Unit I - Introduction

Need for prefabrication - Advantages and Limitations - Principles of prefabrication - Modular Coordination - Standardization - Loads and load combinations - Materials - Production - Transportation - Erection

Prefabrication

Prefabrication is the practice of fabricating, assembling components of a structure in a factory or other manufacturing site, transporting complete assemblies or sub assemblies to the construction site and erecting them to form the planned structure

Aim / Need of prefabrication

-> To effect economy
-> To achieve improvement in quality
-> To increase the speed of construction
-> To utilize the materials available locally
-> To obtain characteristics like light weight, easy workability thermal insulation, non combusibility.
-> To reduce errors in construction
-> To avoid wastage of materials

Advantages of prefabrication

-> Readymade components are used and hence there is no need of formwork and scaffolding.
-> Construction time is reduced due to elimination of curing in site resulting in earlier completion of work and lower labour costs

- Time spent in bad weather or hazardous environment at construction site is reduced
- Quality control can be achieved when the components are fabricated in factory prior to construction
- Advanced prefabricated sandwich composite materials can be utilized improving thermal and sound insulation
- Prefabrication can be done where skilled labour is available and costs of labour, material and space are lower
- Onsite congestion is minimized
- Site accidents are prevented
- Modern prefabricated materials used are either eco friendly or recycled and hence less impact on environment
- Dismantling and ~~recycling~~ reconstruction is easier

Disadvantages or Limitations of Prefabrication

- If not properly handled, the prefabricated units may be damaged
- Careful and safe handling of prefabricated components such as concrete, steel and glass panels is required.
- Attention has to be paid to provide high strength and corrosion resistant joints and connections to avoid failure
- Leaks can be formed at joints of prefabricated components
- Transportation costs may be higher for voluminous (large size) prefabricated components
- It is necessary to arrange special equipments like heavy duty cranes for lifting and moving large prefabricated sections

-> Initial costs of prefabrication are higher
-> Local people cannot be given employment as skilled labour is needed
-> Requires high level of coordination between customer, architects, engineers and manufacturers.

Uses / Application of prefabrication

Prefabrication is used in all fields of construction like,

-> Dwelling houses (living house) and public buildings
-> Precast concrete chimneys
-> Precast water tank
-> Retaining walls
-> Pavement floors
-> Underground tunnels
-> Mobile and radio towers
-> Highway (road panels) and railway (sleepers) elements
-> Electric poles

Modular Coordination

Modular Coordination involves producing standardized components of a structure

Modular coordination is a concept of coordination of dimension and space or span in which building components are dimensioned and positioned in term of a basic unit called as module. Modular coordination is possible if dimensions of all elements as well as dimensions of

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building to be erected are in multiples of one basic dimensional unit called basic module. Modular coordination used pre engineered volumetric blocks called as 'building blocks' installed on site.

Aims of modular Coordination

The aims of modular coordination are as follows,

- The principle aim of modular coordination is standardization of components so that there is ease of manufacturing the components and erecting them on site with proper efficiency and achieving economy
- To facilitate cooperation between building designer, manufacturer, distributor and contractor
- To simplify the building design and preparation of building design

- To determine the size and position of each component in relation to other component and whole building
- To optimize the standard sizes of building components.

Objectives of implementing modular coordination

- The main objective of implementing modular coordination is to improve productivity through reduction of wastages during production, installation
- To improve quality in construction
- Reduction in design time due to use of standard details and dimensional coordination
- Benefits through computer aided design and drafting.

Principles of Modular Coordination

(I) Module

A convenient basic unit of size which is used as increment or coefficient in dimensional coordination

1) Basic Module

Basic module is a fundamental unit of size in modular coordination. The sizes of building components, parts of building they form shall be in multiple of basic module. The value of basic module is choosen as 100mm for flexibility and convenience. The symbol for basic module is 'M'.

