conductors may be made by soldering, brazing, welding or by mechanical coupling.

Methods of earthing: - Various methods of earthing are: -

1) Pipe earthing or pipe earth electrodes
2) Plate earthing or plate earth electrodes
3) Strip or wire (round conductor) earthing
4) Rod earthing
5) Coil earthing

1) **Pipe earthing: -** In this method of earthing, standard cast iron (CI) or galvanized iron (GI) pipe with perforations of approved length and diameter is used. This is placed in upright position in a permanently wet soil. The surface of the pipe should be clean and free from paint, enamel or poorly conducting materials. The size of the pipe depends up on the current to be carried and the type of soil. Cast iron pipe are not to be less than 100mm inner diameter and of 4.5m long in case of sandy soil and 3.60m for other types of soil having thickness of 13mm. Galvanized iron pipe used as earth electrode should be of medium class and not less than 38mm inner dia , 4.5m long in case of sandy soil and 3.6m in other types of soil. It has holes/ perforations at 150mm made on two faces, the holes being staggered. In addition to this, it should satisfy the following:
   a) The electrode shall be preferably embedded below permanent moisture level. Also a number of pipes may be connected together in parallel to reduce the resistance of the earthing system. In such a case, the distance between the two electrodes should not be less than twice the length of the electrodes.
   b) To increase the efficiency of earthing, the resistivity of the soil immediately surrounding the pipe earth electrodes is to be reduced. For this artificial soil treatment is done by filling the pit around the electrode for a width of 15cm with a homogenous mixture of salt, charcoal/ coke, sand in 1:4:2 proportions for a depth of about 50cm.
   c) In case high resistivity soil strata is noticed at the proposed earth pit location, low resistivity filling soil like alluvium, clay etc. may be used for filling up the earth pit after artificial soil treatment.

   This is the most common and best system of earthing for the same soil and moisture conditions. A typical arrangement of pipe electrode or pipe earthing is shown in the figure_____.

   FIGURE

2) **Plate earthing: -** This is another common method of earthing. For plate electrodes, an earthing plate of either copper of dimensions 600mmX600mmX3.15mm of electrolytic quality or galvanized iron of dimensions 600mmX600mmX6.3mm is buried in the ground with its face vertical and the top at not less than 2.5m depth from the surface of the ground. This plate is embedded in a pit containing alternate layers of charcoal and salt for a minimum thickness of 150mm all round and earth connections (GI wire for GI plate and copper wire for copper plate)

are made to this plate by means of nut, bolt and washer made up of respective material. GI plate earth electrodes shall be used except where it is unavoidable to use copper plate earth electrode due to various site requirements. A typical arrangement of plate earthing is given in figure ---------.

FIGURE

3) **Strip or wire earthing: -** In this system of earthing, strip electrodes of cross section not less than 25mmX1.6mm for copper and 25mmX3mm for GI or steel are buried in horizontal trenches of minimum depth 0.5m. If wire or round conductors are used, their cross sectional area are not to be smaller than 2.5 sq. mm for copper and 5.0 sq. mm for GI and steel. The length of the buried conductor is to be sufficient so as to give the required earth resistance. The electrode should be widely distributed as far as practicable, preferably in a single straight or circular trench or in a number of trenches radiating from a point. If the site condition demands use of more than one strip, they are laid either in parallel trenches or in radial trenches. This type of earthing is used at places which have rocky soil earth bed since in that case the excavation work for the plate earthing is difficult.
4) **Rod earthing: -** In this method of earthing, solid rods of copper of 12.5mm dia or solid rods of GI or steel of 16mm dia or hollow section GI pipes of 25mm dia not less than 2.5mtrs in length are driven vertically into the earth either manually or by means of pneumatic hammer. For increasing the embedded length of electrodes under the ground, which is sometimes necessary to reduce the earth resistance to the desired value, more than one rod sections may be hammered one above the other. This type of earthing is suitable for areas having soft rock or sandy soil and is very cheap as no excavation work is involved.
5) **Coil earthing:** - Sometimes in order to increase the effective area of contact, coil earthing is done by using 8 SWG GI wire. This shall be of not less than 15mtrs length and wire shall be wound into spiral form of 50cm dia with its turns closely wound.

LIGHTING

Lighting or artificial illumination is used for both functional and decorative purposes. In present day civilization people have become accustomed to very high level of illumination standards resulting in appreciable consumption of electricity. On the other hand, the use of day light is encouraged with view to reduce energy consumption for lighting. Thus there could be two types of illumination natural and artificial.

Natural illumination which is obtained by the penetration of direct solar and diffuse sky visible radiation calls for correctly designed passive architecture. Although large glazed areas are capable of providing sufficient daylight at some distance into the building, yet it is likely to cause glare and overheating. Vertical narrow slot windows limit the flow of light energy and at the same time may cause very unequal lighting levels near the rooms perimeter. In addition to this, the reflected illuminations from other buildings, particularly from those having reflective glazing or metallic architectural features, may cause annoyance. Hence, a careful consideration of all these largely conflicting and variable elements becomes inevitable for production of a comfortable internal illumination environment. Of course, artificial lighting provided for supplementing daylight on a temporary or permanent basis. Local control of lights by manual and/ or automatic switches helps in reducing the consumption of electric energy.

OBJECTIVES OF LIGHTING: - Good lighting is necessary for all buildings and it has three primary objectives.

1) The first aim is to promote work and other activities carried out within the building.
2) The second aim is to promote the safety of the people using the building.
3) The third aim is to create a pleasing environment conductive to interest of the occupants and a sense of their well being.

REQUIREMENTS OF LIGHTING: - For achieving above objectives, the following points are to be taken care of.

1) Careful planning of the brightness and colour patterns within both the working areas and the surroundings so that attention is drawn naturally to the important areas, details are seen quickly and accurately and the room is free from any sense of gloom or monotony.
2) Use of directional lighting where appropriate to assist perception of task detail and to give good modeling.
3) Control of direct and reflected glare from the light sources to eliminate visual discomfort.
4) Minimization of flicker from certain types of lamps and paying attention to colour rendering properties of light in artificial lighting installations.

5) Correction of lighting throughout the building to prevent excessive differences between adjacent areas so as to reduce the risk of accidents.
6) Installations of emergency lighting systems wherever necessary.

SPECIAL CONSIDERATIONS IN RESPECT OF LIGTHING FOR VARIOUS TYPES OF BUILDINGS: -

a) **Office buildings: -** The electrical installation in office buildings should be done in such a manner that each day is self-sufficient i.e. the control switches for lights and fans are located within the bay itself so that future repartitioning will not result in placing the switches etc. in awkward or inconvenient locations. Fluorescent lighting should be provided in all places in preference to the bare tubes that cause glare to the eyes. Light and socket outlets should be adequately provided so that the length of the trailing flexible wire is reduced to the minimum.

b) **Auditorium, conference hall etc.**: - The general design of the system of lighting in an auditorium largely depends up on scheme of interior decoration and the type of ceiling. In multipurpose auditoriums, where some amount of reading may be required on occasions, a higher value of illumination is obviously required compared to that required solely for recreational purposes. In such a case, the light output should be adjustable to suit the requirement of different occasions. However, for an auditorium with facility of stage function and projection arrangement, aisle lights, "EXIT" and "NO EXIT" lights are required. In addition, some lights may above arranged on a different circuit, to be solely operated by the operator in the projection-room to serve as last lights.

c) **Schools and educational institutions:** -In this case lighting is required for relatively few hours in a day. Good lighting arrangement in the schools is essential on account of preservations of eye sight of the children. Particular attention is paid to the lighting of the black board which must be accomplished through its own special lighting equipment. As a general rule, no source of light should be located below a line drawn from a point on the back wall 1.1m above the floor to a point 1.3m above the upper edge of the black board surface, unless the light fittings are other wisely screened from the view.

d) **Residential buildings: -** Now a days in living rooms, elimination is being provided with table lamps or floor standards instead of pendant lights. This modern concept creates a feeling of speciousness and inviting atmosphere but in general pool residences of medium size, per force suspended lights or bracket lights are preferred to keep down the costs. Ordinarily in candescent lights are provided for domestic installations except a study or office where the use of fluorescent light will be more useful. For deciding the position of light, fans etc. Ultimate use of the building and alternative layout of furnishes must be taken into account. Control switches in residential buildings should be so located that they can be operated quickly up on opening the normal entrance door. This is needed to avoid an awkward switch position that may necessitate a person to walk in darkness to light a lamp. Again if the position of the bed is definitely known, it will be preferable to provide a dual control near the main doors.

LIGHTING FOR MOVEMENT ABOUT A BUILDING: -

Most buildings being complexes of working areas and other areas, such as passages, corridors, stairways, lobbies and entrances, the lighting of all these areas should be properly correlated to give safe movement within the building at all times.

Corridors, passages and stairways: - When people leave a well-lighted working area and pass immediately into corridors or on the stairways where the lighting is inadequate, may result in accidents, because the time needed for adoption to the lower level of the illumination may be too long to permit obstacles or the treads of stair to be seen sufficiently quickly. For the same reason it is also desirable that the illumination of rooms which open off a working area should be fairly high even though the rooms may be used only occasionally. Therefore, when lighting stairways, it is important to prevent disability from the glare caused by direct sight of bright sources to emphasize the edges of the treads and to avoid confusing shadows. The same precautions ought to be taken in the lighting of catwalks and stairways on outdoor industrial plants.

Entrances: - The problems of correctly grading the lighting within a building to allow adequate time for adaptation when passing from one area to another area are particularly acute at building entrances.

During day time, the people entering a building are generally adapted to a very high level of brightness of outdoor environment and there is a definite risk of accident if the entrance areas, particularly any steps are poorly lighted. This problem may often be overcome by arranging windows to give adequate natural lighting at the immediate entrance, grading to lower levels further inside the entrance area. The situations where this cannot be accomplished, supplementary artificial lighting is to be installed to raise the illumination level to an appropriate level to an appropriate value.

At night, it is essential to light the entrance halls and lobbies so that the illumination level reduces towards the exist and also no bright fittings are in the line of sight of the people learning the building. Hence, any entrance steps to the building should be well-lighted by correctly screened fittings.

Recommended values of illumination: -

Illumination required on the working place is determined by the size of the detail to be descend , the contrast of the detail with its back ground, the accuracy and the speed with which the task must be performed, the edge of the worker, the type of space within which the task is to be performed and the length of time to be continuously sport on the task. Of course, working plane in the surface being illuminated and other areas as lit by overall spill from it and by reflections from other room surfaces. Following table ----- gives some typical values of illuminance commonly encountered and used for design.

Table: - Typical values of illuminance

Application	Illuminance (l_x)
Emergency lighting	0.2
Sub-urban street lighting	5
Dwelling	50-150
Corridors	100

Rough tasks with large-details Store room	200
General offices and retail shops	400
Drawing office	600
Prolonged task with small detail	900

Higher level of illuminance may be provided for particularly fine detail tasks at the area of use by local, or task, illumination: e.g. illumination up to **3000l_x**for inspection of small electronic components and as high as **50000l_x** on a hospital operating table. However, bright sunlight provides illuminations up to **100, 0000l_x**. Moreover local spot lighting for display purposes and exterior illumination are used to accentuate particular features of the working plane.

Some representative values of illumination that is commensurate with general standards of lighting as described earlier and related to varying occupations and buildings as per Indian standard are given in the table ----- . There are valid under most of the conditions whether the illuminations are by day lighting, artificial lighting or a combination of the two.

TABLE: -

Sl. No.	Visual task	Illumination **(l_{ux})**
1.	<u>Residence</u>	
a)	Kitchens	200
b)	Bathrooms	100
c)	Stairs	100
d)	Sustained reading	300
e)	Casual reading	150
f)	Garages	70
2.	<u>Hotels</u>	
a)	Entrance halls	150
b)	Reception and accounts	300
c)	Dining room	100
d)	Bed rooms	100
e)	Lounges	150
3.	<u>Hospitals</u>	
a)	Waiting halls	150
b)	Wards	100
c)	Operation theaters	300
d)	Laboratories	300
e)	Casualty and OPD	150
4.	<u>Offices</u>	
a)	Entrance and reception	150
b)	Conference and executive office	300
c)	Corridors and lift cars	70
d)	Lift landings	150
e)	General office	300
5.	<u>Industries</u>	
a)	Very precision works	1500
b)	Engraving	1000
c)	Factory shed	300

d)	Boiler houses	50
6. a) b) c) d) e) f)	Schools and colleges Assembly halls Class and lecturer rooms Library shelves Staff and common rooms Corridors Stairs	 150-300 200-150 70-150 150 70 100

However, if for financial or any other reasons, it is not possible to provide lighting installations to give recommended illumination levels, future provision for additional light fittings or conversion from incandescent to fluorescent lighting may be made during installation of wiring wherever practicable.

ARTIFICIAL LIGHTING: -

1) **Necessity of artificial lighting: -** Artificial lighting may have to be provided
   a) Where the recommended illumination levels is to be obtained by artificial lighting only.
   b) To supplement day lighting when the level of illumination falls below the recommended value.
   c) Where the visual task demand a higher level of illumination.
2) **Artificial lighting to supplement day lighting: -** The need for general supplementary artificial lighting arises due to diminnation of day lighting beyond design hours, that is for solar altitude below 15° or when dark cloudy condition occurs. The need may also arises for providing artificial lighting during the day in the inner most parts of the buildings which can not be provided with adequate day lighting or when the outside windows are not of adequate size or when there are unavoidable external obstructions to the incoming day lighting. In fact, the need for supplementary day lighting on the working plane falls below **100 l_{ux}** and the surrounding luminance drops below 19 cd/m^2 and the working plane illumination level to a range of 100 **l_{ux}** to **150 l_{ux}**.

   The requirement of supplementary artificial lighting increases with the decrease in day lighting availability. Hence, conditions near sunset or sunrise or an equivalent condition due to clouds or obstructions etc. represents the worst conditions when the supplementary lighting is most needed. The requirement of supplementary artificial lighting when the availability of day light becomes poor can be determined from the following figure (Fig. ---) for an assumed ceiling height of 3.0m, depending up on the floor area, fenestration percentage and room surface reflectance.

   FIGURE: -

   Generally cool day light fluorescent tubes are recommended with semi-direct luminaries. To ensure a good distribution of illumination, the mounting height should be between 1.5m and 2.0m above the work plane or a separation of 2.0m to 3.0m between the luminaries. Also the number of lamps should preferably be more in near half of the room than in the vicinity of the windows.

MEASUREMENT OF LIGHT: - Practical measurements of light are connected with three aspects, the luminous intensity of the source, the luminous flux or flow of light from the source and illuminance of a surface.

Luminous flux: - The energy radiated by a luminous source is distributed over a wide range of wavelengths. Luminous flux represents the part of total radiant energy per unit time that is effective in producing the sensation of sight. The other photometric (connected with measurement of light) quantities are defined in terms of luminous flux (F or Ø)

Luminous intensity of a source: - The luminous intensity of a point source is defined as the luminous flux per unit solid angle (measure in steradians) subtended at the source.

$\mathbf{I} = \frac{F}{W}$ -Where F is the flux in the solid angle w

The solid angle **w** = A/b^2 is the ratio of the intercepted area (A) of the spherical surface around the source to the square of the radius (S) of the sphere. The common unit of luminous intensity is the candle which was originally defined as the luminous intensity of the flame of a standard candle of specified dimensions and burning rate in horizontal direction, which has been subsequently replaced by international unit of luminous intensity of a black body radiator operated at a definite temperature. The unit of luminous flux, lumen, is defined from the candle. A lumen is the luminous flux in a unit solid angle from a point source of one candle.

Intensity of illumination or illuminance: - when visible radiations comes to a surface, we say that the surface is illuminated and the measure of illumination is called illuminance which may be defined as the luminous flux per unit area that reaches the surface i.e. $\mathbf{E} = \frac{F}{A}$ Where the flux F may come from one or more source to the area under consideration from any direction. The common units of illuminance are lumen per square foot (foot candle) and the lumen per square meter (lux abbreviated to $\mathbf{l_x}$).

For a light from a point source, the illuminance (E) of a surface varies inversely with the square of the distance (S) from the source and directly with the cosine of the angle (θ) between the direction of flow and normal to the surface $\mathbf{E} = \frac{I}{S2} \mathbf{Cos\ \theta}$, **I** the luminous intensity being constant.

Determination of the luminous flux: - The luminous flux reaching the working plane depends up on the following:

1) Lumen output of the lamps
2) Type of luminaire (Complete apparatus contains lamp light emitter and electrical controls)
3) Propertion of the room (Room index, Kr)
4) Reflectance of internal surfaces of the room
5) Depreciation in the lumen output of the lamps after burning their rated life.
6) Depreciation due to dart collection in luminaries and room surface.

Calculation for determining the luminous flux: - The average illumination level required on the working plane in lux is given by $\mathbf{E_{av}} = \frac{\mu \emptyset}{A}$

Where $\emptyset =$ the total luminous flux of the light sources installed in the room in lumens, A = area of the working plane and μ = utilization factor. This can be other wisely written as $\emptyset = \frac{Eav.A}{\mu}$ for new condition $\emptyset = \frac{Eav.A}{\mu d}$ for working condition, d being the maintenance factor. In practice, it is earlier to calculate the number of lamps or luminaries from the following formula

N lamp/ luminaries = $\frac{Eav.A}{\mu d \emptyset^{lamp}/_{Luminaries}}$

Where $\emptyset lamp/_{luminaries}$ = Luminous flux of each lamp/ luminaries in lumen and N lamp/ luminaries = No. of lamps or luminaries

Number of fittings $= \frac{lux \times working\ plane\ area(m^2)}{LDL \times UF \times MF}$

Where LDL = lighting design lumens produced by each lamp.

UF = Utilization factor

MF = Maintenance factor.

Utilization factor: - It is the ratio of the luminous flux received at the working plane to the installed flux. Generally it is provided by the manufacturer and takes into account the pattern of light distribution from the whole fitting, its light distributing efficiency, the shape and size of the room for wihich it is being designed and the reflectivity of the ceiling and walls. The values of utilization factor vary from 0.03 (where purely indirect distribution is employed, the room has poorly reflecting surfaces and all the light is upwards on to the ceiling and walls) to 0.75 for the most energy efficient designs. Spot lighting can have a utilization factor of nearly unity.

The configuration of the room is indicated by the room index (Kr) which is given by

Room index = $\frac{lw}{H(l+w)}$

Where l is the room length in meter, w is the room width in meter and H is the height of the light fitting above the working plane in meters.

The ability of a surface to reflect incident light is given by its reflectance or luminance factor.

Maintenance factor: - It is defined as an allowance for reduced light emission due to built up of dust on a lamp or within a luminaire. Its value is normally taken as 0.8 but may be taken as 0.9 if the lamps are cleaned regularly or if a ventilated luminaire is used. It is because a planned maintenance schedule includes regular cleaning of light fittings and the lamp so as to ensure the most efficient use of electricity. The ventilated luminaires in air conditioned buildings remain clean for quite long periods as the air flow through the building is mechanically controlled and fattened. The lamp also operates at a lower temperature, which prolongs its life and maximizes light output.

Light loss factor: - It is the overall loss of light from the dirtness of lamp (0.8), luminaire (0.95) and the room surface (0.95). The values of LLF in clean condition may be taken as 0.7 but it is taken as 0.5 when the equipment and the room become soiled. It is preferred to maintenance factor.

Example – *1. A spot light equipped with a 35-cd bulb concentrates the beam on a vertical area of 120 m^2 at a distance of 75m. What is the luminous intensity of the spot light?*

Solution: The purpose of reflector and lens in a spot light is to concentrate the beam into a small solid angle. Since the surface area of the sphere is 4πr², the solid angle $\omega = \frac{A}{S^2} = \frac{4\pi r^2}{r^2} = 4\pi$

Then the total flux emitted by the bulb is given by

$F = I\omega = 4\pi I = 4\pi \times 35 = 439.82 \approx 440\ lm$

For the beam, the solid angle is $\omega = \frac{A}{S^2} = \frac{120}{75^2} = 0.0213$ sterad.

Luminous intensity, $I = \frac{F}{\omega} = \frac{440}{0.0213} = 18779$ cd ≈ 18780 *cd*.

Example – *2. A point source un-shaded electric lamp of luminous intensity 100 cd is 3.5m above the top of a table. Find the illuminance of the table*

a) at a point directly below the lamp and

b) at a point 2.5m from the point directly below the lamp.

Solution:

Case (a) – When directly below the lamp, the light falls directly on the surface.

Then θ = 0° and Illuminance $E = \frac{I}{S^2} = \frac{100}{3.5^2} = 8.163\ lx$

Case (b) – At the second point, $S = \sqrt{3.5^2 + 2.5^2} = 4.30$ m

and $\cos\theta = \frac{3.5}{4.3} = 0.814$

Illuminance $E = I\cos\theta / s^2 = \frac{100 \times 0.814}{4.3^2} = 4.402\ lx$.

Example – *3. A small un-shaded electric lamp hangs 6.0m directly above the table. To what distance should it be lowered to increase the illumination to 4 times its former value.*

Solution:

Here, $E_2 = 4 E_1$

$\frac{I}{S_2^2} = 4 \times \frac{I}{S_1^2}$ or $S_2^2 = \frac{S_1^2}{4} = \frac{6^2}{4} = 9$

Or, $S_2 = 3.0$ m

Example – *4. A drawing office 15 m x 12 m and 3.2 m high has a white ceiling and light coloured walls. The working plane is 0.75m above the floor. If double lamp luminaries are to be used with normal spacing to height ratio (SHR) is 1.75, calculate the number of luminaries needed and draw their lay out arrangement. Given luminance factor for the ceiling and walls are 70 and 50* *respectively. The lighting design lumen for the whole light fitting is 5200 lm.* utilization factor (*U.F.) for room index of 2.5 and 3 are 75 and 79 respectively. Windows are along the long side of the office.*

Solution :

For drawing office, illuminance required is 600 *lm/m²*.