Basic Module = M = 100mm

2) Multimodule

Multimodules are selected multiples of basic module. Using multimodules it is possible to achieve large reduction in number of coordinating sizes

3) Sub module

Submodules are selected sub division of basic module

(II) Reference system

A reference system is a system of points, line and plane within which a building and its components are related. Reference system should be used during the design stage and also may form the basis of drawing through which the measurements are taken on the site

Modular line - Line in modular reference system

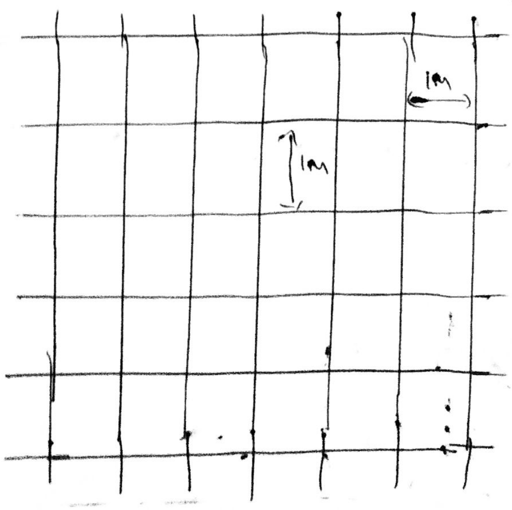
Modular plane - Plane in modular reference system

Modular zone - Zone between modular planes.

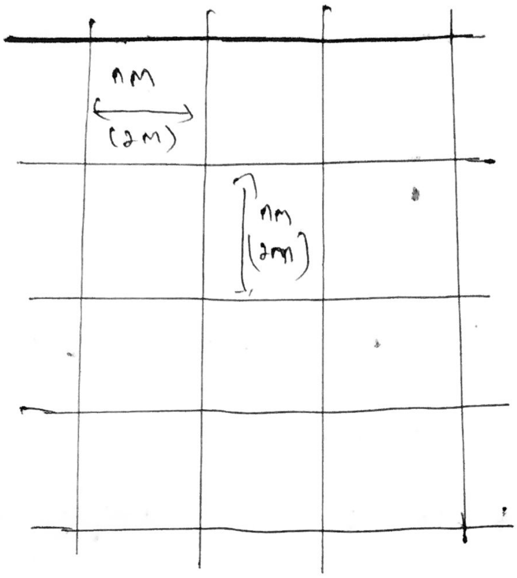
Modular grid - A reference grid in which the distance between consecutive parallel modular lines is basic module or its multiple is called modular grid

1) Basic modular grid - This is the smallest planning grid used as basis for developing other grids

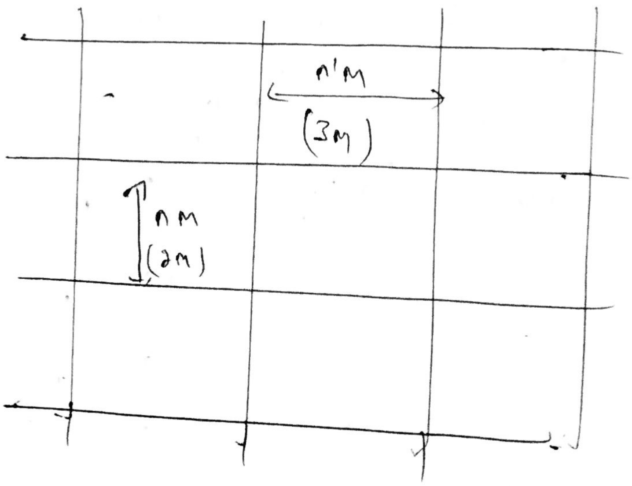
- Normally shown shown on small scale drawings
- Each square is 1m by 1m (100mm x 100mm)
- These drawings are of scales 1:10 or 1:20



2) Multi modular grid - Multi modular grid is formed with the intervals being multi modules
- They can either be squares with same intervals in both directions called as square multi modular grid or rectangular with different intervals called as rectangular multi modular grid