The height H of the fittings above the working plane is H = 3.2 – 0.75 = 2.45 m

Room index (K_r) = $\frac{lW}{H(l+W)} = \frac{15\ x\ 12}{2.45\ (15+12)}$ = 2.72

By interpolation, utilization factor (U.F.) = 77% = 0.77

Assuming a maintenance factor of 0.9 for a high standard of maintenance,

No of fittings = $\frac{lux\ X\ working\ plane\ area(m^2)}{LDL\ X\ UF\ X\ MF} = \frac{600\ X\ 12\ X\ 15}{5200\ X\ 0.77\ X\ 0.9}$ = 29.97 ≈30

The ratio of the spacing *S* between rows to the height H above the working plane is SHR = $\frac{S}{H}$ = 1.75

Spacing between rows + 1.75 H = 1.75 x 2.45 = 4.29m ≈4.3 m

Assuming that the rows of luminaries are parallel to the windows so as to gain maximum benefit from the side daylight without glare and reflection, the perimeter rows of luminaries may be spaced about half of S from the side walls.

Since the width of the room is 12m, the value of S may be taken as 4m and 3 rows of 10 nos. of luminaries i.e. 30 luminaries may be provided giving a slightly increased illuminanance.

FIGURE

VENTILATION

INTRODUCTION: - Ventilation of building is mainly required to supply fresh air for respiration of occupants, for dilution of inside air to prevent vitiation by body odours and to remove any products of combustion or other contaminants in air and also to provide such thermal environments as will assist in the maintenance of heat balance of the body in order to prevent discomfort and injury to the health of the occupants. Thus, ventilation may be simply defined as a process of removing or supplying air by natural or artificial means to and from a air source or any space.

Good and adequate ventilation is essential to maintain the temperature limits inside the building, to remove the air vitiated by the products of respiration, bacteria and all objectionable or unpleasant odours i.e. very important for providing comfort in buildings. On the other hand, poor ventilation gives rise to a feeling of discomfort to the inhabitants, because it may cause an increase in temperature and humidity leading to perspiration or sweating. The dearth of fresh air may produce nausea, headache,sleepiness, laziness and unattentiveness. It is therefore, essential that sufficient air change in a building must be available so as to remove any smoke, odour etc. to an acceptable level. Apart from the necessity of supplying air for breathing, the quantity of air that is needed for effective ventilation depends on outer conditions such as control on the concentration of bacteria within permissible limits, presence of smoke or odour keeping the humidity within allowable range or other factors. An unventilated room may be subjected to unsuitable living and working conditions because of increased dust amount, excessive content of carbon-dioxide, unsuitable humidity or relatively uncontrollable air movements present.

NECESSITY OF VENTILATION: - The necessity of ventilation arises due to the following reasons.

1) Creation of air movement so as to remove the vitiated air or to replace it by fresh air.
2) Prevention of undue concentration of body odours, fumes, dust and other industrial products.
3) Removal of products of combustion and in some cases the body heat and the heat liberated by the operation of electrical and mechanical equipments.
4) Creation of healthy living conditions by preventing the undue accumulation of carbon dioxide and moisture and depletion of the oxygen content in air.
5) Removal of smoke, odour and foul smell generated or liberated by the occupants.
6) Prevention of accumulation of dust and bacteria carrying particles.
7) Prevention of flammable concentration of gas or vapour in case of industrial buildings.
8) Maintenance of conditions suitable to the contents of the space or avoiding suffocation condition in conference rooms, committee halls, cinema halls etc.

FUNCTIONAL REQUIREMENT OF VENTILATION SYSTEMS: -

From the point of view of human comfort and working conditions, ventilation systems should meet the following requirements.

1) **Air movement or air changes: -** In an enclosed space, where a number of people work or live together, air has to be moved or changed to cause proper ventilation. Air change is the volume of outside air allowed in the room or enclosed space per hour compared to the volume of the room. The minimum and maximum prescribed rates of air change per hour are one and sixty respectively. If the rate of air change is less than one per hour, it will have little effect on ventilation where as if the rate of air change is more than sixty per hour, it may cause discomfort to the occupants owing to high velocities of air. For ventilation system to be effective, five to six air changes per hour are considered to be adequate. Moreover, the air movement is required to be uniform and there should be no formation of pockets of stagnant air at any spot in the room. The following values of air changes are recommended based on maintenance of required oxygen, carbon dioxide and other air quality levels as well as control of body odours when no products of combustion or other contaminants are present in the air.

Schedule of air changes: -

Space to be ventilated	Air change/ hour
Assembly halls/ Auditoria	3-6
Bed rooms/ Living rooms	3-6
Bath rooms/ Toilets	6-12
Cafes/ Restaurants	12-15
Cinemas/ Theaters	6-9
Class rooms	3-6
Factories (medium metal work)	3-6
Garages	12-15
Hospital Wards	3-6
Kitchen (common)	6-9
Kitchen (domestic)	3-6
Laboratories	3-6
Offices	3-6
Corridors/ Passages	1

In naturally ventilated buildings, cross ventilation is effected in order to secure air movement, whereas in case of mechanically ventilated buildings, air movement is obtained either by means of increased rate of fresh air supply or recirculation of a part of air in water. In fact, the rate of air change or air movement depends up on the velocity of incoming fresh air, deposition of inlets, types of activity in the premises as well as number of occupants etc. Generally the air movement is varied both in velocity and direction which is achieved by mechanical means i.e. fans or blowers.

2) **Rate of fresh air supply: -** The quantity of fresh air that is to be supplied to a building is mostly influenced by the specific use of the building. But, since the amount of fresh air required to maintain the CO_2 concentration in air within permissible limits as well as to induct sufficient

oxygen to fulfill respiratory demand is very small and the rate of ventilation for maintaining satisfactory thermal environment of a region varies from season to season, the minimum standards of ventilation are generally based on control of body odour or the removal of products of combustion in accordance with specific requirement.
However, the volume of fresh air requirement per person for the removal of body odour is decided by the availability of air space per person; the volume decreasing with increase in the air space per person. The following table may be taken as a rough guide.

Air space per person (m^3)	**Fresh air supply per person (m^3/ h)**
5.5	28.5
8.5	20.5
11.0 and upwards	17.0

I.S: code recommends the following values of minimum rates of fresh air supply for different types of buildings for habitation.

Types of buildings	Minimum rates of fresh air supply to buildings
1.Office buildings i) Office rooms with space from 5.5 m^3 per person to 11 m^3 per person ii) Lavatories and W.C.s	 28 m^3 / person/ hour to 17 m^3/ person/ hour 2 air changes/ hour
2.School buildings i) Rooms; 5.5 m^3 per person to 8.5 m^3 per person ii) Lavatories and W.C.s	 28 m^3 / person/ hour to 20 m^3/ person/ hour 2 air changes/ hour
3. Hospitals i) Operation theaters ii) Wards	 10 air changes/ hour 3 air changes/ hour
4.Factories and work shops i) Work rooms ii) Lavatories	 23 m^3/ person/ hour 2 air changes/ hour
5.Assembly halls, Canteens, shops, restaurants etc.	28 ^{3} / person/ hour

3)

Effective temperature of air: - It is desirable that the incoming ventilating air is cool in summer and warm in winter, before it enters the room. Whenever, the velocity of incoming air is high, its temperature should not be lower than the room temperature. The temperature difference between the inside and outside is not to exceed 8°C.

In this connection, a term, effective temperature is more useful than the actual temperature as far as human comfort is concerned. This is an index which essentially combines the effect of air movement, humidity and temperature into a single value. It indicates the temperature of air at which a person is likely to experience sensation of some degree of cold or warmth as in quiet fully saturated air (100% humidity) at the same temperature. Therefore, for two rooms having same effective temperature, a person leaving one room and entering the other should not experience any change of temperature even if the actual temperature of the two rooms may be different. Thus it is the effective temperature which is more important than the actual temperature itself. The value of effective temperature is seen to be dependent upon the type of activity, geographical conditions, amount of heat loss from the body and age of occupants etc. The common values of the effective temperature in winter and summer are 2O°C and 22°C respectively.

4) **Humidity of air: -** In view of human comfort, a relative humidity in the range of 30 to 70% at a working temperature of 21°C is considered to be satisfactory. But when work is required to be carried out at high temperature and low humidity, greater air movements are necessary for removing a greater portion of heat from the body. For theaters, a higher value of humidity is considered to be desirable.
5) **Purity or quality of air:** - The ventilating air should be free from impurities, odours, organic matter and inorganic dust. Simultaneously, it should also be free from unhealthy fumes of gases, such as carbon monoxide, carbon dioxide, sulpher dioxide etc. All these impurities depends on the habits of occupants, volume of the room, surrounding conditions, source of ventilating air etc. In order to obtain pure air, the ventilating air should not come from the vicinity of chimneys, kitchens, latrines, urinals, stables etc. or such other sources.

   Generally, air containing less than 0.5mg of suspended impurity per cubic meter and less than 0.5 part per million of sulpher dioxide is considered to be clean enough not requiring any special treatment.

   Air within a room containing more than 0.06% carbon dioxide is considered to be vitiated and it becomes stuffy or unbearable when its concentration approaches the value of 0.09 to 0.1%. Hence, air in habitable rooms should contain carbon dioxide less than these limits. Thus pure air in a building is necessary for sustenance and improvement of health, for perfect combustion of fuel and for preservation of building materials.

METHODS OF VENTILATION: - Generally ventilation involves providing a building with relatively large quantities of outside air in order to improve the overall environment of the building. This may be achieved in one of the following ways:-

1) Natural supply and natural exhaust of air
2) Natural supply and mechanical exhaust of air
3) Mechanical supply and natural exhaust of air
4) Mechanical supply and mechanical exhaust of air

SYSTEMS OF VENTILATION: - Basically, systems of ventilation may be divided into the following two categories;

I. Natural ventilation or Aeration.
II. Artificial or mechanical ventilation.

I. **Natural ventilation: -** In this system, ventilation is effected by elaborate use of doors, windows, ventilators and sky lights etc., where cross ventilation is normally relied to secure air movement. This system of ventilation may be employed where precise control over the air conditions and the rate of air changes is not required. Thus natural ventilation is usually considered suitable for residential buildings and small houses, but it is not suitable for big offices, assembly halls, theaters, auditoriums, large factory, workshops etc. This system is very economical since no equipment is required for keeping the room ventilated; rather desired ventilation is achieved by the provision of sufficient openings exposed to external air. Area of opening generally equal to not less than $1/12^{th}$ of the floor area of the building is considered to be sufficient in view of proper ventilation, where top of such openings are not more than 45cm below the ceiling. Here the rate of ventilation depends upon the following two effects.

a) *Wind action or effect: -* In this case, the rate of ventilation is primarily influenced by the direction and velocity of wind outside as well as the size and disposition of openings. Wind creates a pressure difference, when it blows against a building. This causes the wind to blow from one side to the other if there is an opening. Thus, when wind blows at right angles to one of the rectangular faces of the building, a positive pressure (thrust) is created on the exposed side or windward face and a negative pressure (suction) on the opposite side or leeward face. Whereas, if the wind direction is at 45° to one of the faces, it results in positive pressure on the two windward faces and negative pressure on the two leeward faces. These effects are shown in the following figure.

FIGURE

The rate at which air changes or air flow takes place totally depends upon the pressure difference between the inside and outside. So while designing a system of natural ventilation, it is aimed to make maximum use of available wind forces which are not constant being dependent on the speed and direction of wind, resulting in ventilation that is likely to be variable in quantity. However, for the design purposes, the wind way be assumed to come from any direction within 45°of the direction of prevailing wind. In case of pitched roof, the pressure also depends upon the pitch of the roof where the roof pressure in general are negative except the windward side of a roof having slope greater than 30°.

b) *Stack effect: -* In this case, the rate of ventilation is affected by the convection effects arising from the temperature or vapour pressure difference or both, between inside and outside of the room and the difference of height between the outlet and inlet openings. When the temperature of air inside is higher than that of the outside, warmer air rises up and passes through the openings located in the upper part of the building. Simultaneously, the incoming cooler air from outside through the openings at lower elevation replaces it. Here the rate of air flow in addition to the temperature or preesure difference and height difference, also depends upon the ratio between the areas of two openings. Ventilation due to stack effect is illustrated in fig. -----.

FIGURE

c) <u>Ventilation due to both the effects or combined effect: </u>- When both the wind and stack effects exist, it is proper to calculate each effect acting independently under conditions ideal to it and then apply a correction percentage. But, in residential buildings, usually the ventilation due to stack effect is insignificant and hence neglected. Thus, where both wind and stack effect are prevalent, the wind pressure effect may be assumed to be predominant. For unequal areas of inlet and outlet openings, the magnitude of area 'A' is taken to be the smaller area and the volume of air flow will be increased by the percentage as below.

Ratio of outlet to inlet area of openings or vice versa	Increase in percentage (approximate)
1.0	Zero
1.5	18
2.0	27
3.0	34
4.0	37
5.0	38
6.0	38

N.B.: - For other ratios between the areas of openings, the percentage can be interpolated from the above table.

GENERAL RULES FOR NATURAL VENTILATION: - The following consideration and rules are to be followed for natural ventilation in buildings.

1) Inlet openings in a building should be well distributed and located in the windward side at a low level where as the outlet openings should be located on the leeward side near the top, so that incoming air stream passes over the occupants. Otherwise, inlet and outlet openings at high levels may only clear the top air without producing air movement at the level of occupancy. But where the outlet also serves as inlets, they shall be located at the same level.
2) Inlet and outlet openings should be preferably of equal size for greatest air flow, but when the outlet is in the form of a roof opening, the inlet should be larger in size.
3) Where the stream of wind is quite constant and dependable, the openings may be readily arranged to take full advantage of the wind. But, where the wind direction is quite variable, the openings are to be so arranged that as far as possible there are approximately equal areas on all sides and the openings are located at the same levels. Thus, irrespective of wind direction, there are always some openings directly exposed to wind pressure and others to air suction so that effective movement through buildings is assured.
4) Inlet openings should not, as far as possible, be obstructed by adjoining buildings, trees, sign boards or other obstructions or by partitions inside the path of air flow.
5) Increased height of the room gives better ventilation due to stack effect. The long narrow room should be ventilated by providing suitable openings in short sides.
6) Natural ventilation by stack effect occurs when air inside a building is at a different temperature than air outside. Generally, the outside air being cooler than inside air, the cooler air enters

from the bottom and after becoming hot during its stay in the building, leaves through the openings at higher level. Therefore, it is advantageous to provide ventilators as close to the ceiling as possible. Ventilators can also provided in roofs as cowl, vent pipe, covered roof and ridge vent. The efficiency of roof ventilation depends on their location, wind direction and the height of the building.

7) The ventilation through windows can be improved by using them in combination with a radiator deflector and exhaust duct.
8) For cross ventilation, the position of outlet should be just opposite to inlets. The openings over the doors of back walls create good conditions for cross ventilation.
9) Windows of living rooms should either open directly to an open space or to an unobstructed facing on open space. In places, where building sites are restricted, open space may be created in the buildings by providing adequate courtyards.
10) The rate of air change in a building mainly depends on the design of opening locations(inlet and outlets) as well as temperature difference between the inside and outside air. Where the space is to be used for burning gas or fuel, enough quantity of air should be available by natural ventilation for meeting the demands of burning and comfortable living.

II. **Mechanical or artificial ventilation: -** Artificial or mechanical ventilation involve the use of some mechanical equipment for effective air circulation. It is suitable under those circumstances where satisfactory standard of ventilation in respect of air quantity, quality or controllability cannot be obtained by natural means. Though this system is somewhat costly, yet it results in considerable increase in the efficiency of the persons under the command of the system.

In this system of ventilation, the outside air is supplied into the building either by positive ventilation or by infiltration by reduction of pressure inside due to exhaust of air or by a combination of positive ventilation and exhaust of air. The supply of outside air by means of a mechanical device, such as a fan, is termed as positive ventilation, where as the removal of air and its disposal to outside by means of such devices is termed as exhaust of air. Positive ventilation may be provided by centrally located supply fans which are usually of the centrifugal type or sometimes axial flow type, whereas for exhaust of air, wall or roof-located exhaust fans of propeller type are normally used. This application requires use of some mechanical arrangement like duct work for a wide range of satisfactory and quiet operation against high pressures.

Of course, a mechanical system is capable of meeting the requirements of air quality and quantity with regard to humidity, temperature etc. and producing comfortable conditions at all times throughout the year. Generally this system is considered as desirable in case of enclosures occupied by more than 50 persons where the space per occupant is less than 3cum. Hence this system is adopted for big offices, banks, assembly halls, auditoriums, theaters, large factories, workshops, places of entertainment etc.

The following types of mechanical or artificial ventilations are in common use.

a) Extraction or exhaust system
b) Supply or plenum system
c) Balanced or combination of extraction and plenum systems

d) Air-conditioning

a) ***Extraction or exhaust system: -*** This system is based on the creation of partial volume inside the building by exhausting the vitiated inside air by means of propeller type fans. The extraction of air from inside results in the flow of fresh air from outside to inside through the openings. Such fans for exhaust are installed at suitable places in the outside walls or roofs which are further connected to different rooms through a system of duct-work.

This exhaust system is best suited to situations where it is essential to create an air flow towards the ventilated rooms such as in kitchens, lavatories, industrial plants etc. It is useful for removing smoke, odours, fumes, dust etc. from the above mentioned space. Here the ducts are to be placed near the place of formation of smoke, fumes, odours, dust etc.

b) ***Supply or plenum system: -*** In this system, fresh air is forced into the room whereas the vitiated air is allowed to leave through the ventilators without any special provision for its removal. The air inlet is selected on that side of building where the air is purest. The incoming air which is mechanically forced into the room is passed through a fine gauge screen or filter and a fine stream of water may be impugned in the path of the incoming air for removal of all the mechanical impurities present in it. In addition this also results in cooling of air in summer. Further, at this point air may be disinfected by introduction of ozone at inlet point. In winter, the air may be heated by forcing it through a battery of hot water tubes before being forced into the room. Thus by this system of mechanical ventilation, it is possible to control the quality, humidity and temperature of the incoming air.

This ventilation by plenum process could be downward or upward. In the downward case, the incoming air is allowed to enter at the ceiling height which is taken out through the outlets situated at floor level. But in upward ventilation, the fresh air is allowed to enter at the floor level and moves out through the outlets provided at the ceiling level. This ventilation system is costly and is used for factories, conference halls, theaters, and big offices etc. where the distribution of this air is done through properly formed sheet iron ducts with well dimensioned branches.

c)***Combined or balanced system: -*** This system is a combination of both the exhaust and plenum system which makes use of fans for supply and extraction of air through input fans and exhaust fans. It ensures full control over the air movement so as to attain desired conditions and is adopted where accurate performance is intended. In majority cases, only about seventy-five percentage of the quantity of air supplied is required to be extracted so that positive pressure is maintained within the rooms. This measure is essential to prevent the entry of hot air when the doors are open as well as infiltration of dust and air borne contaminants. Of course, this system is suitable where the delivery of fresh air is either sluggish or where it is desired to discharge the vitiated air containing obnoxious fumes such as from kitchens, latrines or various manufacturing processes in specially isolated areas. However, this system involves the recirculation of air.

d) ***Air-conditioning: -*** This is the most effective system of artificial ventilation, in which provision is there for heating or cooling, humidityfying or dehumidityfying, filtration etc. of the air to create most comfortable working and health condition to meet the necessity of industrial processes, efficient functioning of commercial premises etc. thus meeting the requirements of conditioned space.

Removal of heat gains: - Ventilation air is also used to remove excess heat gains from the buildings. Two types of heat gains are involved; sensible heat and latent heat. Of course, sensible heat gains result from solar radiation, conduction from outside to inside during hot weather, warm ventilation air, lighting, electrical machinery and equipments, people and industrial processes. Such heat gains may affect the temperature of the air and the building construction. On the other hand, latent heat gains results from the exhaled and evaporated moisture from people, moisture given out from the industrial processes and humidifiers. These heat gains actually do not directly affect the temperature of the surroundings but takes the from of transfer of moisture. They can be measured in terms of weight of water vapours transferred or its latent heat equivalent in Watts.

Removal of sensible heat gains to control room air temperature is carried out by cooling the ventilation supply air and increasing the air change rate to nearly 20 changes per hour. The following figure shows this scheme. Of course, the temperature and moisture content of the supply air increases as it absorbs the sensible and latent heat gains until it reaches the desired room condition. The net sensible heat flow will be into the room in summer and in the outward direction in winter.

FIGURE

The rooms that are isolated from the exterior building surfaces have internal heat gains from the people and electrical equipments, producing a net heat gain throughout the year. Then the heat balance is as follows:

Net sensible heat flow from the room = Sensible heat absorbed by ventilation air.

Volume of air required for sensible heat and latent heat: - As sensible heat is given off by different sources and latent heat may be gained from various processes, the volume of air required is calculated by using both the sensible heat or latent heat gain as the basis. The larger of the two figures obtained should be used in actual practice.

A) *Volume of air required for removing sensible heat*: - When the amount of sensible heat given off by different sources, namely, the sun, the manufacturing processes, machinery, occupants and other sources is known and a suitable value for the allowable temperature rise could be assumed, the volume of outside air to be provided for removing sensible heat may be calculated from

$$Q_1 = \frac{2.9768 K_s}{t}$$

where Q_1 = Quantity of air in m^3/h

K_s = Sensible heat gained in Watt and

and t = Allowable temp. rise in °C

B) *Volume of air required for removing latent heat: -* If the latent heat gained from the manufacturing processes and occupants is also known and a suitable value for the allowable rise in vapour pressure is assumed

$Q_2 = \frac{4127.26 \text{ X } K_l}{h}$

where Q_2 = Quantity of air in m^3/h

K_l = Latent heat gained in watt and

h = Allowable vapour pressure difference in mm of mercury.

However, in majority of the cases, the sensible heat gain far exceeds the latent heat gain so that the amount of outside air to be drawn by the ventilating equipment in most cases is calculated on the basis of sensible heat only.

DETERMINATION OF RATE OF VENTILATION: -

A) Natural ventilation: - The rate of natural ventilation is difficult to measure as it varies from time to time, depending on wind action and stack effect through out the year. The amount of outside air through windows and other openings depend upon the direction and velocity of outside wind (wind action) and/ or convection effects arising from temperature or vapour pressure differences (or both) between inside and outside of the building (stack effect).