Square modular grid



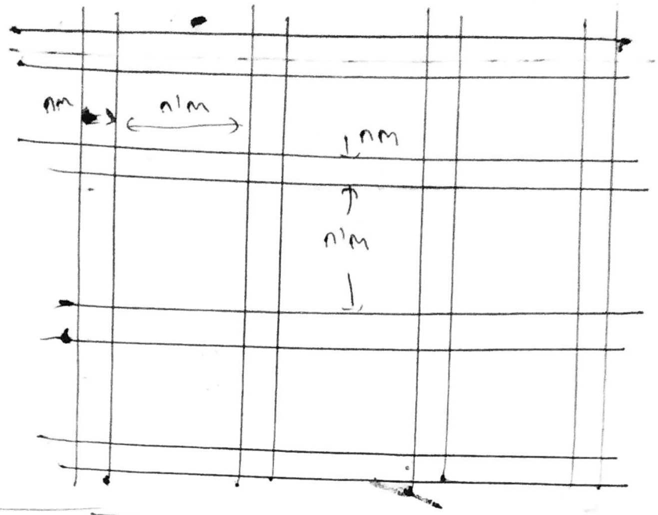
Rectangular modular grid

→ They are used in key plans showing layout of buildings, position of main building components
→ The drawings usually have scales of 1:50

3) Tartan grid - The tartan grid is an interrupted modular planning grid in which the intervals or bands of interruption are regularly spaced

in both directions and are of different modular order

-> This pattern may be used in very regular plans like those with Columns at constant intervals throughout the floor



Rules of Modular Coordination

-> Structural grid is 3M or multiples of 1M. 3M is choosen as most materials like precast floor slabs are in multiples of this dimension (horizontal direction)

(a) 3M for residential buildings

(b) For industrial buildings - 15M for span upto 12M
- 30M for span 12 to 18M
- 60M for span greater than 18M

-> In vertical direction shall be 1M upto a height of 2.8M and 2M for height above 2.8M

-> For doors, multiples of 1M (width and height) shall be choosen. Measurements include door frames

-> For windows, multiples of 1M (width and height) shall be choosen. Measurements Include window frames

-> Sub modular increment may be 0.5M or 0.25M as determination of thickness of many building components may be governed by sub modular increments

→ Dimensions for columns are multiples of 1M with 0.5M as second preference

→ Depth of beams are multiples of 0.5M while width of beam have less relevance to modular coordination

→ Depth of floor slabs will be in sub modular increments of 0.5M (50mm) or 0.25M (25mm)

→ Thickness of walls will be in sub modular increments of 0.5M (50mm) or 0.25M (25mm)

→ The internal dimensions of lift cores shall be multiples of 1M with 0.5M as second preference

→ Length of flights shall be multiple of 1M and width of landings shall be multiple of 0.5M

→ In case of internal walls or columns, grid lines shall coincide with centre line of walls or columns. In case of external walls, the grid lines shall coincide with centre line of wall or column or a line 50mm from internal face

Standardization

Standardization refers to the creation and use of guidelines for the production of interchangeable components of uniform or regular size especially for use in mass production. It also refers to the establishment and adoption of guidelines of global marketing

Standardization ~~The problem~~ is used to describe the simplification of production to achieve economy.

Advantages of standardization:-

Following are the advantages of standardization,

- Easier in design as it eliminates unnecessary choices
- Easier in manufacture as there is limited number of variants
- Makes repeated use of specialised equipments in erection resulting in easier and quicker completion
- Encourage designers to use the recommended dimensions as a starting point of their design
- Minimise errors and rectification works

Factors to be considered in ~~influencing~~ standardization

- To select the most rational type of member for each element from the point of production, assembly, serviceability and economy.
- To limit the number of types of elements and to use them in large quantities
- To use the largest size element according to the extent possible thus reducing the number of joints.
- To limit the size and number of ~~prefabricates~~ by the

to weight in overall dimension that can be handled by the handling and erection equipment and by the limitation of transportation.

→ To have all the prefabricated elements approximately of same weight very near to the lifting capacity of equipment.

Systems:

Definition:-

The word system is referred to a particular method of construction of buildings by using prefabricated components which are inter-related in functions and are produced to a set of instructions. The degree of flexibility varies from system to system.

Characteristics of system:-

The following characteristics are to be considered in selecting a system.

- → Intensified usage of spaces
- → Straight and simple walling scheme
- → Regulated location of partitions
- → Standardized units
- → Structural clarity and efficiency
- → Limited sizes and number of components.

→ Limited openings in bearing walls
→ Limited sizes of doors and windows at required positions.
→ Speed and ease of erection
→ Simple jointing system

Types of system

The system of prefabricated construction depends on the extent of the use of prefabricated components, their materials, sizes and their technique adopted for their manufacture and use in the building. The various systems are explained below.

Based on extent of use of prefabricated Components:

1) Open prefab system

This system is based on the use of basic structural elements to form whole or part of a building. The standard prefab concrete components which can be used are,

→ Reinforced / Prestressed concrete slabs
→ Reinforced / Prestressed concrete beams
→ Reinforced / Prestressed concrete columns
→ Reinforced / Prestressed concrete wall elements
→ Reinforced / Prestressed concrete trusses
→ Hollow core slabs
→ Cellular concrete slabs

There are two categories of open prefab systems depending on the extent of prefabrication used in construction given below,

Partial prefab open system - This system highlights the use of precast roofing and flooring components and other minor elements like lintels, sunshades and kitchen sills in the building construction. The structural system (frame or load bearing walls) are cast in situ

Full prefab open system - In this system all the structural components are prefabricated.

2) Closed prefab system

In this system, the whole elements are casted with connections and erected on site as a whole unit.

Example - Toilet & kitchen blocks

This system provides enough stiffness and stability as they are formed by four adjacent walls. This type of system can also be called as box type system.

Based on size of prefabricated components

1) Large panel prefab system

This system is based on the use of large prefab components. This system refers to system composed of large wall and floor concrete panels connected in vertical and horizontal direction.

The casting of the components could be at the site or factory Thickness of wall panels ranges from 120mm for interior walls to 300mm for exterior walls. Floor panel thickness varies from 50mm to 100mm. Large panel prefab system is classified as below,

Wall - System - Cross wall system
- Longitudinal wall system
- All wall system

<u>Based on their manufacture</u>

1) <u>Cast in site prefabrication</u>

When the prefabrication factory is situated at a long distance from the construction site and the vechicle have to cross a congested traffic with heavy weighed elements, the cast in site prefabrication is preferred. The elements are casted in moulds, cured and then erected at site to form the building.

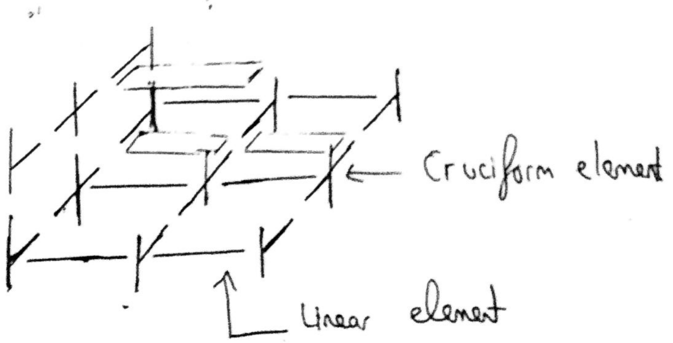
2) <u>Off site prefabrication (or) Factory prefabrication</u>

In this system, the elements are fabricated in factory, transported to the site and erected to form the building.

Based on their use in building

1) Frame Systems

Precast frames is an assembly of beams and columns with proper connection between them. The frame is constructed using two main modular elements a cruciform element and a linear beam element. The cruciform element consists of a frame joint with half of the adjacent beam and column lengths. The frames are constructed by installing the linear beam element in between the cruciform elements. The joint between the linear beam element and cruciform elements are made by welding the projected bars and casting concrete in place



2) Slab Column systems :

The slab column system resists mainly gravity loads

Lift slab system with walls - This consists of precast reinforced concrete columns and slabs assembled by means of special joints. Precast concrete floor slabs are poured in moulds placed in grounds

After cured, the precast concrete floors are lifted ground up to the position of column where it is to be connected. Temporary supports are used to keep the slabs in position until final connections are made.

Prestressed slab column system – In this system after erecting the slabs and columns of storey, the slabs and columns are prestressed by means of prestressing tendons that pass through ducts in the column at floor level along the gap left between adjacent slabs. After prestressing, the gaps between the slabs are filled with concrete.

3) Staircase system

Staircase system consists of single flights with in built risers and treads. The flights are normally unidirectional, transferring the loads to supporting landing slabs or load bearing walls.

Production

For the production of prefabricated elements, all the production processes shall be planned in a systematic way. The various process involved in the production of prefabricated elements are classified as follows,

1) Main Process

It involves the following steps,

-> Assembling the moulds

-> Placing reinforcement cage in position for reinforced concrete work and stressing the wires in case of prestressed elements.