Rate of air flow in wind effect: - In an isolated enclosure in which opening is provided in each of the two opposite walls, the rate of air flow through an opening due to wind blowing on the wall containing the opening is given by the expression **Q = KAV**

where Q = the rate of air flow, in m^3/h

K = Coefficient of effectiveness

A = Area of smaller opening, in m^3 and

V = wind speed in m/h

The coefficient of effectiveness K depends upon the direction of wind relative to the opening and on the ratio between the areas of the two openings. It is maximum when the wind blows directly on the opening and it increases with the relative size of the larger opening. Fig._____ gives the values of K.

FIGURE

Rate of air flow due to stack effect: - The rate of air flow due to convection effects arising from the temperature difference between inside and outside is given by the following formula

$$\mathbf{Q = 640C_e.A.\sqrt{h(t_i \sim t_o)}}$$

where Q = Rate of air flow in m^3/hr

C_e= Coefficient of effectiveness

= 0.65 for general condition

= 0.50 for unfavorable conditions

A = Free area of inlet openings in m^2

h = Vertical height difference between the inlet and outlet in mtr.

t_i = average temperature of inside air in °C

t_o = average temperature of outside air in °C

When the areas of inlet and outlet openings are unequal, 'A' given in the equation of previous sections is taken as the smaller area and the volume of air is increased according to the percentage given in the following figure

FIGURE

When both faces (wind and thermal) act together in the same direction, even without interference, the resulting air flow is not equal to the two flows estimated separately. Rather flow through any opening may be taken as proportional to the square root of the sum of the two heads acting on that opening.

Of course, wind velocity and direction, outdoor temperature and indoor distribution cannot be predicted with certainty and undue refinement in calculation is not justified. However, a simple method is to calculate the sum of two flows produced by each force separately. Then using the ratio of the flow produced by the thermal forces to the above said sum, the actual flow due to the combined forces can be approximated from the following figure. When the two flows are equal, the actual flow is about 30% greater than the flow caused by either force acting independently. Besides, judgment is necessary for proper location of openings in a building especially in the roof where heat, smoke and fumes are to be removed. Usually windward monitor openings should be closed but if wind is so feeble that temperature head can overcome it, all openings may be opened.

FIGURE

(B) Mechanical ventilation: - The volume of outside air by positive ventilation can be measured by using proper instruments such as properly calibrated anemometer, velocity meter and Pitot tube. For measuring the average velocity of air flow, it is necessary to make a traverse of the instrument over the cross sectional area of the inlet openings or ducts and obtain the average velocity from these results. Then the volume of air is given by

Q = AV

where Q = Volume of air in m^3/h

A = Free area of inlet opening or ducts in $m^2$and

V = Average velocity of air in m/h

But when the ventilation is achieved only by exhaust of air, the volume of exhaust air is measured in the same manner as in the case of positive ventilation by measurement of air velocity and area of exhaust ducts or openings and multiplying one with the other.

Combined effect of different methods of ventilation: - When combination of two or more methods of general ventilation is used, the total rate of ventilation is reckoned as the highest of the following three: -

a) 1.25 times the rate of natural ventilation
b) Rate of positive ventilation and
c) Rate of exhaust of air.

Example-1. *A room 15m x 12m x 4m high is to have a ventilation rate of six air changes per hour. Air enters from a duct at a velocity of 12m/ sec. Find the flow rate of air volume to the room and the dimension of the square duct required.*

Solution: - The rate of air flow is given by

$$Q = \frac{N_{air\ changes}}{Hour} \times \frac{V\ m^3}{air\ change} \times \frac{1\ hour}{3600s} \quad \text{where 1 air change = room volume V } m^3$$

Hence, $Q = \frac{NV}{3600}\ m^3 / s = \frac{6x15x12x4}{3600} = 1.2\ m^3 / s$

Also, Q m^3 / s = Cross sectional area of the duct, *A* , m^2 x air velocity, *v*, m/s

Therefore, A = Q/*v* = 1.2/12 = 0.1 m^2

If each side of the squre duct = *x* m, then area $A = x^2$ or $x = \sqrt{A} = \sqrt{0.1} = 0.316$ m

Rate of flow of air volume is 1.2 m^3 /s and the duct size required is 0.316 m x 0.316m.

Example-2. *A lecturer theater has dimensions 35m x 25m x 4m high and has 60 occupants. For each person, 15 ltrs/s of fresh air and 50 ltrs/s of re-circulated air are supplied to the theatre for each person and a singe-duct ventilation system is used. If 10% of the supply volume leaks out of the theatre, calculate the room air change rate and the air volume flow rate in each duct.*

Solution:- Supply air quantity per person = (15 +50) ltrs/s x 1m^3 / 1000 ltr = 0.065 m^3 / s

Hence Q = 0.065 x 60 = 3.9 m^3 / s.

Now, $Q = \frac{NV}{3600}$ or $N = \frac{3600\ Q}{V} = \frac{3600\ x\ 3.9}{35\ x 25 x4}$ = 4.01 air changes per hour

The leakage from the theatre is,

Q_L = 10% of Q = 0.1 x 3.9 = 0.39 m^3 / s

The quantity of air extracted from the system is,

$Q_E = Q - Q_L = 3.9\text{-}0.39 = 3.51\ m^3 /s$

The quantity of fresh air entering the duct work is

$Q_F = \frac{15x60}{1000} = 0.9\ m^3/ s$

The quantity of re-circulated air is,

$Q_L = Q_L - Q_L = 3.9 – 0.9 = 3\ m^3 / s$

The exhaust air quantity is

$Q_{EX} = Q_E – Q_R = 3.51 – 3 = 0.51\ m^3 / s$

Example-3. *There are 30 people in a gymnasium, each producing carbon dioxide (CO_2)at a rate of 15 x $10^{-6}$$m^3$/s. If the maximum CO_2 level is not to exceed 0.3%, find the air supply rate necessary. The CO_2 concentration of the out door air is 0.1%.*

Solution :- The rate of air supply Q = $\frac{P}{C_R - C_S}$ = $\frac{30\ x\ 15\ x\ 10^{-6}}{(0.3-0.1)x10^{-2}}$ = 0.225 m^3/ s

where P = carbon dioxide produced.

Example-4. *A room has a heat loss in winter of 12 kW and a supply air flow rate of 2.5 m^3/s. If the room air temperature is to be maintained at 2°C, calculate the supply air temperature to be used.*

Solution: Sensible heat loss K_s = 12000 W

Rate of flow of supply air Q_1 = 2.5 m^3/s = 2.5 x 3600 m^3/h

If t = temperature drop in *°C* ,

Then Q_1 = $\frac{2.9768\ K_S}{t}$ or t = $\frac{2.9768\ K_S}{Q_1}$ = $\frac{2.9768\ x\ 12000}{2.5\ x\ 3600}$ = 3.97 *°C*

Supply air temperature = 20 + 3.97 = 23.97 ≈ 24 *°C.*

MECHANICAL SERVICES: -

Mechanical services are required for the transportation of man and material around and in between the buildings or different parts of a building. This is accomplished by the use of mechanical transportation systems which is of considerable importance in view of the degree of satisfactory service required. These are permanently installed energy consuming systems that needs the designer's attention at the early stages of building design. Standards of service should be commensurate with the requirements of the final user and provisions of access for the disabled persons. Of course, convenient, cost effectiveness and energy efficient transportations are always in demand. Even if the energy consumption of these systems is low, but their electrical power requirement is significant for short periods. Moreover, integration of these systems in other services such as fire protection, means of escape and correct maintenance are of paramount importance. Lifts, escalators and elevators are most commonly used mechanical services in building.

Lifts: - Generally lifts are meant for vertical transportation in buildings and may be designed as appliance designed to carry persons or materials between two or more levels in a vertical or substantially vertical direction by means of a guide car or platform. They may be classified as passenger lifts, goods lifts, hospital lifts, service lifts etc. Passenger lifts are commonly provided for buildings with more than four storeys. However, if wheel chair movement is needed, provision of lift may be made for buildings having less storeys also. The number of lifts and their capacity depends upon the floor area and the number of floors to be handled. Normally as per minimum standard of service one lift is to be provided for each four storeys, with a maximum walking distance of 45m between the work stations and lift lobby.

Lifts with different capacities are available in the market, ranging from 4-20 persons. Two smaller lifts provide a better service than a single large lift because the later would run only partly loaded during major portion of the day with a resulting decrease in efficiency and increased running cost. On other hand, one of the smaller lifts could be kept idle to reduce cost during off peak hours. Thus the advantages of using smaller lifts outweigh the additional capital cost involved. For designing lifts the weight of a person is taken 68kg.

Figure ------ shows the cross section of a lift room. It consists of the following components.

- A lift car moving on rails.
- Suspension ropes
- Counter height on pulleys
- A machine room with winding machine
- A lift pit with buffer for car
- Landing doors

The lift well usually extends from 1.6 to 2.6 m below the bottom loading. A machine room of suitable size is provided at the top and opening height of 2m is provided for entry of people at each level.

FIGURE: -

Lifts can be either electric traction type or hydraulic type. Electric traction is used exclusively in tall buildings where as hydraulic lifts are generally used for low-rise freight passenger service which rise upto about 6 storeys. Hydraulically operated lifts have the advantages of very quite operation and low running costs.

The lift car is a cage of light material supported on a structural frame, to the top of which the wire ropes are attached. The ropes raise and lower the car in the shaft. They pass over a grooved miter driven sheave and are fastened to the counter weights. The path of both the counter weights and the car are controlled by separate sets of T-shaped guide rails. The control and operation machinery may be located in a pent house above the shaft or in the basement. Safety springs or buffers are placed in the pit to bring the car or counter weight to a safe stop. For lifts service more than 3 floors should have provision for ventilating smoke and hot gases from the hoist ways to the outer air in case of fire. Vent area should be at least 3.5 % of the hoist way cross sectional area and such vents may be located in the encloser just below the upper most floors, with direct openings to the outside or with non combustible duct connection to the outside.

The car speed is determined by travel distance and standard of service. Buildings having more than 15 storeys may have high speed lifts that do not stop at the first 10 storeys. Car speeds for various travel distances are shown in the following table.

Table- Design lift car speeds

Floors	**Car speed (m/s)**
4	0.75
9	2
15	3
Over 15	5 -7

Again the car speed is chosen such that the driving motor can be run at full speed for much of the running time to maximize the efficiency of power consumption, because starting and accelerating power is greater than steady speed energy use. Also deceleration during breaking dissipriates the momentum gained by the car and the heat generated due to the friction of the counter weight in lost to the atmosphere. However, the overall speed of operation is determined by the acceleration time, breaking time, contact speed (maximum car speed),speed of door opening, floor level accuracy required as well as switch timing etc.

Computer controlled installations can be programmed to maximize the performance of lifts in a particular direction at different times of the day. Each lift can be parked at an appropriate level to minimize waiting time. In addition the automatic control system should function in an upward collecting and downward collecting mode. Requests for service made sufficiently early at a lobby cause the car in that shaft to break its original journey instructions and stop. Computer controls are used to optimize the overall performance of the installation by causing the nearest car stop so as to minimize power consumption.

Good lift is primarily designed for the transport of goods but which may carry a lift attendant or other persons necessary for loading and unloading of goods. These lifts travel at a maximum speed of 1m/s and have full width door sometimes at each end of the car accurate floor leveling to within 5mm may be provided to facilitate smooth passage of trolleys carrying fragile goods, fluids or patients in a hospital. Although passengers can use good lifts but their service is low.

Hospital lift is normally installed in a hospital/ dispensary/ clinic and designed to accommodate one number bed/ stretcher along its depth, with sufficient space around to carry a minimum of three attendants in addition to lift operator.

Service lift (   ) is a small good lift with a car that moves in guides in a substantially vertical direction having net floor area of 1 to 1.2m^2 total inside height 1.25 to 1.4 m and capacity not exceeding 250-260kg, whether or not provided with fixed or removable shelves and is exclusively used for carrying materials but not to carry person. The serving level may be 0.85m above floor level to coincide with the working plane and documents, goods or food are carried at a speed up to 0.5m/s

Firemen's lift: - In the event of a fire, the fire detector and alarm system signal causes all the lifts to run to the ground floor. Where the building extends out of the reach of conventional fire-fighting turn table ladders on vehicle at least one of the lifts is designated as the fireman's lift. It is provided for all buildings more than 24 meters in height. The platform area and capacity of such lifts should be 1.45m^2 and 55okg (8 persons) respectively and should be capable of reaching the top of the building within 1 minute. It is to have power operated doors not less than 0.8m clear opening that are arranged to remain open at any floor. Preferably, it should have an overriding fire control switch at the fire control floor level, to bring the lift under the manual control of the fire fighting squad. The spatiality of this switch is that it brings the lift immediately to the fire control floor, which is the entrance level of fire men. At that time all other controls are made inoperative.

The outline dimensions of machines room, pit depth, total headroom, overhead distance and sill are specified in table --------- to ---------------- as follows:

PASSENGER LIFT

LOAD		CAR INSIDE		LIFT WELL		ENTRANCE
PERSONS	KG	A	B	C	D	E
4	272	1100	700	1900	1300	800
6	408	1100	1000	1900	1600	800
8	544	1300	1100	1900	1900	800
10	680	1350	1300	1900	2100	800
13	884	2000	1100	2500	1900	900

16	1088	2000	1300	2500	2100	1000
20	1360	2000	1550	2500	2400	1000

N.B: -

1) The total head room is to be calculated on the basis of car height of 2.2m.

2) For normally operated doors, clear entrance will be reduced by the amount of projection of handle on the landing door.

3) Four and six passenger lifts are generally limited to a speed of 1m/s.

4) All dimensions are in mm.

GOOD LIFTS

LOAD	CAR INSIDE		LIFT WELL		ENTRANCE
KG	A	B	C	D	E
500	1100	1200	1900	1500	1100
1000	1400	1800	2300	2100	1400
1500	1700	2000	2600	2300	1700
2000	1700	2500	2600	2800	2000
2500	2000	2500	2900	2800	2000
3000	2000	3000	2900	3300	2000
4000	2500	3000	3400	3300	2500
5000	2500	3600	3400	3900	2500

N.B: -

1) The width of the machine room shall be equal to the width of lift well ‘c’ subject to a minimum of 2500mm

2) The total head room is to be calculated on the basis of car height of 2.2m.

3) Clear entrance width is based on vertical lifting car door and vertical bi-passing doors. For collapsible mid bar doors, the clear entrance width will reduced by 200mm or over depending on the lift design.

HOSPITAL LIFT

LOAD		CAR INSIDE		LIFT WELL		ENTRANCE
PERSONS	KG	A	B	C	D	E
15	1020	950	2400	1700	3000	800
20	1360	1300	2400	2200	3000	1200
26	1768	1600	2400	2350	3000	1200

N.B: -

1) The total head room is to be calculated on the basis of car height of 2.2m.

2) For normally operated doors, clear entrance will be reduced by the amount of projection of handle on the landing door.

SERVICE LIFTS

LOAD		CAR INSIDE		LIFT WELL		ENTRANCE
KG	A	B	H	C	D	E
100	700	700	800	1200	900	700
150	800	800	900	1300	1000	800
200	900	900	1000	1400	1100	900
250	100	1000	1200	1500	1200	1000

N.B: - Entrance width E is based on assumption of provision of vertical bi-passing doors (no car door is normally provided.

Escalators: - Escalators are powered stairs or electrically operated moving stairs. These are primarily used where large number of passengers form surges at discharge times from offices, commercial complexes railway stations or airport terminals. In exhibitions big departmental stores and the like, escalators encourage the people to move freely. Thus they are capable of handling heavy traffic of persons between the floors having continuous operation requiring no operators and are deemed essential where the movement of people in large numbers at a controlled rate in the minimum of space is involved. Escalators consume less power compared to lifts and provide suitable transport for all ages lader or unlader. Also their operating direction can be made reversible to correspond to peak travel times.

The escalators are in the form of an inclined bridge spanning between the floors. The essential components of an escalators include a structural steel frame work supporting an endless belt carrying steps and handrails. At the lower end, a pair of sprocket wheels is provided while at the upper end a matching pair of sprocket wheels and a worm gear driven machine is provided. Two precision made roller chains travel over the sprockets pulling the endless belt of steps around the steps which move on an accurately made set of tracks attached to the frame with each step supported on four resilient rollers.

Normally tread widths range from 0.6 to 1.05m and the angle of inclination is not to be in excess of 30°from the horizontal excepting the case of a vertical rise less than 6m and speed not exceeding 0.5m/s an angle up to 35°may be permitted. However, speeds of up to 0.75m/s are permissible as this is the maximum safe entry and exist velocity.

The speed of escalators is generally in the range of 25 to 40minute. For a given speed of travel, the width of steps determines its capacity. Escalators are generally installed in pairs – one for downward movement and another for upward movement. These units may be arranged either parallel or cris-erros pattern, the later being more compact and reduces the walking distance between stairs at various floors to a minimum.

FIGURE ------

As the escalators operate at a constant speed, serve only two levels and have known maximum capacity, the traffic handled can be studied easily. For normal peak periods, the recommended handling capacities for design purposes may be taken as 3200 to 6400 persons per hour depending on the width of the escalators.

Each escalators is generally provided with an electrically released mechanically applied brake capable of stopping the up or down travelling escalators within rated load. This brake is located either on the driving machine or in the main drive shaft.

Elevators and conveyors: -

Elevators and conveyors or endless belt are normally used for transporting purposes. While the elevators are mainly used for vertical transportation of men and material, conveyors are used for horizontal transportation of materials or goods in different terrain., Elevators are generally considered economical only for such activities as raising of bricks or roofing tiles to the fixing position. Most elevators consists of an endless belt with raised transverse stripes at suitable spacing's against which the materials to be raised up to a maximum of 7m height can be placed. Conveyors are generally considered economical only on large sites where huge quantities of materials are to be handled and they may be two types – belt conveyors or bucket conveyors.

They can move at high speeds, have short chaises and strong dumping bodies. Dumping of materials can be in the front or at the back. The body takes up upside vertical position while dumping. Loading transporting and dumping can be done in quick succession. The engine can be diesel/ petrol operated or electrically powered.

CHAPTER-6

CONSTRUCTION AND EARTHMOVING EQUIPMENTS

6.0 – INTRODUCTION:-

Construction is the ultimate goal of any infrastructure engineering design and transformation of a design into construction is accomplished by men and machines. The machines constitute vital resource of a construction project and play a pivotal role in transferring a project plan into reality. With the evolution of machines, there is a continuing transformation of construction process of the projects. One of the most obvious problems in constructing a project is the handling of bulky as well as heavy construction/ building materials; the solution of these problems being provided by the machines. Proper selection and utilization of appropriate machines is very important in this context. Of course, unique act of production conditions directly affect equipment management and the very concept of machines utilization aims at economically matching machine capability to specific project construction requirements. As the array of useful equipments expand, the importance of careful planning and excavation of construction operations increases.

6.1 PLANNING AND SELECTION OF CONSTRUCTION EQUIPMENTS.

6.1.1 Planning of construction equipments:-

Technological advancements have greatly enhanced our ability to formulate equipment planning and construction decisions but one must first have an understanding of machine capabilities and how to properly apply those capabilities to construction challenges. Any construction equipment is specifically designed by the manufacturer to perform certain mechanical operations. A machine is only economical if used in the proper manner and in the environment for which it has the mechanical capability to engage. The task of the project planner/ estimator or the engineer on the job is to match the right machine or combination of machines to the job at hand. Considering individual tasks, the quality of performance is measured by matching the equipment spreads production against its cost. Of course, production is the work done; it can be the volume or weight of the material moved, the number of pieces of materials cut, the distance travelled or any other similar measurements of progress.

For estimating the equipment component of project cost, determination of machine productivity is the first and foremost necessity. Whereas productivity is governed by engineering fundamentals and management ability, each level of productivity has a corresponding cost associated with the effort expended. The expenses that a firm experiences through machine ownership and use as well as the method of analyzing such costs are very important.

Although each major type of equipment has different operational characteristics, it is not always obvious which machine is best for a particular project task. After studying the plans and specifications, visiting the project site and performing a quantity take off, the planner may be able to visualize how best the specific pieces of equipment may be employed to accomplish the work.

Sometimes, there are alternative methods that yield the same end result; for example, excavating with scrapers or top-loading with drag line. But to answer which is the most economical method of attack for the given project conditions, the planner is required to develop an initial plan for employment of scrapers and then calculates their production rate and the subsequent cost. The same process may be followed for the top-load operation. The type of equipments that has the lowest estimated total cost, including mobilization of the machines to the site, may be selected for the job.

In order to effectively carryout such analysis, the planner has to consider both machine capability and methods of employment. In developing suitable equipment employment techniques, the planner must have knowledge of the material quantities involved. The quantity take-off is strongly influenced by the equipment and methods under consideration. If there is possibility of using different equipments and methods as an excavation progresses, then it is necessary to divide the quantity take-off in a manner that is compatible with the proposed equipment utilization. While performing quantity take-off, one must calculate the quantities so that groups of similar materials (dry earth, wet earth, rock etc.) are easily accessed. Thus, it is not just a question of estimating the total quantity of rock or the total quantity of materials to be excavated, rather, all factors, that affect equipment performance and choice of construction methods, such as locations of water table, clay or sand seams, site dimensions, depth of excavation as well as compaction requirements, must be considered in making the quantity take-off.

For successful completion of each individual project, all possible approaches to the construction process have to be carefully studied. One has to use project preplanning, risk identification and quantification techniques in approaching the work. No two projects are exactly alike; therefore, it is important that the planner begins each new project with a completely open mind and reviews all possible options. In addition to it, the machines are being constantly improved and the new equipments are being introduced.

There are two types of identification/ classification for heavy equipments i. e. functional identification or operational identification. For example, a bulldozer, used to push a stock pile of material, could be identified as a support machine for an aggregate production plant, a grouping that could also include front-end loaders. The bulldozer could however, be functionally classified as excavator. However, a combination of functional and operational groupings may be used and it is the job of the estimator and the field personnel to match equipment to project situations.

6.1.2**- Selection of construction equipments**

Proper selection of equipments for a construction project is of paramount importance for its speedy and economical completion. In view of the large variety of equipments being manufactured now-a-days, the problem of equipments selection has become more complicated. For proper selection of equipments, a considerable experience in the operation and maintenance in the field is essential. Records of previous projects in respect of operation, maintenance and actual output obtained under comparable conditions greatly helps in taking decision for equipment selection.

Following are the main points which are to be considered in the process of equipment selection.

1) Suitability for job conditions:- The equipments should meet the requirement of the work, climate and working conditions.
2) Size of the equipments: - Size of the equipments should be compatible with other matching units. A larger size equipment will either remain idle for most of the time or shall work on part loads leading to an increase of cost of production. On the other hand, a smaller size equipment may not be able to work with the matching equipments for which other equipments will have to remain idle or are to be allowed to work on part loads and hence uneconomical.
3) Standardization:- It is desirable to have same type and size of equipments in a project because it means lesser spare parts' reverse, more interchangeability of parts if required; easy understanding for operators, better maintenance and repair by mechanics as they become expert by handling one type of equipment.
4) Ease of availability in the market:- The equipment which is easily available in the market is to be purchased. Again, it should also be ensured that the equipments is of repute and is likely to be continued to be manufactured in future also. This is necessary for future standardization and ensuring spare parts supply. Also it is easy to dispose off such equipment after completion of project.
5) Ease of availability of spare parts: - While selecting a particular type or make of equipment, the availability of spare parts at reasonable price throughout the working life of the equipment should be ensured. It should also be ensured that the downtime of the equipment for want of spare parts may not be more. This is very important in case of imported equipments.
6) Multipurpose equipments: - Certain type of equipment is not fully utilized in respect of any particular function. In such a case, they should be capable of performing more than one function. For example, excavator with wheel loader bucket arrangement or with rock breaker attachment.
7) Availability of know-how: - The equipments selected should be satisfactorily handled by available operators and mechanics. A sophisticated equipment capable of giving excellent performance will be less effective, if it will be difficult to handle and maintain it through available know-how.
8) Use in future projects: - While selecting an equipment, which is to complete only a part of their useful life in a project, it should be kept in view that the equipment do not become obsolete and can be used in future projects.
9) Economic aspects:-During selection of an equipment, it should be ensured that the cost of unit production is kept as low as possible.
10) Reliability of the equipment: - Equipment selected for any particular project must be reliable one for the intended purpose.
11) After sale service support:- Service support should be available in the area of the project where equipment is to be used and that is why service after sales is a major criteria for selection of equipment.

12) Satisfaction of operational requirements: - The equipment selected should be easy to operate and maintain familiar to the operator and fuel economic.
13) Investigation of past performance: - If the equipment to be purchased is of new make and model, it is imperative to enquire about its performance from other users who are using the same make and model.
14) Versatility of the equipment: - It means a machine is capable of being used for more than one function and so can be used for many jobs. The versatility of the equipment should be given due priority because it promises extra profit from two directions;
    i) Allows one machine to do the job of several machines and thus cutting into ownership and operating costs associated with additional plant and labour.
    ii) It increases utilization, which means a machine earns money when it might otherwisely be idle.

    To facilitate multiple functions of machines, now-a –days, attachments can be fitted or changed quickly with the help of couplers.
15) Miscellaneous criteria:-Besides there are certain other criteria such as the size and number should be such that the full life of the equipment is utilized in the project with very little residuals. Reputation of the manufacturer as well as warranty or guarantee offered by manufacturer should be taken into account. Due considerations must also be given to the use of standard components in the equipment and the adequacy of drive mechanism or power of the prime mover.

    Thus, a balance between the reliability, investment cost and operating cost should be found because a policy of selecting only the lowest priced equipment may often lead to overall higher costs.

6.2- **EARTHMOVING EQUIPMENTS:-**

The equipments that are exclusively used for excavating and carrying earth or earthen materials are termed as earthmoving equipments. A wide range of earth excavating equipments are commercially available in the market, the most common among them are drag line, tractor, bull dozer, power shovel etc. None of these machines are designed for a particular set of conditions only; rather, they are designed to suit varying conditions of work, as discussed in the following sections.

Earthmoving equipments can be broadly classified into following two types:

i) Production equipments: - Equipments used for digging and moving the material to the site of construction (such as dam, irrigation project, road project, mining or building construction project etc.) or to the crushing plant.
ii) Service equipment: - These equipments help the main production equipment to achieve optimum capacity.

    For small works dozer can be used as productive equipment. Motor grader is usually used as production equipment in road construction projects where as it is used as service equipment for keeping proper gradient of service roads for dams, mines and quarries.

6.2.1- Drag lines:-

The drag line is a versatile equipment capable of wide range of operations. Wide range of materials starting from soft to medium hard materials can be handled by this machine. It derives its name from its prominent operation of dragging the bucket against the material to be excavated or dug. It essentially consists of a long light crane boom and a digging bucket with the teeth loosely attached to the boom through cable (fig. 6.1). Due to its special construction features, it is characterized by long reach of digging and dumping i.e. a drag line can dig and dump the excavated material over long distances. Thus, it is not necessary to place the machine near the pit or to go into the pit to be excavated because of its long reach owing to its long boom. Again with the help of its long boom, it can easily handle the digging of wet material or incapable of underwater digging standing on the firm soil from the pit. Additionally, a drag line can dig below its track level and can handle soft materials effectively. However, a drag line doesn't have the positive digging force of a power shovel or hoe. Actually the bucket's filling force (breakout force) is entirely derived from its own weight and that is why it may bounce, tip over or drift sideways when it encounters any hard material. Of course, these short- comings are particularly noticed in smaller machines with light weight buckets.

FIGURE: 6.1

Drag lines are usually employed for excavating materials and dumping it into hauling units such as trucks or tractor-pulled trollies or for depositing it near the pit of excavation. A drag line is not required to go into the pit to excavate; rather it can operate on natural ground adjacent to the pit while excavating the material from the pit. Use of a drag line enables the loading of haul units that are positioned at the same level outside of the pit. This offers a particular advantage when the material being excavated is wet, since the haul units (like trucks, tractors etc.) do not have to go into the excavation and maneuver through the mud or mire. Wherever possible, it is better to position the haul units in the pit i.e. the excavation below the drag line, which results in reduction of hoist time and increase in production. Owing to the long boom of a drag line, frequently it is possible to dispose off the excavated materials in one operation if the material can be deposited along the canal or near the pit. This definitely eliminates the requirement of hauling units, reducing the cost of handling of materials. In summary, the greatest advantage of a drag line over such equipments of shovel family is its characteristic long reach for digging and dumping.

The size of a drag line is indicated by the size of the bucket, expressed in cubic units. However, most machines may handle more than one size of bucket, depending upon the length of the boom utilized and the unit weight of the material excavated. However, in a machine, the bucket size, the boom length and angle are related. Of course, the boom can be angled relatively low when operating but boom angles of less than 35° from the horizontal are not advisable because of the risk of tipping the machine. It is also necessary to reduce the size of the bucket when a long beam is used or when the excavated material has a high unit weight, because the maximum lifting capacity of a drag line is actually limited by the force that will tilt the machine over. Therefore, the combined weight of the bucket and its load should not produce a tilting force greater than 75% of the force required to tilt the machine. Secondly, if the material is difficult to excavate, the use of a smaller bucket that will reduce the digging resistance may enable an increase in production. Usually bucket capacity may range from 0.95 to 1.912 cubic meters.

Types of drag lines: - The drag lines may be divided into four categories

1) Crawler mounted drag lines
2) Wheel mounted drag lines
3) Truck mounted drag lines
4) Walking drag lines

Crawler mounted drag lines are suitable for operating on surfaces which are very soft for wheel or truck mounted machines. However, their travel speed is very low, usually less than 1.5kmph which necessitates the use of auxiliary hauling equipments to transport these machines from one job to another when the distance is large. Wheel and truck mounted units may travel at a speed of about 50kmph. Walking drag lines are used to handle more load; the capacity of the bucket being 3 cubic meters or more, due to which the weight of the machine increases. To use the large machines on softer ground, the crawler system is replaced by a walking mechanism.

Basic parts of a drag line: -Drag line components consists of the following

1) A boom 2) A bucket 3) A fair lead 4) Hoist dump and drag cables.

1) <u>Boom</u>: - It is actually a standard crane boom made up of sections of suitable lengths connected together by bolts. The central portion of assembled boom is wider in section and tappers to small sections at top and bottom ends. These ends are called the points and foot respectively. Each section consists of angles or tubes welded together. Such construction results in longer length, reduced weight and enhanced structural strength.

   For some selected models of walking drag line, the top sections of the boom are made up of aluminum in order to reduce the overall boom weight or to enable a longer boom construction or to enable an increase in the bucket size. It is attached to the deck with pins at the foot and supported at the point through the boom hoist cable passing over a pair of sheaves placed one on each side. A central sheave at the bottom point carries the bucket hoist cable. The boom is generally set at an angle of 30° to 40° to the vertical while working.

   FIGURE 6.2

2) <u>Bucket</u>: - It is a steel box open at top and front; the cutting teeth being filled to the lower front edge pointing towards the machine. Out of the two sets of chains that are attached to the bucket, one set known as drag chains is attached to the front and the second set of chains called hoist chains is attached to the near. The drag chains terminate in a drag yoke to which a drag cable is anchored. The hoist chains end at the hoist line socket which takes the hoist cable. A dump cable is stretched between the bucket front and the drag yoke passing over a dump sheave which is supported by the hoist lines through a socket attached to the sheave case. Thus, the bucket has a three way control i) the hoist, ii) the drag and iii) the dump. The dump is used to turn the bucket upside down, teeth pointing downwards for dumping excavated material or

for making impact with the ground. However, the digging range can be extended beyond the true swing radius by skillful operation of the bucket.

Operation of a drag line: - For excavation work, the drag line is operated by swinging the empty bucket to the digging position by releasing both the hoist and drag cables, till it rests on the ground with digging teeth into the ground. By suitably adjusting the pull on the two cables, it is possible to make use of the momentum to drop the bucket beyond the true radius of the boom. There are separate drums on the basis crane unit for the drag and hoist line cables and therefore their motion can be coordinated into a smooth operation. Digging is accomplished by pulling the bucket towards the machine, while regulating the digging depth by means of tension maintained in the hoist cable. When the bucket is filled, the hoist cable is pulled while slackening the drag cable and it is then hoisted. The bucket is so constructed that it will not dump its contents until the drag cable tension is released. When the required dump height is attained, the boom is swung to the position of dumping and the drag brake is released. Releasing tension on the drag cable causes the tension on the dump cable and drag chain also to be released which makes the front (open) end of the bucket to fall vertically allowing the material to slide out. In this way, the excavated material from the bucket is dumped into the hauling unit. The boom is then swung back to the digging position and the same cycle of operation of hoisting, swinging and dumping of the loaded bucket is repeated.

To control the accuracy of dumping of a drag line is more difficult compared to a hydraulic excavator (power shovel). Therefore, when a drag line is used to load hauling units, it is desirable to use larger hauling units to reduce the spillage of dumping material. The capacity of hauling units may be five to six times the capacity of the drag line bucket.

Output of a drag line: - The following factors influence the output of a drag line:

1) Type of material to be excavated.
2) Depth of cut.
3) Angle of swing of the drag line (which may be 45°, 90°, 135° and 180°).
4) The size and type of bucket.
5) Length of the boom.
6) Method of disposal or loading haul units.
7) Size of the haul units used.
8) Skill of the operator.
9) Physical condition of the machine.
10) Job conditions.

Optimum depth of cut for a drag line:

A drag line gives maximum output when it is allowed to work at the optimum depth. The ideal output of short boom drag lines working at optimum depth and 90°swing are given in the following table.

TABLE 6.1

Optimum depth of cut and ideal output of short boom drag line at 90° swing

Sl. No.	Size of bucket/ Class of material	0.29 m^3	0.38 m^3	0.57 m^3	0.765 m^3	0.956 m^3	1.15 m^3	1.34 m^3	1.53 m^3	1.93 m^3
1	Moist loam of light sandy clay	1.5 53	1.7 72	1.8 99	2.0 122	2.1 149	2.2 168	2.4 187	2.5 202	2.6 233
2	Sand and gravel	1.5 49	1.7 69	1.8 95	2.0 118	2.1 141	2.2 160	2.4 180	2.5 195	2.6 225
3	Good common earth	1.8 42	2.0 57	2.4 81	2.5 104	2.6 127	2.7 147	2.8 162	3.0 177	3.2 204
4	Hard tough clay	2.2 27	2.4 42	2.7 69	2.8 85	3.1 104	3.3 123	3.5 139	3.6 150	3.8 172
5	Wet sticky clay	2.2 15	2.5 23	2.7 42	2.8 58	3.1 73	3.3 85	3.5 100	3.6 112	3.8 135

N.B: - 1st row shows values of optimum depth in meters and 2nd row shows ideal output in cubic meters.

6.2.2 Tractors: -

A tractor is a multipurpose machine which exerts/ converts engine power into tractive effort. It works with diesel engine and having power ranging from 14 to 200 H.P. Tractors have multirole uses as a construction equipment; their primary purpose being to pull or push loads. They may also be used as mounts for many types of accessories. They are available in all sizes and types and fit almost to any job for which they are usable. However, from the point of view of earthmoving equipment, they are used as clearing, excavating, hauling and conveying machinery.

Tractors may be classified into two types as follows:

1) **Wheel tractors: -** These type of tractors move on pneumatic tyres and are generally employed for light but speedy jobs having maximum speed of even more than 50 kmph. Such units are of great advantage on construction works requiring travel over considerable distances. Of course, due to smaller contact area between the tyre and the haul surface, there is a tendency for these tractors to sink more depth into soft surfaces.

   FIGURE 6.3
2) **Crawler tractors: -** These units are track laying units moving on an endless chain. They are generally employed for heavy duty work, where more tractive power is required. Here the speed of movement required is less than wheel type units. Average speed of the units is 5 to 6 kmph and the maximum speed being about 10 to 12 kmph. It is best suited for short hauls up to 150m and is often used to build haul roads to be used by rubber tyred equipment. They have the ability to climb steep grades.

   FIGURE**.**6.4

TABLE 6.2

Comparative study of wheeled and crawler tractors.

Sl. No.	Wheeled tractor	Sl. No.	Crawler tractor
1.	They can travel faster than the crawler tractors and are suitable for long distances, where high speeds are required.	1.	They are more compact and powerful.
2.	They can handle light duty job of hauling and digging.	2.	They can handle heavier jobs of hauling and digging.
3.	They are less costly.	3.	Crawler tractors need expensive work. They are more costly
4.	They have wheel steering control as in case of other automobile vehicles and can be maneovered easily.	4.	Crawler tractors have stic control for steering and need greater skill in operation.
5.	Wheel tractors can move on tarred roads with speed without causing any damage to the road.	5.	Crawler tractors if moved in pavement and tarred road is likely to damage them unless lifted with special shoes and device.
6.	They can be self driven over long distances.	6.	Usually transportation of crawler tractors over long distances is done on trailers due to their low speed of traveling and to avoid excessive load over the tracks.
7.	The wheeled tractors are liable to slip over very smooth or loose spots when increased power is to be applied to wheels.	7.	A crawler tractor can pass over very smooth and loose spots as it moves on its own tracks and the grousers on the tracks have a better grip on the road.
8.	Wheeled tractors need less maintenance and repair. They need less skill to drive than crawler tractors.	8.	Crawler tractors require more skill in operation. They also need more maintenance and repair.

These tractors are generally rated by their size and power. The weight or size of the units determines the maximum pull. This pull is the product of weight of the equipment times the coefficient of traction for a particular road surface, regard less of the power supply of the engine. The following table gives the values of co-efficient of traction for different types of surfaces.

Table – 6.3

Coefficient of traction for various road surfaces

Sl. No.	Surface	Rubber types	Crawler tracks
1.	Ice	0.13	0.10 to 0.25

2.	Dry snow	0.20	0.15 to 0.35
3.	Loose dry sand	0.2 to 0.3	0.3
4.	Wet sand and gravel	0.3 to 0.4	0.35
5.	Wet clay loam	0.4 to 0.5	0.70
6.	Dry clay loam	0.5 to 0.7	0.90
7.	Dry, rough concrete	0.8 to 1.0	0.45

However, now-a-days, for all practical purposes, wheeled tractors are being used as earthmoving machinery which may again be divided into two types i.e. two-wheel and four-wheel tractors. Two-wheel types are characterized by their higher tractive force, less rolling resistance on account of elimination of extra axle, increased maneuverability etc., whereas the four-wheel types have the advantage of better steering properties giving more confidence to the drivers, less tendency to bump over rough haul roads, can be driven at greater speed and most importantly can work as an independent unit when detached from the trailing unit.

Factors affecting the selection of tractors: - Following points are to be considered while making selection of tractors:

1) The nature of the work for which it is to be employed i.e pulling a trailer, wagon or scrapper etc. or bull dozing as the case may be.
2) The size of the unit required for the particular work.
3) The type of footing over which it will travel as a wheeled or crawler unit i.e. low or high tractive power unit.
4) The smoothness and firmness of the haul road.
5) The length and slope of the haul road.
6) The type of work it is supposed to do after completion of the job in hand.

Components of tractor: -

The principal components of a tractor are a) Engine b) Engine clutch c) Transmission system including power takes off d) Ground drive and controls. The main difference in the construction of wheeled and crawler tractors is in the manner of delivering power to the final drive owing to the different stirring mechanism of the two types of tractors.

Gradability**: -**

Gradability may be defined as the maximum slope expressed as percent up to which a wheel or crawler type tractor can move at a uniform speed. It may be found for an empty or loaded vehicle. The gradability for a loaded or an empty vehicle is different. It is given by the following formula,

$$\mathbf{K} = \frac{\mathbf{11660 \times T \times G}}{\mathbf{W \times R}} - \frac{\mathbf{N}}{\mathbf{40}}$$

where K= Gradability %

G= Total gear reduction for the particular gear selected.

T= Rated engine torque, kg-cm.

R= Rolling radius, the radius of the loaded driving wheels in cm.

N= Rolling resistance, Kg-per tonne.

W= Gross weight of the complete unit, kg.

Factors affecting upward motion of a prime mover: -

The following factors affect the upward pull of a prime mover.

1) The rolling resistance of the haul road.
2) The power development by the engine which is available as rim pull or drawbar pull.
3) The expected load of the prime mover and its gross weight.
4) The grade to be negotiated.

Note: - Favorable grade is to be subtracted from the resistance while adverse grade is to be added to the resistance.

Ratings of tractors: -

The rating of the wheeled tractors is specified by the engine horse power at the fly wheel or belt, the rim pull at different speeds in various gears, the total operating weight of the tractor and the number and size of tyres. Besides, other information supplied by the manufacturer include a) Turning radius b) Wheel base c) Ground clearance d) Capacities of fuel tanks e) Cooling system f) Crank and transmission cases etc.

Rim pull and draw bar pull: -

The rim pull of a tractor at any speed is defined as the force between the tyres of the driving wheels of the tractor and the surface on which the tractor travels. It can be calculated by the following formulae.

$$\textbf{Rim pull} = \frac{\textbf{375}\times\textbf{efficiency}\times\textbf{horse power of the tractor}}{\textbf{Speed in miles per hour}} \quad \textbf{(FPS system)}$$

$$= \frac{\textbf{268.5}\times\textbf{efficincy}\times\textbf{metric horse poiwer}}{\boldsymbol{Speed\ in\ kmph}} \quad \textbf{(In metric system)}$$

The pull exerted on the trailing load= (Rim pull – rolling resistance – grade resistance – trailing load). Thus the pull depends up on the traction of the surface of travel and the weight of the tractor.

In case of a crawler tractor, the equivalent pull rating is equal to the draw bar pull. This is the net hauling force which a crawler tractor can exert on a trailing load. The draw bar horse power can be calculated from the drawbar pull and speed as follows:

$$\textbf{Draw bar horse power} = \frac{p \times v}{1000} \textbf{ (In FPS units)}$$

$$= \frac{p \times v}{75} \textbf{ (In MKS units)}$$

where p= the draw bar pull in lbs or kg.

V= speed in feet per minute or meter per second.

6.2.3 Bulldozers: -

The bulldozer, often simply called dozer, is primarily a pushing unit and is largely employed for excavating and moving earth. It is used to push, shear, cut and roll materials ahead of the dozer. It is one of the most important machines on construction projects. A dozer is essentially a self contained tractive power unit equipped with blades. They may be used for operations such as:

1) Moving earth or rock for short haul (push) distances, up to 100m in case of large dozers.
2) Spreading earth or rock fills.
3) Backfilling trenches.
4) Opening up pilot roads through mountainous or rocky terrain.
5) Clearing floors of burrow and quarry pits.
6) Helping load tractor-pulled scrapers.
7) Clearing land of timber, stumps and root mat.

FIGURE 6.4 (a & b)

Various parts of a bulldozer are shown in the fig. 6.4 (a & b). It consists of a blade mounted at the front of a tractive unit which may be either wheel-mounted or mounted on crawler tracks. The blade widths may be 2 to 8.5 meters and the height of blades may vary from 0.6 to 2.0 meters.

The early versions of bulldozers had wooden blades and were being pulled by horses. The crawler mounted dozers with steel blades became popular only after First World War. In case of early designs, the blades were raised or lowered by hand, which was quite time consuming. Now this method has been superseded by cable and hydraulic controlled bulldozers.

The dozers are designed to provide tractive power for draw bar work. The most effective work done by them is moving earth downhill for short hauls; the limits in grade may be such as to allow the machine to reverse and return uphill. They are also important tools in excavation plant for rapid digging and dumping. However, a dozer has no set volumetric capacity. The amount of material that a dozer can move depends on the quantity of materials that remains in front of the blade during the push. Crawler dozers are excellent machines for land clearance as special clearing blades can be attached to them.

In general, they are low center of gravity machines consistent with their purpose as a unit for draw back work. This is an pre-requisite of an effective machine, because if there is large difference between the line of force transmission from the machine and the line of resisting force, it will result in less utilization of developed force.

Classification of bull dozers: - The dozers may be classified based on blade direction, mountings, or method of raising or lowering of the blades.

A) *On the basis of blade direction:*
   i) Bull dozers: - These are mounted with the blades perpendicular to the direction of travel. It pushes the earth forward.
   ii) Angle dozers: - These are mounted with the blades set at an angle with the direction of travel. It pushes the earth forward as well as to either side. The angle of indication of the blade is kept up to 65° with the direction of motion of the bull dozer.

B) *On the basis of mountings: -*
   i) Wheel mounted bull dozer: - These are mounted on pneumatic tired wheels.
   ii) Crawler mounted bull dozer: - These move on end-less chains.