-> Fixing of inserts and tubes where necessary

-> Depositing the concrete into moulds

-> Vibrating the moulds

-> Demoulding

-> Curing the prefabricated element

-> Stacking the prefabricated element

2) Secondary Process

This process is necessary for the successful completion of the processes covered by the main process. It has the following steps.

-> Mixing of fresh concrete in mixing station.

-> Prefabrication of reinforcement cage in workshop

-> Manufacture of inserts and other items to be incorporated in the element

-> Finishing the prefabricated element.

3) Subsidiary Process

This process takes care of all other works involved to keep the ~~main~~ secondary production process to run in cyclic manner

- Transport of cement and aggregate from batching plant
- Storage of materials
- Transport of fresh concrete and reinforcement cage from mixing station and workshop respectively to the mould
- Transport of the prefabricated element for stacking

Methods of Production

The production techniques (or) methods involved are,

- Stand method or stationary mould method
- Conveyor belt method (or) production line method or assembly line method
- Aggregate method

1) Stand method (Stationary mould method)

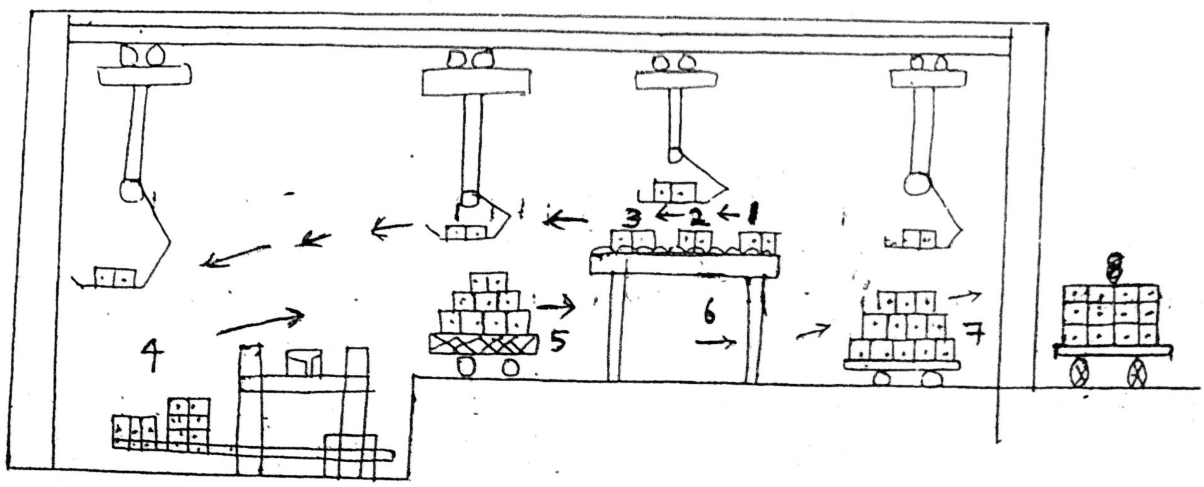
- In the stand system the prefabricates mature (or) fabricated at the point where they are moulded.
- The production team moves to successive stands
- The bed on which the prefabricates are cast may be fixed or movable.
- Tilting forms (moulds) are often used and steam curing is generally done.
- In this method wall panels, floor panels and slabs are cast using this method.

2) <u>Conveyor belt method</u>: (Assembly line production)

→ In the conveyor belt system, the whole production is split into series of operations carried out at successive and permanent points maintained by specialised teams.

→ The movement of the mould from one point to other is by means of conveyor belt, trolleys, cranes etc. The operations of placing reinforcement cage, fixing inserts, casting of concrete, vibrating of moulds, demoulding, curing are done successively when the mould moves to successive points.

→ The joint between the members is made in site with concrete.



Conveyor belt method

→ Following is the procedure involved in production of prefabricates by conveyor belt method, Station 1 → The mould is prepared by treating with mould oil to reduce adhesion of concrete

Station 2 → The mould is fixed with reinforcement cage in case of reinforced sections or tendons in case of prestressed sections

Station 3 → Achoring of prestressing wires are carried out.

Station 4 → The prepared mould is then carried to next station for casting. Here the concrete is poured into moulds and casting is done.

Station 5 → Transportation of casted components to next station for curing. The casted specimens should be carried such that no stresses are induced due to jerks

Station 6 → At this station, the prefabricates are passed through a tunnel autoclave for curing.

Station 7 → After steam curing, the prefabricates are moved to station 7 where demoulding of elements is done

Station 8 → Finally the prefabricated elements are stocked at station 8.

→ This method is used in the production of large arches

3) Aggregate Method

→ In this method, aggregate refer to large complex permanently installed machines and mechanical appliances - which carry out most of the separate operations involved in the casting of concrete components.

→ At production point, the reinforcement is fixed, the inserts and the tubes are fixed, concrete is casted.

→ After casting, the prefabricate is cured in autoclave and concrete is hardened.

→ Aggregate method is used for large scale production

→ Used for casting solid web beams, lattice members, arches etc.

Transportation:

Transport of prefabricated elements inside the factory and to the site of erection is of considerable importance not only from the point of view of economy but also from the point of view of design. Transport of prefabricated elements should be carried out with extreme care to avoid any jerk and distress in elements and handled as far as in the same orientation as it is to be placed in final position.

1) Transport inside the factory

Transport of precast elements moulded inside the factory depends on the method of production selected for the manufacture. As the transportation of the precast elements inside the factory is for a short distance and the elements to be transported per shift is less, lifting equipments like cranes are enough for transportation. These equipments are owned or rented for daily rent. Hence transportation cost in this case is not a considerable one.

2) Transportation from factory to site of erection

Transport of precast concrete elements from the factory to site of erection should be planned in conformity with the traffic rules and regulations as stipulated by authorities. The size of the elements is often restricted by availability of suitable transport equipment. The equipment should be capable of suiting the load and dimensions of the member. Further the load carrying capacity of roads and bridges should facilitate transportation. Equipments like wagons, trucks and bullock carts are used for transportation. Care should be taken to avoid excessive cantilever actions and desired supports should be used. Special care should be taken while negotiating sharp bends and uneven or slushy roads.

Before loading the elements in the transporting media, care should be taken to ensure the base packing for supporting the elements at specified positions.

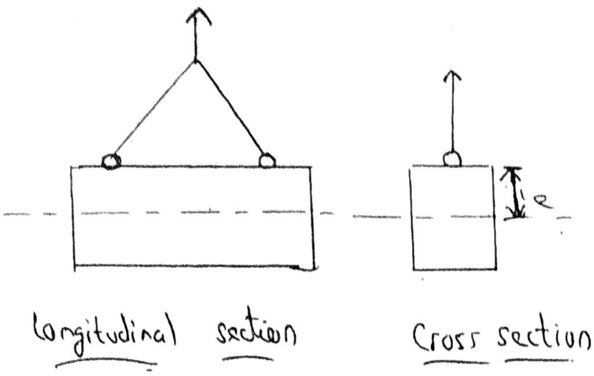
Lifting and Handling / Elimination of stresses

Lifting and handling positions shall be clearly defined paticularly where these sections are critical. When necessary special facilities such as bolt holes or projecting loops shall be provided in the units.

For precast prestressed concrete members, the residual prestress at the age of paticular operation of handling and erection should be considered. The stress thus computed shall not exceed 50 percent of the cube strength of concrete at the time of handling and erection. Following indicates the way of lifting the precast elements

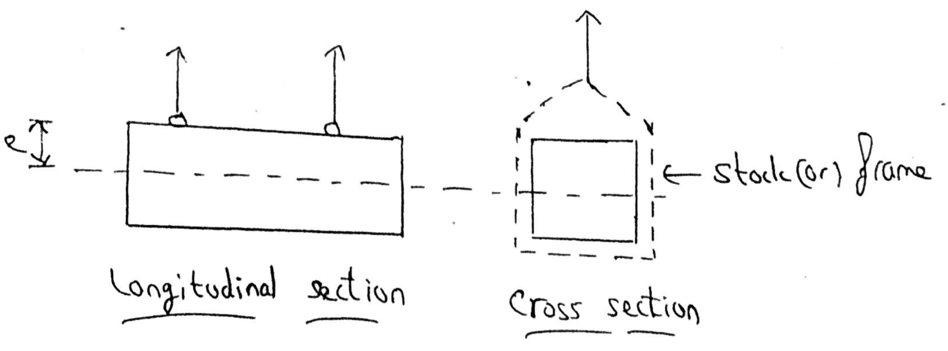
1) Suspension of beams by sloping cables.