C) *According to the method of raising and lowering of blades:*
   i) Cable controlled.(Fig. 6.5)
   ii) Hydraulic controlled. (Fig. 6.6)

FIGURE 6.5 & 6.6

Cable controlled Bulldozers: - In this case, the transmission that can be shifted while transmitting full engine power is called power shift. Such transmissions are provided with cables/ torque converters to absorb drive chain shock loads caused by changes in gear ratios. A power shift transmission provides an efficient flow of power from the engine to the tracks and gives superior performances in applications involving variable load condition. The cable controlled bulldozers have the following advantages:

a) It is simple in operation.
b) It is easy to repair and control.
c) Its installation is simple and easy.
d) There is less chance of damaging the machine because the blade can move up and ride over a rigid obstruction e.g. in hilly area, big boulders.
e) It can be used for bigger capacity machines.

Hydraulic controlled bulldozers: - In this type of dozers, part of the engine power is used for driving a pump which draws oil from an oil reservoir and pumps it to two housing rams at a pressure of 20-28 kg/cm^2. Each ram is provided with sliding piston double acting and a piston rod. The piston rod is attached to the back of the dozer blade. Two hoist cylinders are attached to the radiator guards on both sides. When the oil under pressure is supplied through the supply oil pipe of the lower side of the hoist ram, the piston moves up, thereby raising the push arm and the blade of bulldozer upwards. However, hydraulic controlled system is limited to small units only. The following are the advantages of the hydraulic controlled bulldozers:

a) Position of the blade can be maintained more accurately.
b) To force the blade into the ground, high down pressure on the blade is produced in addition to its weight.

Crawler Dozers: -These dozers are actually track laying machines. They have a continuous track of linked shoes that moves in the horizontal plane across fixed rollers. At the rear of the machine, the track passes over a vertically mounted sprocket drive wheel, which is a wheel having a row of teeth around it. As the sprocket turns, it forces the track forward or backward imparting motion to the dozer. In the front end of the machine, the track passes over a vertically mounted idler wheel that is connected to a recoil device having adjustable tension. The idler wheel maintains proper tension in the track and enables it to absorb heavy shocks. The linked shoes are made up of heat treated steel designed to resist the wear and abrasion.

FIGURE 6.7

The low ground pressure under carriage configuration is for soft ground conditions. The ground pressure exerted by such crawler dozer is about 21-28 kPa. However, such machines should not be used in hard and rocky conditions as it is likely to reduce the life of the under carriage. A crawler dozer operates on slopes up to 45°.

Wheel mounted dozers: - In this case, the dozer is mounted on wider tyres which provide greater contact area and increase floatation (movement). However, the width of the tyre should be as per requirement since it has been observed that larger tires reduce the rim pull developed.

FIGURE 6.8

TABLE- **Comparison between crawler and wheel dozers**

Sl. No.	Crawler mounted dozer	Sl. No.	Wheel mounted dozer
1.	It gives greater tractive effort especially when operating on soft grounds as loose or muddy soil. Its speed is low (about 8 to 16 kmph).	1.	It gives higher travel speed on the job or from one job to another job.
2.	It is capable of traveling over muddy surfaces and it can work on variety of soils.	2.	It eliminates the necessity of hauling equipment required to transport the dozer to the job.
3.	It has the ability to operate in rocky formations, where the rubber tyres have the chance of being damaged seriously.	3.	Greater output, especially when considerable travel is necessary.
4.	It has the ability to travel on rough surface, which may reduce the cost of maintaining the hauling roads.	4.	Less fatigue to the operator. It is good for long travel distances.

5.	Greater flotation due to the lower pressure under the track. It is good for short distance jobs.	5.	It can travel on paved highways without damaging the surface.
6.	Greater versatility of use on jobs.	6.	It is best for handling loose soils.
7.	Can push large blade loads.	7.	It can push moderate blade load.

Output of the bulldozers: -

The theoretical capacity of the blade is given by the size of the blade, nature of the soil etc. Total output of the bulldozer is the capacity of the blade multiplied by the number of passes per hour.

Uses of dozers on projects: - A dozer can be economically used on a project for the following purposes.

1) Striping: - Dozers are excellent machines for stripping which means removal of top thin layer of soil. The stripping operation by the dozers is to be conducted in such a manner that the push distances are minimized. Large dozers have been found economical for moving the material up to about 100m or 300ft. The economical push distance decreases as the size of the dozer decreases and it also depend on the nature of material being handled. Of course, a material of cohesive nature is easier to push than a granular material as sand which tends to run in front of the blade. However, when a material is to be pushed to more than 100m distance, then scrapers should be preferred.
2) Backfilling: - A dozer can accomplish backfilling efficiently by drifting materials sideways with an angle blade. This process enables forward motion parallel to the excavation. When a straight blade is used, the dozer approaches the excavation at a slight angle and then at the end of the pass turn in towards the excavation. During this operation no part of the tracks should hang over the excavation.

   While making initial pass completely across pipes and culverts, caution must be exercised so that a minimum of 30cm of material should cover the pipe or structure before accomplishing a crossing. However, the diameter of the pipe, the pipe type, the distance between the side walls of excavation and the number of lines of pipe in the excavation dictate the minimum required cover. Thus, larger diameter pipes, larger excavation widths and multiple lines of pipes are factors that all dictate more cover before crossing the structure.

3) Spreading: - One of the common dozer tasks is the spreading of materials dumped by trucks or scrapers. Generally it is required to control lift thickness to achieve density requirements as per proposed compaction equipment. Uniform spreading can be accomplished by keeping the blade of the dozer straight and at the desired height above the previously placed fill surface. The dumped material is forced directly under the cutting edge of the blade. Fairly uniform spreading can be achieved in two passes of the dozer over the dumped area. The second pass

should be made at right angles to the first pass. Today laser control blades are available for this type of work.

4) Slot dozing: - It is a technique where the blade end slippage from the first pass or the side walls from the previous cuts are used to hold materials in front of the dozer blade on subsequent passes. When employing this method to increase the production, the cuts are aligned parallel, leaving a narrow uncut section between the slots. Then the uncut sections are removed by normal dozing. This technique prevents slippage at the end of the blade and usually increases production by about 20%. However, this increase in production is highly dependent on the slope of the push and type of material being pushed.
5) Ditching: - A dozer can be used for digging a trench. Ditching by dozer can be accomplished in very rough sections. Large and deep ditches are generally cut either with the help of excavators or scrapers. Scrapers are used when the cut is made before the water enters into the ditch. However, after ditching by the scrapers, the dozer may be used for final dressing of the slopes. If a dozer is used to cut rough ditches, the machine pushes the material out of the cut by working perpendicular to the line of the ditch. Moreover, small shallow ditches are usually cut with a motor grader.
6) Side hill cut: - In fact, it is a difficult task to develop the initial table for excavations made on steep ground. The excavated material from such a cut usually is pushed over the side of the hill. The first pushes are made perpendicular to the long direction of work. Starting from higher side, short passes are made to push the material across the central line and over the side. The perpendicular passes being short, the dozer usually is not able to develop a full blade load. Once a bench is developed, the dozer starts pushing in the long direction of the work developing a full blade load. Pushing downhill is usually easier due to gravity.
7) To move rocks or frozen ground: -Rocks and frozen ground can be moved by dozers by using proper technique. In both the cases, the blade must be worked under the materials to be moved. This can be done by tilting the corner of the blade. To maximize the driving force of the blade, the tilted end is only hooked under the rock or ground. When the blade is in contact under side or beneath the rock and the dozer is driving forward, the operator is required to lift the blade to split or remove up the rock.
8) Blade to blade dozing: - This technique is also some times referred to as side-by-side dozing and is used with a view to increase production. Here the two machines maneuver such that their blades are right next to each other during the pushing phase of the production cycle. This results in reducing the side slippage of each machine by about 50%. However, the extra time necessary to position the machines together increases that phase of the cycle. Therefore, this technique is not much effective on pushes of less than 50ft because of the excess of maneuver time required. Moreover, when the machines operate simultaneously, delay to one machine is in effect a double delay. The combination of less slippage but increased maneuver time tends to make the total increase in production for this technique somewhere between 15 and 25%.

Power to dozers: - In almost all dozers, usually internal combustion engines are used to power them; the diesel engines being the most common primary units. However, for smaller machines, gasoline may also be used. For tunnel work, electric and air powered dozers are also available.

The crank shaft rotation, derived from the engine is usually too fast and does not have sufficient force (torque). The transmission of the machine reduces the rotational speed of the crank shaft and increases the force available to do work. Transmission provides the opportunity to the operator to change the machine's speed-power ratio, so that it matches to the work requirements. Though manufacturers provide dozers with a variety of transmission, but the basic options are as follows:

1) Direct drive 2) Torque convert and power shift transmission.

Less than 100hp dozers with hydrostatic power trains are available in the market. The smaller less than 300hp diesel powered machines are commonly available with either direct or power shift type transmission. However, large dozers are always equipped with power shift transmission.

Comparison of performance of crawler and wheel type dozers: -

Of course, the usable pull or rim pull depends up on weight and traction of a fully equipped dozer. Even though the engine can develop a certain draw bar pull, all of that pull may not be available to do work. Actually, the coefficient of traction factor on a dry clay loam for rubber tyres may be taken as 0.5 to 0.7 and for track as 0.9. Thus, although both the crawler or wheel type machines have approximately the same operating weight and fly wheel power, yet the track dozer can supply about 1.5 times the usable power than wheel tyred dozer due to the variation of coefficient of traction factors.

In most cases of soil conditions, the coefficient of traction for wheels is less than tracks. Thus a wheel type dozer must be approximately 50% heavier than a crawler dozer to develop the same amount of usable force. With the increase in the weight of the wheel type dozer, a larger engine will be required to maintain the weight to horse power ratio. Of course, there is a limit to increase of the weight of the wheel type dozer, but still it is a machine with advantage over track dozers in respect of speed and mobility.

Types of blade used on dozers: -The following five types of blades are used on dozers engaged in earthwork.

1) Straight blades: - These blades are abbreviated by the symbol 'S' and have no curvature in their length being mounted in a fixed position, perpendicular to the line of travel of the dozer. The straight blade is generally designed for short and medium distance passes such as grading, backfilling and spreading the fill material. Actually it is a heavy duty blade and normally it can be tilted within a 10° arc for increasing the penetration for cutting or decreasing penetration when back dragging. It may be equipped or set to pitch i.e. the operator can set the cutting edge to dig hard materials or to move the edge's plane of attack to ease the drifting of light materials.

2) Angle blades: - These blades are abbreviated by 'A'. This type of blade is 30 to 60cm wider than straight blades and can be turned or angled up to a maximum angle of 25° to the left or right of the perpendicular to the dozer or used as a straight blade. A angle blade is attached to the dozer by a ‘C’ frame mount. Hence it cannot be pitched rather it can be tilted. It is very effective for side casting material particularly for making hill side cuts and back filling.

3) Universal blades (U): - This type of blade is wider than straight blade without side edges having a forward cant (slope) of about 25°. The canting of the edges reduces the spilling of the loose material resulting in increased efficiency of U-blades in moving large loads over long distances. The ratio of horse power and length of the blade is lower for U-blades than for S-blades mounted on similar dozers. However, penetration is not a prime objective of the U-blade. This blade is best suited for lighter materials. Typically it is best suited as for stock piling and drifting loose or non-cohesive materials.

4) Semi universal blade (S-U): - These types of blades have the characteristics of both straight and universal blades. By the addition of short wings, the capacity of this blade is increased.

5) Cushion blades (C): - These classes of blades are mounted on large dozers which are primarily used for push loading scrapers. This class of blade is shorter in length than S-blade. The shorter length avoids the pushing of blade into the rear tires and cutting it. In addition to this, the shorter length also facilitates the maneuvering of the dozer while pushing loading into position behind the scrapers. Rubber cushions and springs in the mounting enables the dozer to absorb the impact of contacting “pusher block” to push the scrapers. By using a cushion blade instead of push block to push the scrapers, the dozer can clean the cut area and the production of the total fleet is increased. This blade has limited utility in pushing the material. Therefore, it is not used in production dozing. It cannot be pitched, tilted or angled.

Estimation of dozer production: -

A dozer has no set volumetric capacity, because there is no hopper or bowl to load it. The amount of materials which a dozer moves depends on the quantity of material that remains in front of the blade during the push. The output of a dozer is controlled by the factors such as type of blade of the dozer, type and condition of the material and cycle time.

Blade type: -By virtue of design, the straight (S) blades roll material in front of the blade and universal as well as semi-u blades control side slippage by holding the material within the blade. As the U and S-U blades force the materials to move to the centre, there is a greater degree of material volumetric swell. Moreover, the quantity of loose material in case of the U and S-U blade will be greater than that of the S blade. But the ratio of this difference is not the same when considering bank cubic yards. This is because the factor to convert loose cubic yards to bank cubic yards for the universal type of blades is not the same as that for a straight blade. The U or S-U blades boiling effect causes the difference.

Actually, the same type of blade comes in different sizes to fit different size dozers. Blade capacity then is a function of blade type and physical size. Information concerning blade dimensions can be obtained from manufacturer’s specification sheets.

Types and condition of material: -The shape of the pushed mass in front of the blade is affected by the type and condition of the material being handled. Cohesive materials (clays) boil and heap. Generally, the materials that exhibit a slippery quality or those that have a high mica content ride over the ground and swell out. Cohesionless materials (sands) are known as dead materials because they do not exhibit heap or swell properties.

***Cycle time**: -* The sum of the time required to push a load, back track and maneuver into position to push again represents one dozer production cycle. The time required to push and back track can be calculated for each dozing situation considering the travel distances as well as obtaining a speed from the machine's performance chart.

Dozing, however, is generally performed at a slow speed of 1.5 to 2 miles per hour. The lower figure is appropriate for very heavy cohesive materials. Return speed is usually the maximum that can be attained in the distance available. When using performance charts for determination of possible speeds, it is to be remembered that the chart identifies instantaneous speeds. In calculating the cycle duration, onemust use an average speed that accounts for the time required to accelerate to the attainable speed as indicated by the chart. Actually, it is not possible to shift the machine past second gear in the case of distances that are less than 30m (100ft. For greater distances, when the ground conditions are relatively smooth and level, maximum machine speed may be obtained. Maneuver time for power shift dozers used in pushing material is about 0.05 min.

Blade load: - The load that a blade can carry can be estimated by the following methods:

1) Manufacturer's blade ratings.
2) Field measurements.
3) Previous experience.

Manufacturer's blade ratings: - It is given by $V_s = 0.8\ W\ H^2$ And $V_u = V_s + ZH\ (W\text{-}Z)\ \tan x°$

Where V_s = Capacity of straight or angle blade under ideal conditions.

V_u = Capacity of the universal blade under ideal conditions.

W = Effective blade height in yards.

Z = Wing length measured parallel to the blade width in yards.

x = Wing angle.

H = Effective blade height in yards.

Field measurement: -The procedure for measuring blade load consists of first obtaining the normal blade load and then taking the measurements. To obtain a normal blade load, the normal blade of dozer is pushed on to a level area, and dozer's forward motion is stopped. While raising the blade, it is moved forward slightly to create a symmetrical pile. Then it is reversed and moved away from the pile. The height (H) and width of the pile (W) is measured at the inside edge of each track. The greatest length (L) of the pile is measured which may not necessarily be at the middle. Finally computation is done by taking average of the two height and the two width measurements. The blade load is calculated by the formula,

Blade load (in loose cubic yards) = 0.0139 HWL

where H, W and L etc. are measured in feet.

Previous experience*:* - Properly documented past experience is an excellent blade load estimating method. The requirement of documentation is that the excavated area be cross-sectioned to determine the total volume of the material moved and that the number of dozer cycles be recorded. Also production studies can be made based on the weight of the materials moved. However, in the case of dozers, the mechanics of weighing the material is more difficult to accomplish than surveying the volume.

Dozer pushing production: - The formula to calculate dozer pushing production in loose cubic yards per 60 min is given by

$$\text{Production in ideal conditions per hour (all time in minutes)} = \frac{60 \times \text{blade load}}{\text{Push time} + \text{Return time} + \text{Maneuver time}}$$

Manufacturer's production estimation guidance: - The thumb rule formula provided by equipment manufacturers for estimating dozer production in FPS units is given below

$$\text{Production (in loose cubic yards per 60 min)} = \frac{330 \times \text{net H.P.}}{\text{D} + 50}$$

Where D = One day push distance in feet

Net H.P. = Net horse power at the fly wheel for a power shift crawler dozer.

6.3 Earth compacting equipments: -

The objective of soil compaction is to achieve the required density by removal of entrapped air from the soil mass through mechanical process. The device used to remove air from the soil mass is called compaction equipment. The earliest application of compaction was in road construction where the aim was to improve the engineering properties of soil. Though the main objective of compaction is to increase the unit weight, but it takes care of the following properties of soil also.

1) To reduce or prevent settlement.
2) To increase the strength of the soil.
3) To improve the bearing capacity of soil.
4) To control volume changes of soil.
5) To lower the permeability of soil

Compaction of soil at optimum water content is the most widely used method for achieving desired properties.

Types of compaction equipments: - The compaction of soil is achieved by the application of energy to the soil by any of the following methods.

1) By impact – with sharp blows of rammer.
2) By pressure – application of static weight.
3) By vibration – shaking of the ground
4) By kneading – rearrangement of soil particles mechanically.

The effectiveness of different compaction methods depends on the type of soil being compacted. The appropriate compaction methods based on soil type are shown in the following table.

TABLE -:

Appropriate compaction methods of soil compaction

Material	Impact	Pressure	vibration	Kneading
Gravel	Poor	No	Good	Very good
Sand	Poor	No	Excellent	Good
Silt	Good	Good	Poor	Excellent
Clay	Excellent with confinement	Very good	No	Good

Types of compaction rollers: -

1) Smooth wheeled rollers
2) Grid rollers
3) Tamping rollers
4) Sheep foot rollers
5) Vibrating compactors
6) Pneumatic tired rollers

Compaction is done by sheep foot rollers by means of impact vibration and kneading where as in case of tamping rollers only vibration and kneading process is effective. Vibrating rollers compact by means of pressure and vibration and pneumatic tired rollers cause impact as well as pressure.

Selection of compacting equipment: - The selection of compacting equipment depends on the type of soil to be compacted. The type of compactor to be used, the number of passes and the thickness of the soil layer etc. in respect of different soil materials are given in the following table.

TABLE – **Compaction equipment based on soil type**

Sl. No.	Material	Type of equipment	Lift Thickness in cm.	No. of passes	Remark
1.	Gravel	Vibratory roller Pneumatic tired	20 - 30	3 - 5	Foot pressure 10.5 to 14 kg/cm^2 Tire pressure 2.45 to 9.1 kg/cm^2

		Sheep foot roller			Foot pressure 10.5 to 14 kg/cm^2
2.	Sand	Vibratory roller Pneumatic tired Smooth static	20 - 25	3 - 5	-- Tire pressure 2.45 to 4.55 kg/cm^2 Tandem pressure 14 to 28 kg/cm^2
3.	Silt	Vibratory roller Tamping foot Pneumatic tired Sheep foot roller	15 - 20	4 - 8	Foot pressure 14 to 28 kg/cm^2 -- Tire pressure 2.45 to 3.5 kg/cm^2 Foot pressure 14 to 28 kg/cm^2
4.	Clay	Vibrating roller Tamping foot Sheep foot roller	10 - 15	4 - 6	Foot pressure 17.5 to 35 kg/cm^2 -- Foot pressure 17.5 to 35 kg/cm^2

Brief description of different types of rollers: -

1) Smooth wheeled roller: - This type of roller is suitable for compaction of cohesive soils. It usually contains three rollers; one in the front and two in the rear. The weight of such rollers varies from 5.5 tonnes to 24 tonnes. The rear wheel exerts a pressure of the order of 30 to 80 kg/ cm^2 along its length. This type of roller is also used to compact silt, sandy low plastic soils etc. Generally 10 to 15cm thick layers of above soil laid at optimum moisture content is rolled and standard proctor density of soil is obtained in 8 to 10 passes of the roller.
   FIGURE: -
2) Sheep foot rollers: - This roller essentially consists of a hollow drum, on the periphery of which pads or projections of the shape of sheep's foot are attached. The desired weight of the drum is obtained by filling it with moist sand or stones. For a medium sheep foot roller, the specifications are
   i) Diameter of the drum – 1.5m
   ii) Length of the drum – 1.5m.
   iii) Length of pad or projection – 15cms to 35 cms.
   iv) Area of pad in contact with soil – 45 to 80cm^2.
   v) No. of projections – one p[projection per 265cm^2 area of surface.
   vi) Pressure of projection on soil - 0.15 to 0.3 kg/cm^2.
   vii) Weight of the roller – about 35 tonnes.
   viii) Speed of the roller – 6.5 to 9.5 kmph.

   This roller can be used to compact the following types of soils.

   a) Silty sand and sandy clay.
   b) Clayey soils.
   c) Medium and heavy clays.

   The thickness of the soil layer is kept up to 30cm or length of the projection or pad plus 5cm for satisfactory compaction by this roller. About 12 passes of the roller are sufficient for compacting

30cm thick soil layers. For compaction of 20cm clay layer, 6 to 10 passes of the roller have been found satisfactory.

Since this roller tends to aerate the soil as it tends to compact it, it is ideal for compacting soil having moisture content above the acceptable moisture range. However, the upper 5 to 8cm thickness of soil layer is not compacted adequately by this roller. Therefore, a lighter pneumatic tyred or steel wheeled roller should follow the sheep foot roller to compact such layer if no further layer is to be placed or if it is the last layer to be compacted.

FIGURE

3) Grid rollers: - This roller also works on the principle of sheep foot roller. In this roller an iron grid made of 4cm diameter rods and having an effective area of $9cm^2$ which comes in contact with the soil to be compacted. Two rollers are attached at the axle of the machine. In these rollers, rock pieces or concrete blocks etc. can be put to increase the weight of the equipment. The total weight of the equipment is about 15.5 tonnes. This roller can be drawn by a tractor at a speed of 16 kmph.
4) Tamping rollers: - Tamping foot compactors are high-speed, self propelled, non-vibratory rollers. These rollers usually have four steel padded wheels and can be equipped with a small blade to help level the lift. The pads are tapered with an oval or rectangular face; the pad face being smaller than the base of the pad at the drum. As a tamping roller moves on the surface, the feet penetrates into the soil so as to produce a kneading action and a pressure to mix and compact the soil from the bottom to the top of the layer. With repeated passage of the roller over the surface, the penetration of the feet decreases until the roller is said to walkout of the fill. Since the pads are tapered, a tamping foot roller may come out or walkout of the fill without spreading the soil. If the roller does not walkout, in that case either the roller is too heavy or the soil is too wet and the roller is shearing the soil.