Beams are usually suspended (or) lifted at two points using a sloping cable.



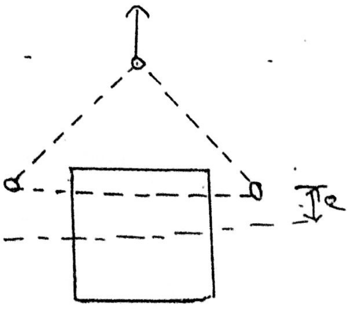
From the figure, it is shown that the points of lifting must be situated above the median of beam otherwise the beam becomes unstable

2) Suspension of beams by stocks



The stability of lifting the beam can be increased by enclosing the beam by a stock (ie) by placing the beam into a rigid frame.

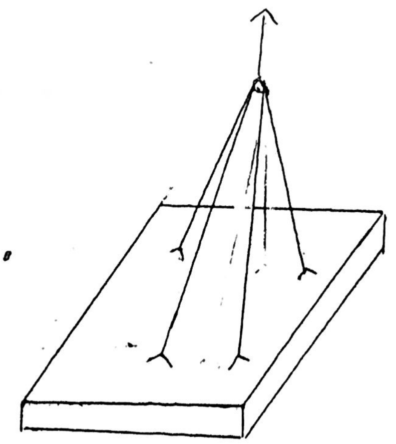
3) Suspension of beams by triangular cable rocker



In this system, high stability is achieved by using extension cable from triangular cable rocker. The extension cables should be of equal length. The lifting should begin simultaneously at every point on either side. If not the member may be distorted and cracks may develop.

4) Suspension of slabs or walls by two way balance rocker

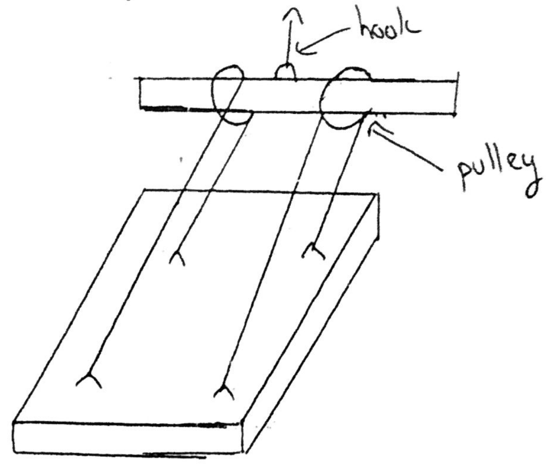
If members have to be lifted at three points or more especially slab and wall elements, two way balance rocker is used.



Due to uneven lifting this may result in determinant cracks (or) even breakage of the member.

5) Suspension of slabs or walls by self setting cable rocker

For even lifting of slab and wall elements, self setting cable rocker is used. This consists of a set of suspension cables suspended from a pair of hook through a pulley arrangement. The pulley enables the movement of cable in any direction.



Erection:

Erection is the process of assembling the prefabricated elements in site at their final position. In the erection of the prefabricated elements the following items of work has to be carried out, in

- ~~Suspending~~ erecting the prefabricated element.
- Typing up of erection ropes to the hooks.
- Cleaning of the elements and site of erection.
- Cleaning of the joints of the elements
- Lifting up the elements, setting them down into correct position.
- Adjustment to get the stipulated level.
- Welding of joints
- Removing the erection ropes.
- Removing the scaffolding or supports
- Finishing the joints to bring a finished product.