   The working speed of these rollers is in the range of 12 to 18 kmph. Generally two or three passes of the roller over 20 to 30cm thick layer of soil can compact it to the desired density, but it is dependent on the size of the roller. As much as four passes may be necessary in poorly graded plastic silt or very fine clays. This type of roller has been found to be very effective in compacting all types of soils except clean sands.

   Like sheep foot rollers, these rollers are also found not to compact effectively top 5 to 7.5cm thick layer of soil. Therefore, if a succeeding lift is not going to be placed, it is followed up with a pneumatic tyred or smooth drum roller to complete the compaction or to seal the surface. However, to realize their true economical compaction potential, they require long un-interrupted passes so that the roller can built up speed, which generates high production.

FIGURE

5) Vibrating compactors: - Vibration creates impact forces which results in greater compacting energy than an equivalent static load. The impact forces are higher than the static forces

because the vibrating drum converts potential energy into kinetic energy. Therefore, vibratory compactors are more economical than static load rollers. Vibratory compactors may have one or more drums. However, on two drum models, one drum is powered to transmit unit propulsion. Single drum models usually have two rubber tired drive wheels. Also, there are towed vibratory compactors.

Non-cohesive soils such as sand, gravel, blasted rock etc. respond quite well to compaction produce by a combination of pressure and vibration. When these materials are vibrated, the particles shift their positions and reset more closely with the adjacent particles to increase the density of the mass.

The vibrating drum rollers are actuated by an eccentric shaft that produces the vibrating action. The eccentric shaft is a body that rotates about an axis other than the axis which passes through the centre of the mass. The vibrating mass (drum) is always isolated from the main frame of the roller. Normally the frequency of vibrations varies from 1000 to 5000 per minute.

Vibration is characterized by two parameters-amplitude, which is the measurement of movement or magnitude of throw and frequency, which indicates the rate of movement or number of vibrations (oscillations) per second or minute (rpm). The amplitude controls the effective area or depth to which the vibration is transmitted into the soil, whereas frequency determines the number of blows that are transmitted in a period of time.

The impacts imparted by the vibrations produce pressure waves that set the soil particles in motion producing compaction in the soil. However, in compacting granular materials, usually frequency is a critical parameter in comparison to amplitude.

Actually compaction results are a function of the frequency of blows, the force of the blows, and the time period over which the blows are applied. The frequency/ time relationship accounts for the working speed requirement of vibratory compactors, which is all the more important because it determines how long a particular fill is to be compacted. A working speed of 3 to 6.5 kmph provides the best result when using vibratory compactors.

a) *Smooth drum vibratory compactors:* - These compactors, whether single or dual drum models, generate three kinds of compactive forces i.e. i) pressure ii) impact and iii) vibration. These rollers are most effective to compact granular materials with particle size ranging from fine sand to large rocks. They can also be used to compact semi-cohesive soils having up to about 10% materials whose plasticity index (PI) is 5 or more. Large steel drum vibratory rollers can be effective on rock layers or lifts up to thickness of 90cm.

   FIGURE

b) *Padded drum vibratory compactors:* - These rollers are effective on soils with up to 50% of the material having a plasticity index value of 5 or more. These units can compact soil layers ranging from 30 to 45cm thickness. The edges of the pads are rolled inward so that they can walk out of the lift without spreading the soil. Sometimes these units are equipped with a leveling blade also.

   FIGURE

Of course, small vibratory rollers having width varying from 60cm to 95cm are also available, which are especially suitable for working in confined areas or trench work. The drums of these rollers extend beyond the sides of the roller body, which aid to compact adjacent area of the trench walls.

6) Pneumatic tyred rollers: - These are essentially surface rollers and basically work on the principle of kneading action to produce compaction in the soil below the surface. These rollers may be either self propelled or towed. These are used on small-to-medium size soil compaction jobs, primarily on bladed granular base materials.

FIGURE:

Usually small tyred units have two tandem axles with four to five wheels on each axle. The wheels oscillate, enabling them to follow the surface contour and reach into low areas for uniform compaction. The rear tyres are spaced in such a way that they travel over the surface between the front tires, resulting in complete coverage of the surface. Very often, the wheels are mounted slightly out of line with the axle, virtually giving them a weaving effect to increase the kneading action on the soil. However, the weight of a unit can be increased by adding ballast to suit the material being compacted.

The small units are not suitable for high production or thick lift embankment compaction projects. Large tired rollers varying in size from 7 to about 100 metric tonnes gross weight are generally available. In such rollers, two or more big earth moving tyres on a single axle are attached. In these tires, the air pressure may vary from 6 to 11kg/cm^2 and these rollers are capable to compact all type of soils to greater depths due to their heavy load and high tyre pressure. These units are used for precision work such as to roll highways sub grade and air field bases as well as earth fill dams.

The compacting ability of pneumatic tyred rollers may be determined from the following four parameters. 1) Wheal load, 2) Tyre size, 3) Tyre ply and 4) Tyre inflation pressure.

6.4 Economics of construction equipments: -

At the time of equipment selection and planning of finances for construction equipment, it is advisable to make use of principles and techniques of engineering economics. This encompasses the study of working of the equipment and computation of the unit cost of production. This economic evaluation is essential for taking a decision to select an equipment or to retire it. Unit cost of production may be calculated after estimating the cost of production by calculating hourly ownership and operating cost of the equipment as well as knowing hourly production of that equipment.

Equipment selection, of course, is a decision making process which takes into account the least cost of unit production from various alternatives available. Various factors of economics are to be considered such as the rate of interest of the equipment, time requirement for completion of the project and the effect of time on the project as it is a well known fact that time is money.

The hourly working rate of construction equipments comprises of the following components:

1) Owning cost – It consists of the following elements.
   a) Investment cost
   b) Depreciation cost
   c) Major repair cost
2) Operating costs – The elements of operating cost are as follows.
   a) Cost of fuel (or power)
   b) Cost of lubricants, filters and grease
   c) Servicing and maintenance cost
   d) Labour cost
   e) Cost of field repairs
   f) Various other overheads
   g) Tires
   h) Replacement of high wear items.

*1. **Owning cost**: -*

a) Investment cost: - It is a kind of fixed cost which is the cumulative result of those cash flows an owner usually incurs whether the equipment is productively used or not. It comprises of the following components:

- Interest on the money invested in the procurement of the equipment.
- Various taxes on the equipment
- Insurance expenses
- Storage and miscellaneous expenses

The owner has to invest certain amount for the purchase of an equipment. Interest would have accrued, if the money spent on the purchase of equipment was invested in the bank or similar other agencies. Thus, the amount equivalent to the interest where such rate of interest is equal to the prevailing market rate is to be recovered from the equipment. Wherever possible, it is desirable to workout the average annual cost of the construction equipment. The method of calculating the average annual cost of the equipment is as follows:

Let p = Original cost of the equipment

n = Number of useful years or life period of the equipment

Q = Average annual cost

Then, average annual depreciation = p/n

$$\therefore \mathbf{Q} = \frac{\mathbf{P}+\frac{\mathbf{P}}{\mathbf{n}}}{\mathbf{2}} = \frac{\mathbf{nP+P}}{\mathbf{2n}} = \frac{\mathbf{P(n+1)}}{\mathbf{2n}}$$

If average value is to be considered, then average annual cost

$$\mathbf{Q} = \frac{\mathbf{p} + \left(\frac{\mathbf{P-S}}{\mathbf{n}}\right) + \mathbf{S}}{\mathbf{2}}$$

where S = Salvage value or scrap value.

Again, taxes pertaining to the ownership of the equipment are those paid by the owner for the equipment that is charged by any government department. They are commonly assessed at a percentage rate applied against book value of the machine. Similarly, the owner is also required to pay the insurance premium for the equipment in order to cover the risk of theft, fire, damage or accident. In addition to this, storage facilities are required for equipments between jobs or during bad weather. Typical storage cost includes the space rental and other expenses incurred by the owner for up keeping the equipment like utilities and the wages paid to labours or watchman. However, these investment costs are taken as about 10 to 15% of the total cost of the equipment where the total cost comprises of the followings:

i) F. O. R. price of the equipment with all attachment and accessories
j) Insurance and freight charges
k) Expenses on un-loading, clearance and custom duty
l) Cost of transportation to the job site including loading and un-loading
m) Errection and commissioning charges.

b) Depreciation cost: -

Due to constant use, wear and tear as well as going out of date, there is a definite loss of value for each and every equipment. This reduction of efficiency and value of machine or asset with lapse of time during use is known as depreciation. The other causes of depreciation are the physical delay, accidents, differed maintenance and neglect, inadequacy etc. Those may be grouped under two broad divisions as follows

Diagram -------------- (FLOW CHART)

When any machine performs work, wear and tear of certain components are bound to take place despite all precautions to minimize it, and the cost of replacement because of this cause, is the value of depreciation due to wear and tear. There are certain items which get decay because of unavoidable/ local climatic and atmospheric effect as a result of which the value these articles goes on reducing with the lapse of time. This reduction in cost is depreciation due to physical decay. Again, accidents may occur either due to some wrong operation or erratic motion of certain loose components or some other cause resulting in heavy damage and the depreciation cause due to this reason is called accidental depreciation. Further if the manufacturer's instructions or the proper maintenance schedule is not followed by negligence, the life of the equipment is reduced and depreciation of value because of this is called depreciation due to differed maintenance and neglect. Inadequacy is a form of functional depreciation which means reduction in efficiency of a machine in spite of proper precautions and sufficient maintenance as well as the equipment being not able to cope with increased demand of the work or project. This requires additional money either to replace it with a bigger size plant or installation of additional similar plants, which is called depreciation due to inadequacy. If a new equipment comes in the market which is more efficient because of new invention or better design than the existing one resulting in cheaper production, existing machine has to be replaced to withstand market competition. This is called depreciation by obsolescence and is of functional type.

Therefore, some money must be set aside yearly from the profits, so that when an equipment becomes uneconomical or unserviceable, it can be replaced by the new one. The term cost depreciation is used to indicate the process of allocating a prepaid expense to accounting periods during which there are benefits realized from the depreciable equipment. The methods employed to determine the cost of depreciation are arbitrary because it is not possible to carry out tests, either theoretically or practically, to work out the rate of consumption of the economic productive usefulness of depreciable equipment. However, for achieving the accounting objective, cost depreciation seems as a useful tool for redistribution of a prepaid investment cost to production expenses. The following methods are employed to work out the cost depreciation.

1) Straight line method
2) Diminishing balance or constant percentage method
3) Sinking fund method
4) Annuity charging method
5) The insurance policy method
6) The revaluation/ regular valuation method
7) Machine hour basis method
8) The sum of the year's digits method.

The first three methods are mostly used and are described:

*Straight line method: -*This method assumes that the loss of value of machine is directly proportional to its age i.e. the property losses its value by the same amount every year. It implies that one should deduct the scrap value from the original value and devide the remaining value by the number of years of useful life.

If P = Initial cost (original cost) of the machine

S = Salvage or scrap value

n = Life of the machine in years

D = average annual depreciation,

Then $\mathbf{D} = \frac{\mathbf{P-S}}{\mathbf{n}}$ where the total depreciation = P – S

This method of calculating depreciation fund is also known as “fixed installment’’ method, because every year some fixed amount is deducted and no consideration is made about the maintenance and repair charges, which gradually increases with the age of the machine.

<u>Diminishing balance or constant percentage method: -</u>

This is also called “reducing balance” method. It depreciates rapidly in the early years and later on slowly. Thus, the diminishing value of the machine is greater in yearly years, when the repair and renewals are not costly. So under this method, the book value of the machine goes on decreasing as its existence continues. Hence, it is assumed that a property losses its value by a constant percentage of its current book value at the beginning of every year.

Let P = Original or initial cost

S = Salvage value or scrap value

n = Life of the machine in years

x = Fixed or constant percentage taken to calculate the yearly depreciation of book value.

Then, the value of the property at the end of n years or life time $= \mathbf{P}\ (\mathbf{1} - \mathbf{x})^{\mathbf{n}}$

Or $\mathbf{x} = \mathbf{1} - \left(\frac{\mathbf{S}}{\mathbf{P}}\right)^{\frac{\mathbf{1}}{\boldsymbol{n}}}$ ------------------ (1)

The value of the property at the end of m years can be obtained by the expression **Q** = $\mathbf{P}\ (\mathbf{1} - \mathbf{x})^{\mathbf{n}}$

$\approx \mathbf{P}\left(\frac{\mathbf{S}}{\mathbf{P}}\right)^{\frac{\mathbf{m}}{\mathbf{n}}}$ ------- (2)

Here it is to be noted that, the second formula will fail where S= 0 and when the ratio S/P is small, the depreciation for the first year will be considerable.

<u>Sinking fund method</u>: - In this method the depreciation of a property is assumed to be equal to the annual sinking fund plus the interest on the fund for that year. Thus, if A is the annual sinking fund and b, c, d, etc. represents interest on the sinking fund for subsequent years, a schedule may be prepared as shown in the following table.

Age in years	Annual sinking fund	Interest of	Depreciation	Total depreciation

		sinking fund		
1 2 3 4	A A A A And so on	- b c d	A A + b A + c A + d	A 2A + b 3A +b+c 4A + b + c + d

The amount of the annual installment of the sinking fund may be found out by the following formula: $\boldsymbol{l} = \frac{\mathbf{S \times i}}{\mathbf{(1+i)^n - 1}}$

where S = amount of sinking fund

i = Rate of interest expressed in decimal

n = Number of years required to create the sinking fund

l = annual installment required.

c) Major repair cost: - In contrast to the minor or field repairs that are carried out during the day to day working of the equipment, the major repairs are carried out after the substantial use of the equipment. Major repairs and overhauls refer to the replacement of major parts of the equipment because of excessive wear through a long period of use. As these repairs demand a heavy amount of expenditure, they are met out of the major repair fund. However, the major repair cost is spread over entire life span of the equipment and a flat rate is levied per working hour in order to have a uniform rate. The amount thus collected in the pool is known as major repair fund and major repairs and overhauls are carried out from this pool.

But, the usual practice is to consider this major repair cost as a percentage of straight line depreciation cost and is generally taken varying from about 80 to 200% of the cost of depreciation depending upon the type of equipments and the manner in which it is looked after. Moreover, the records of similar equipment may serve as a good guide in this respect.

Example – 1: -

A construction equipment was purchased in Rs. 15000/-. Assuming its salvage value at the end of 5 years to be Rs.5000/-, determine the amount of depreciation for each year by
i) Straight line method,

ii) Constant percentage method iii) Sinking fund method

Solution:-

i) Straight line method: -

Here, initial cost, P = 15000/-

Salvage value, S = 5000/-

Machine life, n = 5 years

Then, average annual depreciation $D = \frac{P-S}{n} = \frac{15000-5000}{5}$ = 2000/-

And total depreciation = P – S = 15000 – 5000 = 10,000/-

This is depicted in the following table

Depreciation – Straight line method

Age in years	Book value at the end of years (Rs)	Depreciation	Total depreciation
0	15,000	--------	---
1	13,000	2000	2000
2	11,000	2000	4000
3	9000	2000	6000
4	7000	2000	8000
5	5000	2000	10,000

ii) Constant percentage method: - Here the fixed percentage of depreciation $x = 1 - \left(\frac{S}{P}\right)^{\frac{1}{n}}$

$$= 1 - \left(\frac{5000}{15000}\right)^{\frac{1}{5}} = 1- 0.8027 = 0.1973$$

Depreciation – constant percentage method

Age in years	Book value at the end of years (Rs)	Depreciation	Total depreciation
0	15,000	--------	---
1	15000-2960=12040	0.1973X15000=2960	2960
2	12040-2375=9665	0.1973X12040=2375	2960+2375=5335
3	9665-1907=7758	0.1973X9665=1907	5335+1907=7242
4	7758-1531=6227	0.1973X7758=1531	7242+1531=8773
5	6227-1228=4999 ≈ 5000	0.1973X6227=1228	8773+1228=10,002 $\approx 10,000$

iii) Sinking fund method: - Let the rate of interest 'i' = 5% = 0.05

Amount of sinking fund S = (15,000 – 5000) = Rs 10,000

Annual sinking fund to replace 10,000 in 5 years @ 5% interest

$$A = \frac{S \times i}{(1+i)^n - 1} = \frac{\mathbf{10,000 \times 0.05}}{\mathbf{(1+0.05)^5 - 1}} = 1470.00$$

Depreciation – sinking fund method

Age in	Book value at	Annual sinking	Interest in sinking fund	Depreciation	Total depreciation

years	the end of years (Rs)	fund			
0	15000	--	--	--	--
1	13530	1470	--	1470	1470
2	11986.50	1470	0.05 X1470=73.50	1470+73.50=1543.5	1470+1543.50=3013.50
3	10366.00	1470	0.05 X1543.50+73.50=150.50	1470+150.50=1620.50	3013.50+1620.50=4634
4	8664.50	1470	0.05 X1620.50+150.50=231.50	1470+231.50=1701.50	4634+1701.50=6335.50
5	8348.00	1470	0.05 X1701.50+231.50=316.50	1470+316.50=1786.50	6335.50+1786.50=8122

Example-2

The price of construction equipment is Rs 12000/- and its useful life is estimated as 6 years. Assuming no scrap value, calculate average annual cost of the equipment. Also workout the percentage of average annual cost to the original cost.

Solution: - Here, the original cost, P = 12000/-

FIGURE

Number of useful years, n = 6

Then, available annual cost $Q = \frac{P(n+1)}{2n} = \frac{12000(6+1)}{2X6} = 7000$

Percentage of average annual cost to the original cost $= \frac{7000\times100}{12000} = 58.33\%$

Thus, the average annual cost of an equipment with an estimated life of 6 years is 58.33% of the original cost as depicted in graphical representation of the problem.

Example – 3 (a) A machine was purchased for Rs 4, 50,000/- on 1st January 2004 and the errection and installation work cost Rs 60,000/-. It was replaced by a new one on 1st January 2012. If the scrap value was estimated as Rs 1, 50,000/-, what should be the rate of depreciation and depreciation fund on 15th April, 2008.

(b) If after 5 years of running, some assemblies are replaced and the replacement cost is Rs 90,000/-, what will be the new rate of depreciation?

Solutions: -

(a) Total cost = Machine cost + Errection and installation charges

P = 4, 50,000 +60,000 = 5, 10,000/-

Scrap value S = Rs 1, 50,000/-

Life of the machine = 1st January 2004 to 1st January 2012 = 8 years

$\therefore$ Rate of depreciation $D = \frac{P-S}{n} = \frac{5,10,000-1,50,000}{8} = 45,000/-$

$\therefore$ Depreciation/ year = Rs 45,000/- only

Depreciation fund on 15th April 2008 is (4 installments from 1st Jan. 2004 to 15th April, 2008)

= 4 X 45,000 = 1, 80,000/-

(b) As after 5 years, assemblies have been replaced and the cost of replacement is Rs 90,000/-
Now book value in 5 years will be =4, 50,000 – 5 X 45,000 = 2, 25,000/-
Considering replacement cost = Rs 90,000/-
New book value = 2, 25,000 + 90,000 = 3, 15,000/-
As the scrap value is same, i.e. Rs 1, 50,000/-, hence the depreciation for the rest 3 years will be

= 3, 15,000 – 1, 50,000 = 1, 65,000/-

New rate of depreciation = 1, 65,000/3 = 55,000/-
∴ New rate of depreciation per year = Rs 55,000/-.

Example – 4

A lathe is purchased for Rs 3, 00,000/- and the assumed life is 12 years and scrap value is Rs 75,000/-. If the depreciation is charged by diminishing balance method, calculate the percentage by which the value of lathe is reduced every year and depreciation fund after 2 years.

Solution: - Here, original cost P= 3, 00,000/-

Salvage value S = 75,000/-

Life span, n = 10

Then, fixed percentage x = $1 - \left(\frac{S}{P}\right)^{\frac{1}{n}} = 1 - \left(\frac{75000}{300000}\right)^{\frac{1}{10}}$ = 0.1295

∴ Required percentage = 12.95%

Value of lathe after 1 year = 3, 00,000 (1 – 0.1295) = 2, 61,150/-

Depreciation fund after 1 year = 3, 00,000 – 2, 61,150 = 38,850/-

Now value of lathe after 2 years = 2, 61,150 (1 – 0.1295) = 2, 27,331/-

Depreciation of 2^{nd} year = 2, 61,150 – 2, 27,331 = 33,819/-

Depreciation fund after 2 year = 38,850 + 33,819 = 72,669/- ∴
Depreciation fund after 2 years will be Rs. 72,669/-

2. Operating cost: -

Operating cost is the sum of those expenses an owner experiences by working a machine on a project. It consists of the following components.

a) Power or fuel cost: - Prime movers for construction equipments are generally diesel engines or electric motors. Fuel expenses are best determined by measurements on the job. Accurate service records indicate how many liters of fuel a machine consumes over what period of time and under what job conditions from which hourly fuel consumption can be calculated directly.

When such records are not available, manufacturer's consumption data can be used to construct fuel use estimates. The amount of fuel or electricity required to power a piece of equipment for a specific period of time depends on the brake horse power (BHP) of the machine and the specific work application. Therefore, most tables of hourly fuel consumption rates are divided according to the machine type and the working conditions.

Fuel consumption can also be calculated on a theoretical basis. The resulting theoretical values are adjusted by the time and load factors that account for working conditions, since the theoretical formulae are derived assuming that the engine is operating at maximum output. Working conditions that are to be considered are the percentage of an hour that the machine is actually working (time factor) and at what percentage of rated horse power (load factor).

Optimum fuel consumption in liters per hour may be calculated using the following formula

Fuel consumption = 0.27 X load factor.

Actually, the equipments used in construction industry seldom operate at the rated output, except for a short period of time. During the balance part of its cycle, the demand on the engine will be reduced substantially resulting in decreased consumption of fuel. To allow for this, the value of load factor may be taken as per the following table taking into consideration the job conditions also.

Sl. No.	Type of equipment	Job conditions		
		Excellent	Average	Severe
1.	Wheel type equipment (on highway)	0.25	0.30	0.40
2.	Wheel type equipment (off highway)	0.50	0.55	0.60
3.	Truck type tractors	0.50	0.63	0.75
4.	Excavators	0.50	0.55	0.60

Similarly, the construction equipments are rarely operated for 60min. in an hour and therefore, the actual fuel consumption is calculated by multiplying a utilization factor or time factor to the fuel consumption arrived from the above formula.

b) Cost of lubricants: - The cost of lube oils, filters and grease comes under the broad category of lubricants and depends on the maintenance practices and the conditions of work location. In this connection, either machine manufacturer's guidance concerning time periods between lubricant and filter changes are followed or own preventive maintenance change period guidelines may be established. In either case, the hourly cost is arrived at by 1) considering the operating hour duration between changes and the quantity required for complete change plus 2) a small consumption amount that is added between the changes. In extreme dusty conditions, oil is required to be changed after every 50 hours of working while in normal condition it may vary from 100 to 200 hours. The requirement of lubricants including engine oil, air cleaner oil, transmission oil, greases and hydraulic oil can be assessed on the basis of information supplied by the equipment manufacturer. Although actual consumption of lubricants depends on the condition of the equipment, but as a thumb rule, in diesel engines the expenditure on the lubricants can be taken as 30% of the fuel cost and in petrol engines, it is about 20% of the fuel cost.

Following formula may be used for estimating the hourly consumption of oil

$$Q = \frac{\text{H.P} \times \text{f} \times 0.006 \times 4.5}{7.4} + \frac{c}{t} \quad \textbf{Ltr/hour}$$

where Q = quantity of oil consumed in liter/hour

H.P. = Rated horse power of the engine.

f = Operating factor

c = Capacity of crankcase in liters

t = Number of hours between oil changes.

c) Servicing and maintenance cost: -

Regular servicing and maintenance of each equipment is very essential for keeping the equipment in ready and perfectly working condition. This cost includes

i) Care of tyres and tubes
ii) Care of battery and electrical system
iii) Change of lubricants
iv) Checking and servicing of fuel and lubricating systems including change of filter elements.
v) Cleaning of equipment and other similar works.
vi) Salaries of staff engaged on maintenance and servicing.

d) Labour cost: - It is an important element of operating cost and contributes towards a major part of it. The salaries of operators and helpers engaged in the equipment come under this cost. Also, under the head of labour cost, provision for leave reserve is made which may vary from 10 to 12%. A percentage of the supervisory staff is also to be added depending up on the attention required on that particular equipment.

e) Cost of field repairs: - This is the cost incurred on minor or normal maintenance type repairs which are carried out on the site or in field work shops. These repairs includes replacement of minor parts such as fan belts, filters, bearings, wire ropes etc. and other adjustments required to be carried out during normal working of the equipment.

f) Overheads: - These are the charges which are incurred on complete fleet of the equipment. Therefore, proportional expenditure is booked under this head on each equipment. These charges include the pay on watchman, light and water charges in the storage yards, uniform to the operating and maintenance staff etc.

g) Tyres: - The tyres for each wheel type equipment are a major operating cost because they have a relatively shorter life in comparison to metal parts. Tire cost normally includes replacement and repair charges. However, these costs are very difficult to estimate because of the variability associated with the wear and tear of the tyre with the project site conditions and operator skill. Based on the tyre type and job application, tyre life guide lines are published by both the tyre and equipment manufacturers. Moreover, manufacturer’s suggested life periods can be used with local tyre prices to obtain an hourly tyre cost. However, it must be remembered that these guide lines are based on good operating practices and do not account for abuses such as overloading haul units etc.

h) Replacement of high-wear items:- In fact, the cost of replacement of certain items that have a very short service lives in comparison to machine service life can be a critical operating cost. These items generally differ depending on the type of machine, but typical items include cutting edges, ripper tips, bucket teeth, body liners and cables. The cost can be calculated by using either past experience or manufacturer’s life estimates and converted to an hourly basis.

Thus, all types of machine operating costs are to be calculated per working hour and the applicable costs are summed up for a particular class of machine to obtain a total operating hour cost.

Example: - 5

Determine the owing and operating cost of a power shovel of $5m^3$ capacity from the following data :

Initial cost= Rs 18 lacks

Annual investment = 10% of average annual cost of equipment

Life of power shovel = 6 years

Utilization per year = 1500hours

Salvage value of the power shovel = 12% of initial cost

Maintenance and repairs = 25% of annual depreciation

Fuel consumption = 20 ltrs per hour

Cost of fuel = 50/- per liter

Lubricating oil consumption = 0.80liters per hour

Cost of lubricating oil = Rs 250/- per liter

Solution:-

1) Annual depreciation

Here, original cost P = 18 lacs

Salvage value S = 0.12X18 = 2.16 lacs

Life of equipment n = 6 years

Then, average annual depreciation **D** $= \frac{\mathbf{P-S}}{\mathbf{n}} = \frac{\mathbf{18-2.16}}{\mathbf{6}}$ **= 2.64 lacs**

2) Annual maintenance and repairs

Amount of annual maintenance and repairs =25% of annual depreciation = 0.25X D = 0.25 X 2.64 = 0.66 lacs

3) Annual investment

Average annual cost of the equipment considering salvage value Q = $\frac{P+\frac{P-S}{n}+S}{2} = \frac{18+\frac{18-2.16}{6}+2.16}{2} =$ 11.4lacs

Annual investment = 0.10 X Q = 0.10 X 11.4 = 1.14 lacks

4) Total annual investment = (1) +(2) +(3) = 2.64 + 0.66 + 1.14 = 4.44 lacs

5) Hourly owning cost

Utilization per year = 1500 hours

Hourly owning cost = $\frac{\text{total annual investment}}{1500} = \frac{4.44 \text{ X}10^5}{1500}$ = 296 or say Rs 300/-

6) Hourly operating cost

Cost of fuel per hour = 20 X 50 =Rs 1000/-

Cost of lubricating oil/hour = 0.8 X 250 = Rs 200/-

Hourly operating cost = Rs 1000 + Rs 200 = Rs 1200/-

7) Total owing and operating cost

Total owing and operating cost of the power shovel = (5) + (6) = 300 + 1200 = Rs 1500/-per hour.

Cost of fuel per hour = 20 X 50 =Rs 1000/-
Cost of lubricating oil/hour = 0.8 X 250 = Rs 200/-
Hourly operating cost = Rs 1000 + Rs 200 = Rs 1200/-

1) Total owing and operating cost
Total owing and operating cost of the power shovel = (5) + (6) = 300 + 1200 = Rs 1500/-Per hour.

Example -6

Workout the hiring cost per hour for the following data about a bulldozer
Prime cost of bulldozer = Rs 48 lacs
Annual investment = 12% of average investment
Life of bulldozer = 8 years
Utilization per year = 7200 hours
Salvage value of the bulldozer = 15% of prime cost
Maintenance and repairs = 40% of annual depreciation
Annual overhead cost = 60,000/-
Fuel consumption = 30 ltrs per hour
Cost of fuel = Rs 50/- per liter
Lubricating oil consumption = 1.8 liters per hour
Cost of lubricating oil = Rs 250/- per liter
Solution:-

1) Annual depreciation
Here, original cost P = 48 lack
Salvage value S = 0.15X48 = 7.2 lacs
Life of equipment n = 8 years
Then average annual depreciation **D** $= \frac{P-S}{n} = \frac{48-7.2}{8}$ **= 5.1 lacs**
2) Annual maintenance and repairs
Amount of annual maintenance and repair =40% of annual depreciation +annual overhead = 0.40X D +60000 = 0.40 X 5.1 + 0.6 = 2.64 lacs
3) Annual investment
Average annual cost of the equipment considering salvage value Q = $\frac{P+\frac{P-S}{n}+S}{2} =$
$\frac{48+\frac{48-7.2}{8}+7.2}{2} = 30.15$lacs
Annual investment = 0.12 X Q = 0.12 X 30.15 = 3.618 lacks
4) Total annual investment = (1) +(2) +(3) = 5.1 + 2.64 + 3.618 = 11.358 lacs
5) Hourly owing cost
Utilization per year = 7200 hours
Hourly owing cost = $\frac{\text{total annual investment}}{7200} = \frac{11.358 \text{ X}105}{7200}$ = 157.75 or say Rs 160/-

6) <u>Hourly operating cost</u>

Cost of fuel per hour = 30 X 50 =Rs 1500/-

Cost of lubricating oil/hour =1.8 X 250 = Rs 450/-

Hourly operating cost = Rs 1500 + Rs 450 = Rs 1950/-

2) <u>Total owning and operating cost</u>

Total owning and operating cost of the power shovel = (5) + (6) = 160 + 1950 = Rs 2110/-Per hour.

Example - 7

Workout the cost per hour for hiring of a rear dump truck with the following data

Show room cost of the truck = Rs 8, 50, 000/-

Insurance premium per year = 60,000/-

Annual investment = 12.5% of average annual cost of equipment

Life of the equipment = 8 years

Operating time = 3 shift of 8 hours each per day and 25 days per month

Efficiency factor = 0.85

Salvage value = 16% of Show room cost

Maintenance and repairs = 55% of annual depreciation

Annual overhead cost = 75000

Fuel and lubrication cost per hour = Rs 450/-

Monthly salary of operator and helper = Rs 7500/-

Cost of one tire = 8500/- (at least two tires needs replacement twice in a year)

(Use constant % method of depreciation)

Solution: -

1) <u>Annual depreciation</u>

Here, original cost P= 8, 50,000/-

Salvage value S = 0.16 X8,50,000 = 1, 36,000/-

Life of equipment n = 8 years

Then constant percentage of depreciation P = $1-\left(\frac{S}{P}\right)^{\frac{1}{n}}$ = $1-\left(\frac{136000}{850000}\right)^{\frac{1}{8}}$ = 1 - 0.795 = 0.205

Then annual depreciation and total depreciation can be calculated as per the following table

Age in years	Book value at the end of years (Rs)	Depreciation	Total depreciation

0	8,50,000/-	-	-
1	6,75,750/-	1,74,250/-	1,74,250/-
2	5,37,221/-	1,38,529/-	3,12,779/-
3	4,27,091/-	1,10,130/-	4,22,909/-
4	3 ,39,537/-	87,554/-	5,10,463/-
5	2,69,932/-	69,605/-	5,80,068/-
6	2,14,596/-	55,336/-	6,35,404/-
7	1,70,604/-	43,992/-	6,79,396/-
8	1,35,630/-	34,974/-	7,14,370/-

Thus, total depreciation = Rs 7, 14, 370/-

Average depreciation D = $\frac{7,14,370}{8}$ = Rs 89,296/-

2) Annual maintenance and repairs

Amount of annual maintenance and repairs =55% of annual depreciation = 0.55X D = 0.55 X 89296 = Rs 49, 113/-

Replacement cost of two tires per annum = 2 X 2 X 8500 = Rs 34,000/-

Total annual maintenance and repairs = 49, 113 +34,000 = Rs 83, 113/-

3) Annual investment

Average annual cost of the equipment taking salvage value into account

Q = $\frac{P+\frac{P-S}{n}+S}{2} = \frac{850000+\frac{850000-136000}{8}+136000}{2} = 5{,}37{,}625$ lacs

Average annual investment = 0.125 X Q = 0.125 X 5, 37,625 =Rs 67,203/-

4) Total annual investment

Insurance premium per annum = Rs 60, 000/-

Annual over head cost = Rs 75, 000/-

Total annual investment = 89296 + 83113 + 67203 +60000 + 75000 =3, 74, 612/-

5) Hourly owning cost

Operating time per day =3 X 8 = 24 hours

Operating time per month = 24 X 25 = 600 hours

Operating time per year = 600 X 12 = 7200 hours

Efficiency factor = 0.85

Hence total utilization per year = 0.85 X 7200 = 6120 hours

Hourly owing cost = $\frac{\text{total annual investment}}{6120}$ = $\frac{374612}{6120}$ = 61.20 or say Rs 61/- per hour

6) Hourly operating cost

Cost of fuel and lubricant per hour = Rs 450/-

Salary of operators and helpers per month = Rs 7500/-

Salary per year = 12 X 7500 = Rs 90,000/-

Salary per hour = $\frac{90000}{6120}$ = Rs 14.71 or say Rs 15/-

Total operating cost = 450 + 15 = 465/-

7) Total owing and operating cost

Total owning and operating cost of the equipment = 61 + 465 = Rs 526/- per hour
Hence, the hiring charges of a truck will be Rs 526/- per hour.

CHAPTER-7

SOIL REINFORCING TECHNIQUES

It is a well known fact that soil in general and granular soils in particular are strong in compression and shear but weak in tension. The engineering performance of such soils can be substantially improved in the same way as reinforced concrete by introducing reinforcing elements in the direction of tensile strains. Thus, reinforced soil is a composite material which is formed by the association of frictional soil and tension resistant elements of any convenient form in such a way as to reduce or suppress the tensile strain that might develop under gravity and boundary forces.

History of soil reinforcement:-

Soil reinforcement was practiced since ancients times although in crude form and is even seen in the animal kingdom. Beavers build mud dams reinforced with grasses, tree branches and stones etc. to ensure greater depth in shallow streams. Also, some of the historical monuments like Great Wall of China bear testimony to the use of earth reinforcement technique over the centuries. However, no systematic or rational study of the soil reinforcement was made till Henri Vidal; a French engineer published his investigation on soil reinforcement in 1996 and coined the term 'Reinforced Earth'. He, too, demonstrated the rationality of the concept by employing it in retaining wall construction. Moreover, the trust reposed by him in this technique has been amply demonstrated by the satisfactory performance of hundreds of civil engineering structures built using reinforced earth technique over past five decades. No other construction technique has aroused so much interest and awareness amongst the civil engineers in recent times as soil reinforcement has done. It's apparently simple mechanism of construction and the economy in cost and time has made it an instant success for the researchers and field engineers alike.

Advantages of Reinforced Soil:-

Reinforced soil possesses many novel characteristics, which make it very suitable for construction of geotechnical structures, particularly by retaining structures. It makes use of prefabricated elements (both the reinforcing material and facing units) which can be easily stored, handled or assembled. Ordinary frictional soil constitutes most of its bulk and it can be easily placed in position by modern handling and compaction equipments. The flexible nature of reinforced earth mass enables it to withstand large differential settlement without distress. Reinforced earth thus permits construction of geological structures over poor and difficult sub-soil conditions. Reinforced earth structures are consequently economical when height of the structure is large or ground conditions are unfavorable and suitable back fill materials are locally available. Savings even upto 50% have been recorded in many a number of instances by adoption of reinforced earth structures.

To summaries, it can be said that soil reinforcement technique results in

i) a simple composite material quick and easy to make

ii) a flexible material, able to withstand considerable deformation without damage.

iii) a durable heavy material both from the technical and architectural point of view.

iv) an economical and environment friendly materials.

These diverse merits of reinforced soil render it a unique material and enable its use in almost all civil engineering structures.

Basic components of reinforced soil:-

There are three basic components of any reinforced soil structure. They are i) soil or fill matrix ii) reinforcement iii) facing (if necessary). In addition, other materials may be required to cover associated elements such as the foundation, drainage, connecting elements and capping units etc.

Soil matrix:-

In a reinforced soil structure, the fill matrix or soil constitutes most of the bulk. It is always possible to build up a reinforced soil structure either using the soil available at the site or using some soil extracted from the nearby site provided the soil is suitable. The choice of the soil is determined from the following considerations:

i) Type of structure
ii) Long term stability of completed structure
iii) Short term (construction phase) stability
iv) Physiochemical properties of materials
v) Economy

The stability of the reinforced soil structure largely depends on the adequate development of friction bond between the soil and reinforcement. Again, the friction mobilized is a function of the characteristic of soil as well as the reinforcement. The characteristics of the fill that affect the soil reinforcement friction are its composition, density and gradation. Therefore, in vertically filled reinforced soil structures a better quality of fill is likely to be specified in contrast to the embankment structures where the whole objective of reinforcing concept might be improvement of the existing marginal fill.

Cohesiveness soils compacted to densities that result in volumetric expansion during shear are ideally suited for use in the reinforced soil structures. On the other hand, cohesive soils are not suitable for reinforced soil structures as these type of soils are normally poorly grained and excess pore pressure might develop during construction leading to short term instability of the structure. However, cohesive frictional soil (c-$\emptyset\ soil$) can be a convenient compromise between the technical benefits of cohesion soil and economic advantages of cohesive soil. Also the use of waste materials, like pond ash, as a fill for reinforced soil structures is desirable from environmental as well as economic point of view.

Reinforcing material:-

The most common types of reinforcement used in reinforced soil structures are i) Strips ii) Grids and iii) Sheets.

i) Strips:- These are flexible linear elements having breadth greater than their thickness. The thickness of these elements ranges between 3mm to 9mm, while the breadth varies between 40mm to 120mm. The most common types of strips are metals galvanized steel, aluminum magnesium alloy, 17% chrome stainless steel. The strip may either be plain or having special protrusions such as ribs or grooves for increasing friction between the reinforcement and soil. However, when the metal strips are used as reinforcement, provision should be made for the loss of thickness due to corrosion. Ferric steel with 17% chrome is found good corrosion resistant metal. This factor should be kept in view considering the durability of the structure. However, metal reinforcements are used by providing an additional thickness of 0.75-1.25mm for galvanized steel and 0.1 to 0.2mm for stainless steel, depending upon the nature of soil, for making up the loss of corrosion. Strips can also be formed from natural products like bamboo or synthesis products like polymers and glass fibre reinforced plastics.

ii) Grids: - These reinforcing elements are formed from the transverse and longitudinal members, in which the transverse members run parallel to the face or free age of the structure and behave as abutment or anchors. The main purpose is to retain these transverse members in position. Since the transverse members act an abutment or anchor, they need to be stiff relative to their length. The longitudinal members need to be flexible having a high modulus of elasticity but not susceptible to creep.

Grids can be made from steel in the form of plain or galvanized welded wire mesh or from expanded metal. On the other hand, the grids formed from polymers are known as geogrids and are normally in the form of an expanded proprietary plastic product. The raw material for the geogrids are polypropylene or high density polyethylene. The polymer sheets are first perforated, the form, size and the distribution of holes being determined by the end product. The perforated sheets are then stretched in one direction while being gently heated. This action of stretching the sheet, helps to align the polymers long chain modulus in the direction of stretch, giving the grid a high tensile stiffness in this direction. Thus, a uniaxial lattice, that is, a grid stretched in one direction is produced. The term uniaxial owes its name due to the alignment of stretched polymer ribs and greatest strength properties in one direction. Alternative form of gird is produced by clamping the uniaxial lattice on the stretched side and applying a second stretching on the transverse direction. This results in a biaxial grid with a square shape of aperture. Both the types of grids are used for soil reinforcement. However, the grids should be selected with due regard to the intended purpose and specified design life of the structure under consideration. (Fig……….)

Sheet reinforcement: - Generally sheet reinforcement is formed from metal such as galvanized steel or woven fabric (textile). Most common sheet type of reinforcement is called geo-fabrics. These are porous fabrics manufactured from the synthetic materials such as polypropylene, polyester, polyethylene, polyamide and glass fibres. They are generally available in thicknesses ranging from 0.125mm to 7.5mm with permeability comparable in the range from course gravel to fine sand. These can be manufactured in a variety of ways, the most common methods being i) woven, made from continuous monofilament fibres and ii) non woven, made from discontinuous or staple firbres laid down in a random pattern and then mechanically entangled into a relatively thick, felt like fabric by means of punching with barbed needles. A wide variety of both woven and non-woven fabrics are available in the market where the fibres are either borded or inter-locked. In India, the geo-fabrics are popularly known in the trade name of geotextile.

Of course, geofabrics have several distinct advantages as soil reinforcement compared to steel or aluminum strips. It possesses high tensile strength and is flexible and thus not affected by large settlements. Also their durability is high when the fabric is not exposed to direct sunlight. The surface area of geo-fabric being large, the force in it can be affectively transferred to the soil with short anchor length, often resulting in economy. The main disadvantage or limitation of geo-fabric as soil reinforcement is the requirement of large deformation to mobilize its tensile strength which can be substantially reduced by pre-stressing.

Other reinforcing materials: - Besides the preceding three types of reinforcement, anchor and planks are also sometimes used for reinforcing soil. Anchors are flexible linear elements having are or more pronounced protrusions or distortions which act as abutments or anchors in the fill or soil. Usually they are either a double reverse bend of ‘Z’ shape with a short length at one end or a triangle shape incorporating a short length of weld to prevent the anchor being distorted when subjected to tensile forces. The planks can be made of timber, reinforced concrete or pre-stressed concrete. (Fig……..)

Facing elements: - Facing is essential for vertical earth retaining structures. The whole purpose of providing facing is to retain the soil between the layers of reinforcements in its immediate vicinity and to provide a suitable architectural treatment to the structure. Although the facing contributes little to the overall stability of the structure, it should be able to withstand the deformations without distortions and without introducing stresses in the reinforced soil structures. Various materials like galvanized steel, stainless steel, aluminum, bricks, precast concrete slabs, pre-stressed concrete panels, geo-textiles, geogrids, plastics, glass reinforced plastics and timber may be used for this purpose. However, facing made of metal units or precast concrete panels are commonly used because of their easy handling and assembling.

Metal facing: - These elements are manufactured from mild or galvanized steel or aluminum and have the same properties as the reinforcing strips. The size of the metal facing elements is generally 333 mm high. In cross section, a metal facing element is semi-elliptical and there is a continuous horizontal joint along are edge. Holes are provided for bolting the facing elements to one another and to the reinforcing strips. This type of facing was first to be used in reinforced earth construction. It can adopt itself to significant deformation due to the shape in profile and thickness in cross section. The standard facing elements may be straight, measure up to 10m long and weigh 115kg. Also, shorter facing elements are available for connection at the extremities, and special units are supplied for corners. (Fig……..)

Concrete panel facing: - The precast concrete panels are cruciform shaped, separated by a substantial joint and weigh about 1 ton. Vertical dowels set into the panels assists in assembling and ensure the interaction between panels which makes the entire facing behave like a flexible unit, even in situations of significant differential settlement. Generally, the facing is a mosaic made up of units measuring 1.5mx1.5m.

Although, each individual element is rigid, but in combination, the flexibility of facing elements is equivalent to that of metal facing elements. Since the dowel allows rotation of panels, it is possible to construct a curved shape of the wall with a minimum radius of 20 meters. Also, it is possible to create architectural effects by modifying the shape and finish of the concrete panels. Usually, two or three tie strips are cast into the panels to accommodate four or six reinforcing strip starters. The manner in which these starters are set into the panel and their inter locking pattern allow the back fill to be compacted in minimum lays of 375 mm exactly in the same way as in case of metal facing. (Fig………)

Methods of soil reinforcement:- There are two methods by which the reinforcing elements can be installed in soils.

1. By placing the reinforcements in horizontal layers at pre-detemined spacing during earth filling operations.
2. By inserting the reinforcing elements into the existing soil strata as per a specified pattern.

The reinforcing elements of different shapes viz. strips, bars, sheets or grids etc. can be placed in soil during construction phases / stages of earthen structures such as embankment or back fill of earth-retaining structures. The strips and bars are just placed in the compacted layers of soil where as the sheets and grids are spread on the horizontal soil surface by rolling out. On the other hand, for reinforcing existing soil formations, the reinforcement elements are driven or grouted after drilling. These are generally in the shape of rigid bars, rods or pipes and are referred to as soil nails. (Fig…….)

Reinforcement strips are linear elements, usually made up of steel having thickness between 5 to 15mm, width between 50mm to 100mm and length of several meters. Sheet reinforcements are made of woven or non-woven geotextile with the appearance of a thick cloth. Grids are mesh like reinforcing elements having apertures of 50mm to 200mm. They may be made up of steel wires, such as welded mesh or of polymeric material usually referred to as geogrids.

Steel bars, rods or tubes having diameters between 20mm to 70mm are either placed on the soil as reinforcement or when used as soil nails, are driven into the soil by percussion hammering, rotary action, vibrations or firing. These can also be grouted after insertion in predrilled holes of diameter 100-150mm.

Mechanism of soil reinforcement: - To demonstrate the mechanism of soil reinforcement, let us conduct a laboratory experiment. A tank ABCD as shown in the figure (a) is filled with sand and when the side AB of the task is removed, the vertical face of the sand gives in to form a slopping surface at angle of repose of the grains (Fig. b). Let us now repeat the above experiment by using geo-textile material (a flexible material resembling a strong or thick sheet of cloth) as reinforcement in sand or the granular soil mass. The geo-textile sheet is placed in horizontal layers at some regular intervals during sand filling in the tank having its ends folded as shown in the figure (c). After filling the tank up to top level, when the side AB is removed, it will be seen that the vertical face of the sand does not collapse. Even if some bulging may be observed, but the face remains almost vertical and stable. This is because of the fact that the presence of geo-textile prevents the movement of soil particles in the failure zone.

The reason for it becomes apparent when we note that a significant length of each layer of the geo-textile reinforcement is embedded in the soil that does not move (Fig.d). When the sand/soil mass in the unstable (failure) zone, tends to move, it tries to pull the geo-textile reinforcement along with it, which however is prevented by the soil of the stable zone that firmly grips the reinforcement not allowing it to be pulled out. This, in turn, ensures that the soil grains in the failure zone does not move being unable to slip past the reinforcement. Thus, the entire soil in which the reinforcement is embedded remains stable. Hence, the effect of the soil reinforcement is to hold the soil mass together as if some 'apparent confining pressure is acting on the periphery of the soil mass or it could be thought of as some apparent cohesion or 'apparent tensile strength' has developed within the soil mass (Fig……).

Interaction of soil with reinforcing material: - The efficiency of the reinforcing material embedded in the soil mass largely depends upon the following factors:

1. The tensile strength of the element.
2. The amount of deformation undergone by the element under tensile stress.
3. The adherence between the reinforcing material and the surrounding soil i.e. the maximum stress resisted by the soil-reinforcement interface before slip takes place.

Of course, when the tensile strength of an element is low, it is likely to become ineffective by yielding or breaking. But if the tensile strength is adequate but its deformation under stress (tensile) is high, the soil is expected to exhibit large movement in the form of settlement or lateral bulging because of the in adequate stiffness of the soil reinforcement system. Moreover, if the reinforcement is sufficiently strong and rigid but the adherence between the soil and reinforcement is inadequate, it leads to relative movement making the reinforcement ineffective.

To illustrate the mechanism, let us consider a tank ABCD filled with dry sand (fig……..). Suppose side AB of the tank is removable such as a metal plate, called facing, which is attached with the reinforcing element embedded in the sand. If the soil reinforcement interaction is satisfactory, the facing remains in position as shown in fig. a. When the tensile strength of the reinforcement is low, failure takes place due to rapture of the reinforcement at F (Fig. b). Further, if the tensile strength is adequate but the reinforcement undergoes large deformation (extension), it leads to lateral and vertical movement of the soil (Fig. c). Even if it has adequate tensile strength and stiffness (low extensibility) but the soil-reinforcement adherence is inadequate, the failure may take place due to slipping out of the reinforcement from the stable soil mass. (Fig. d)

However, it may be noted that amongst metal strips, geogrids and geo-textiles, the metal reinforcement possesses the highest tensile strength and the least extensibility, where as the geogrids exhibit the highest reinforcement-soil frictional or shearing resistance per unit surface area. Hence, these two types of reinforcements are most widely used. The geotextiles, as reinforcement, are suitable in places where the requirement of low extensibility is not very important as well as these are to perform other functions such as facilitating drainage, separation of layers or filtration etc. simultaneously.

<u>The theory of soil reinforcement:-</u>

If two samples of medium dense sand, one reinforced and the other un-reinforced are tested in a triaxial shear test apparatus under consolidated drained condition, the reinforcement being introduced in the reinforced sample in the form of four discs of thin aluminum foil placed horizontally in the sample, the following important observations can be made from these tests.

a) During the shearing stage, prior to the failure, the reinforced sample shows lower radial and axial strain under the same deviator stress as compared to the unreinforced sample (fig a & b)

b) At failure, the deviator stress of the reinforced sample is significantly larger than that of the sample without reinforcement indicating higher shear strength of the former as shown in the fig. c.

These observations indicate that the reinforcing elements oppose the lateral expansion of the sample and also resist failure of the soil due to development of tensile stresses within them and frictional resistance which counteract the movement of the soil grains. Failure takes place only either due to breakage of reinforcement or slippage of soil over the reinforcement (Fig…).

The shearing resistance R, which is developed at the interface between the soil and reinforcement due to adhesion and friction on account of pull out force can be expressed as follows: (fig a)

$$R = (c_a + \sigma_v \tan\delta)\, A_s$$

Where c_a = adhesion = αc
δ = angle of friction between the soil and reinforcement.
σ_v = vertical over burden pressure
A_s = Surface area = $2bL$ for strips of width b
πdL for bars of diameter d,
$2L \times 1$ for sheets,

L being the length of the reinforcement.

Of course, adhesion c_a is usually estimated as a fraction of the cohesion intercept ‘c’ and can be neglected in soils of low cohesion intercept. Angle of friction δ depends on the surface roughness of the reinforcement and the value of $\tan\delta$ usually varies between ½ $\tan\emptyset$ *to* $\tan\emptyset$. But for the case of strips with ribs or transverse elements buried in dense sands, δ values can be higher than $\emptyset$ by as much as even 100%. (Fig…….)

The mechanism by which the grids and geogrids develop their shear resistance is different from that of strips, bars and sheets. In case, the aperture of the mesh or geogrid is very small, it may so happen that the soil might be clogged in the aperture and the mesh or grid may behave like a sheet. On the other hand, when the aperture is large, as is usually the case, the transverse elements of the grid develop passive resistance or bearing resistance offered by the soil which fills the aperture as shown in Fig C. In this case, a bearing capacity mechanism as shown in Fig d, is thought to be operative. Thus, the pull out resistance is postulated to be a sum of the friction adhesion resistance along the longitudinal elements that are parallel to the direction of pull and the bearing capacity type of resistance along the transverse elements that are normal to the direction of pull.

$$R = (c_a + \sigma_v \tan\delta)\, A_s + (cN_c + qN_q + \tfrac{1}{2}\gamma d N_\gamma)\, A_b \times n$$

Where A_b = bearing area of each transverse element, n = number of these elements.

A_b is taken as the projected area (d x 1), where d is the diameter or thickness of the transverse elements and 1 is the unit width of reinforcement. The N_γ term may be neglected due to very small value of ‘d’.

Application of soil reinforcement:-

The soil reinforcement finds its predominant application in the construction of earth structures with steep or vertical sides as a substitute for heavy retaining structures as well as for improving the engineering properties of soil like load carrying capacity or stability of slopes. The former is called reinforced earth wall and such earth structures are extensively used in congested urban areas where there is scarcity of space for accommodation of the base width of conventional earth structures with gently sloping sides. This is particularly economical in case of approach roads of flyover in urban areas where a structure reinforced earth with vertical sides are used in lieu of back filling behind massive cantilever or gravity retaining walls. (fig.….). Besides, there are other applications of reinforced soil such as in the construction of bridge abutments, highway embankment in hilly regions, steep or vertical cuts in open excavations, stabilization of unstable slopes, unpaved roads on soft soils and embankment on soft soils etc. (Fig. …).

Reinforced earth wall:- It is the most commonly used reinforced soil structure with vertical faces. (Fig. ……..) and usually consists of a facing element, reinforcing material and the back fill (Fig. …..). The facing elements are used to provide a sort of barrier at the exposed vertical surface of the earth mass so that the soil is contained. These are generally prefabricated units which are generally small in size and of lights weight so that they can be easily transported and placed in position. The facing usually comprises of prefabricated concrete or steel panels joined together by an interlocking arrangement and should be strong enough to hold back the backfill with an arrangement for fastening the reinforcement to them. The facing units are generally built over a small concrete footing at the bottom for their stability.

Galvanized steel strips are commonly used as reinforcement due to their large tensile strength and low extensibility property. Each strip is about 50-100mm wide and several meters in length, having thickness upto 9mm. Sometimes, metal rods, wires and geotextiles may also be used as reinforcement. The reinforcement is connected to the facing element and extended into the back fill zone. The friction developed in the reinforcement restrains the facing element.

The soil used as back fill in such construction is granular soil with less than 15 percent fines (passing $75\mu\, I.S.$ sieve) to enable development of large friction between the reinforcement and soil. Usually, construction takes place from the bottom upwards and the reinforcement is placed sequentially as the layers of soil are compacted one after the other as shown in the (Fig…….). First a layer of reinforcement strips is placed at the level ground surface and the back filling is done with the selected granular soil. The entire process of laying the strips and back filling is continued till the required height of the reinforced earth wall is attained. However, during construction, care has to be taken to see that the reinforcement is not damaged and that the facing panels are neither displaced nor tilted by the compaction process.

The design or analysis of the reinforced earth wall requires a check on both the external and internal stability. External stability analysis presumes that the reinforced earth wall is internally stable, that is, the reinforced zone of soil behaves like a cemented block and the stability of this block is checked externally against sliding, overturning, bearing capacity failure and a deep seated slip failure as shown in the following figure (fig………) by a procedure similar to that of a gravity retaining wall.

The internal stability analysis of reinforced earth wall requires a check on rupture as well as slip of the reinforcement. For this purpose, an established earth pressure theory is made use of to determine the magnitude of the earth pressure developed and identification of the likely plane of failure within the reinforced soil mass so as to demarcate the boundary between the potentially unstable and stable soil mass. Rankine's theory is most often used for this purpose and the failure plane is a straight line inclined at an angle of ($45^0+\emptyset/2$) to the horizontal.

After identification of failure plane, the interval stability is analysed in the following steps:

a) Likely magnitudes of the vertical and horizontal spacing of the reinforcing elements are assumed. For sheets, grids and geogrids, the horizontal spacing may be taken as unity.

b) The lateral earth pressure and the resultant horizontal F_i to be resisted by each reinforcing elements at different depths are determined. F_i, at any depth di, is calculated by multiplying the lateral earth pressure acting at that depth and the area over which it acts:

$F_i = \sigma_v\, Hi\, B$ where $\sigma_h = K_A\, \sigma_v$ & $\sigma_v = \gamma_t\, di$

Hi= vertical spacing of the reinforcement

B= horizontal spacing of the reinforcement

Of course, this horizontal force is equal to the tension developed in the reinforcement, $T_d = F_i$

c) The occurance of rupture is checked by ensuring that the safety factor against rupture SF_r, is greater than 1.5

$$S\,F_r = \frac{T_y}{T_d} = \frac{6_y A_s}{T_d} \geq 1.5$$

Where, T_y = yield tensile force in the reinforcement

σ_y= yield tensile strength of the reinforcement

A_s= cross sectional area of the reinforcement

d) The occurrence of slippage is checked by ensuring that the length of the reinforcement in the stable soil mass L_e is sufficient to resist the tension T_d with a safety factor $SF_s = \frac{R}{T_d} > 2$, where R=pull out force developed along the reinforcement soil interface for the length, L_e.

However, the overall length, L_o is calculated as (L_w + L_e), for each reinforcement, where L_w is the length in the failure wedge at the corresponding depth. But, usually it is convenient to adopt a constant length L_o for all elements of the reinforced soil zone which is equal to the maximum value obtained among the strips.

Considerations for the design of reinforced earth wall:

The following assumptions may be made in the design of reinforced earth wall.

a) The back fill is horizontal and without any surcharge.

b) The earth pressure acting on the facing element is same as that acts on the rigid vertical face of a concrete retaining wall.

c) Rankine’s theory of active earth pressure holds goods.

d) Failure plane makes an angle of (45^0+$\emptyset/2$) with the horizontal, where $\emptyset$ is the angle of shearing resistance of the backfill material.

(Fig. …….)

Considering a retaining wall AB of height H that rotates about the point A away from the back fill, a failure plane AC is formed making an angle of (45^0+$\emptyset/2$) with the horizontal.

The active earth pressure acting on the wall at any depth z below the soil surface is given by $P_z = \gamma z K_A$ …………. (1)

and the total pressure per unit length of the wall is given by $P_a = \frac{1}{2}\gamma H^2 \, K_A$ ………..(2). where K_A= active earth pressure coefficient.

Let us divide the height H of the wall into small equal heights h as shown in the figure and z_i be the depth of any reinforcing strip *'i'*. The total earth pressure acting on the elemental strip is represented by the area *abcd* of the pressure diagram. The average pressure p_i on the strip is given by $p_i = \gamma z_i K_A$ ….………. (3)

Assuming that the reinforcing strips are placed at an interval of '*h*' in the vertical direction and the spacing of the strips in the direction perpendicular to the plane of the paper be S, one reinforcing strip is subjected to the earth pressure on the area of (h x S). Therefore, the tension in the strip is given by

$T_i = piA = \ (\gamma z_i K_A\,)$ (h x S) ……… (4).

Using the same procedure, the tension in the other reinforcing strips are determined. Of course, the tension increases as the depth increases. Thus, the sum of the tension in all reinforcing strips is equal to the total earth pressure on a length of 's'.

Thus, $\sum_{i=1}^{n} T_i = sP_{a\text{……….(5)}}$

As the length of the reinforcement strip lying between the wall AB and the failure plane AC is not effective for computing the grip length, the length of strip lying beyond the failure plane AC is taken into account for calculating factor of safety against failure.

Considering the reinforcing strip at depth z_i, the frictional resistance on the reinforcing strip of length 'L_e' is given by

$F_i = F_s T_s$ ……………. (6)

Where F_s is the factor of safety, usually taken as 2 and T_i is the tension in the strip.

If δ is the angle of surface friction between the facing element and the backfill, then $F_i = (\gamma z_i) \tan\delta\, x\ (surface\ area\ of\ the\ strip)$.

The surface area of the strip of width b is taken equal to ($2b\ L_e$) as the resistance develops on both sides of the strip.

Thus, $F_i = (\gamma z_i) \tan\delta\ (2\ b\ L_e)$………… (7)

Substituting the value of F_i in equation (6) and simplifying

$L_e\ \frac{F_s T_i}{2\gamma Zi\ btan\delta}$……………… (8)

The equations (7) & (8) are applicable to rectangular strips.

In case of round bars, the equation is modified to

$L_e = \frac{F_s T_i}{\pi d \gamma Zi\ tan\delta}\ where\ d = diameter\ of\ the\ bar \ldots\ldots\ldots\ldots..(9)$

and for continuous reinforcing sheets, the corresponding equation is

$L_e = \frac{F_s T_i}{2\gamma Zi\ tan\delta}$……………… (10)

Note:- *The angle of surface friction δ depends upon the density and type of the backfill material as well as the roughness of the reinforcing strip. The value of δ usually varies between 0.5∅ to ∅ where ∅ is the angle of shearing resistance of the backfill material.*

The cross sectional area of the reinforcing strip is determined if the allowable tensile stress (f_s) of the reinforcing material is known.

$$Thus\ A_s = \frac{F_i}{f_s} = \frac{F_s T_i}{fs} = \frac{F_s(\gamma z_i K_A)hs}{fs} \ldots\ldots\ldots\ldots\ldots (11)$$

Equations (8) & (9) give different lengths L_e and the cross sectional area 'A_s' for different reinforcing strips. However, for convenience, it is usual practice to adopt the same length and the cross section for all the reinforcing strips.

Reinforced Soil Embankments:-

Reinforcement can be employed in embankments to effect the use of steeper slopes as well as education in the quantity of earth work and for increasing the stability of embankments resting on soft soils.

For steep slopes, particularly when the angle with the horizontal exceeds 45^0, special measures are to be adopted for the protection of slope surface against erosion. These can be done by placing concrete panels, blocks and gabions that is, cobbles held held together in a cage made of wire mesh etc. on the surface of the slope. However, the reinforced soil slopes that are steeper than 70% to the horizontal may be considered to be reinforced earth walls and are designed as such.

The stability of the reinforced earth slope is analyzised in the same manner as that for a soil slope only with a modification that a horizontal force T_i, corresponding to the tension in each reinforcement, is to be introduced additionally in the analysis. The factor of safety against sliding failure is evaluated as the ratio of resisting moment to the driving moment, as follows:

$$F_s = \frac{\sum_i^n (c'_i l_i + W_i cos\theta i \, tan\emptyset'_i) \, R + \sum_{i=1}^m T_i y_i}{(\sum_{i=1}^n (W_i sin\theta_i) R)}$$

For undrained case, with $\emptyset_i = 0 \; and \; c_i = s_u$ the above equation reduces to the form $F_s = \frac{s_u(L_{arc}) \, R + \sum_{i=1}^m T_i y_i}{Wx}$

Where L_{arc} = the length of the curved failure surface, and

X = horizontal distance from the centre of rotation to the centroid of the unstable soil mass, with weight W.

FIGURE

<u>Open excavation using soil nails:-</u>

Vertical or steeply inclined cuts can be made for open excavations by the use of rigid reinforcing elements called soil nails and such slopes are referred to as nailed soil walls. But contrary to reinforced soil walls that are constructed from the bottom to top, the nailed soil walls are usually constructed from top to bottom, in steps, as the excavation proceeds incrementally. Soil nails may be driven or drilled-placed-grouted and the facing of such walls is usually in the form of a wire mesh reinforced shortcrete panels, although metal plates and other type of panels have also been used. Of course, soil nails are installed at an inclination of 20 to 25 degrees to the horizontal near the ground surface with a view to avoid any intercepting underground utilities and the inclination is reduced to 10 to 15 degrees for deeper strata of the cut.

FIGURE

<u>Slope stabilization using soil nails:-</u>

Soil nails may be used for stabilizing potentially unstable soil slopes that are vulnerable to slope failure. Unlike cuts or excavations, which are vertical or near vertical, the soil slopes requiring stabilization, are usually, less steep, often having an inclination of 45^0 or less. For such slopes, the position of critical failure surface of the unreinforced slope and its factor of safety can be obtained from the conventional stability analysis procedures. The increase in the stability of the slope due to introduction of soil nails may also be analysied by using the method of slices along a predetermined circular failure surface. However, the additional forces that must be taken into account are the tensile force T in the nails and the lateral resistance V originating from the interaction of soil and the rigid nails.

FIGURE

Soil reinforcement of unpaved roads

Geo-textiles or geogrids have high tensile strength and hence these can be used to increase the load-carrying capacity of the soil. These are used on soft and compressible soils in the construction of unpaved roads, in which the case base course or stone aggregates are directly placed on the subgrade. The thickness of the stone aggregate can be reduced by placing a geo-textile or geogrid reinforcement on the interface between the subgrade soil and the stone aggregate when the vehicle pass over the road, the geo-textile deforms and the strength is mobilized. The influence of the reinforcement in improving the performance of unpaved road is accomplished by the following mechanisms.

a) By increase in the subgrade strength

b) By increase in the lateral spread of the stress transferred through aggregate or decrease of its intensity and

c) By decreasing the depth of rutting by wheel load due to its tensioned-membrane effect.

If we compare the thickness of stone aggregates for the unreinforced and reinforced cases, for soft soil with undrained strength of less than, 50kN/m^2, the saving in the cost of stone aggregate is significantly more than the cost of the reinforcement which makes the use of reinforcement economically attractive.

FIGURE

Reinforcement of foundation soil

Foundation soils having low bearing capacity beneath the shallow footings can be reinforced for increasing its bearing capacity. The reinforcement is usually designed to with stand rupture and slippage failure.

Placement of reinforcement beneath footings requires excavation of the soil and backfilling the same in layers after careful placement of reinforcement and proper compaction of soil. Hence in these cases, the economics of back filling with the reinforced soil has to be compared with that of backfilling with a better soil or with stabilized soil and may be adopted if viable, since very often the later are more economical. Therefore, the placement of reinforcement at the interface of the footing and the soil beneath is a better alternative where the excavation beneath the footing can be avoided. But such reinforcements are required to possess high strength, high stiffness and high adherence to soil - a combination which is not feasible at present.

However, one reinforcement system which has been found to be useful for embankments on soft soils is the geocell mattress system (fig….). The geocell mattress is constructed of vertical cells made of geo-grids which are interconnected to each other and are filled with gravel. Such mattresses, which can be typically 1m high, improve the performance of the foundation soil by increasing the bearing capacity and reducing the settlements as well as lateral extrusion of the foundation soil.

FIGURE