Following are the equipments used for erection,

Stationary cranes - Guyed Derrick
- Climbing Crane
- Tower crane with fixed base

Cranes on rails - Portal Crane
- Tower Crane

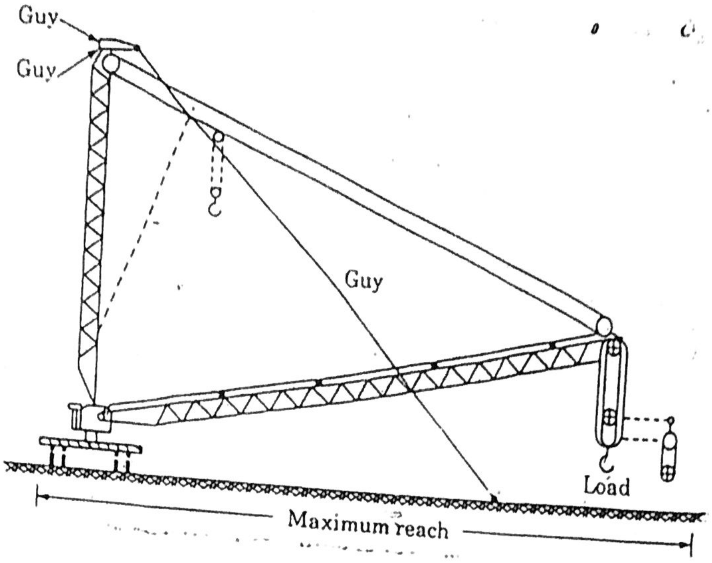
Mobile crane moving on ground - Truck mounted cranes
- Crawler mounted cranes

Stationary cranes :-

1) **Guyed Derrick**

These are used of framed buildings for the erection of floor panel, columns and slab panels. The derricks being lighter in weight can be shifted from floor to floor operating from on erected floor. Following is the step by step procedure for erection using guyed derrick.

→ The column are first erected
→ The beams are then laid connecting these columns.
→ On having completed frame of one storey height, few slab strips are laid around column beam assembly.
→ The Guied derrick is lifted to next floor
→ After shifting, remaining slab strips at bottom floor is completed

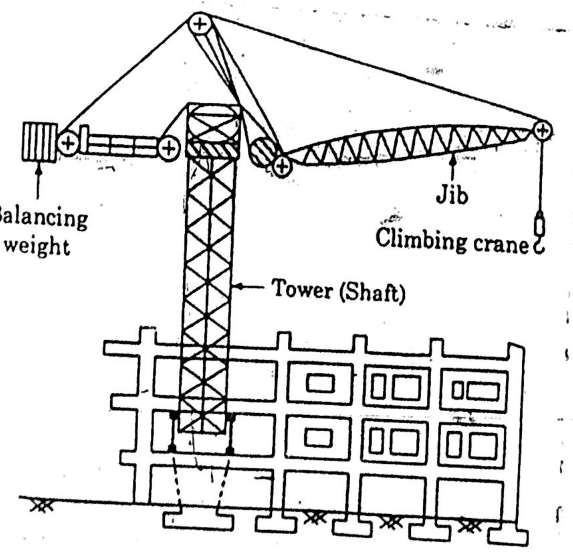


Guyed Derrick

2) Climbing crane

When tall buildings over 20 storeys are constructed this type of cranes are used. This crane consists of

-> a shaft in centre
-> a counter weight placed on top
-> a horizontal jib

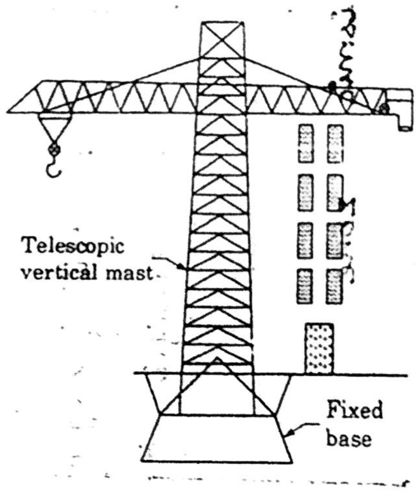


Climbing Crane

The shaft remains stationary and the jib operates at 360°. The elements are lifted with the help of jib and the construction is carried out. The crane can be lifted up to new position as the building goes up. On completion of the building erection, the crane is dismantled and taken through the sides. Such cranes are used where construction is carried out in congested areas. This type of crane can pick the prefabricated elements from all sides of the building and have a reach more than the plan dimensions.

3) Tower crane with fixed base

Where use of climbing cranes are not possible tower cranes with fixed base are installed.



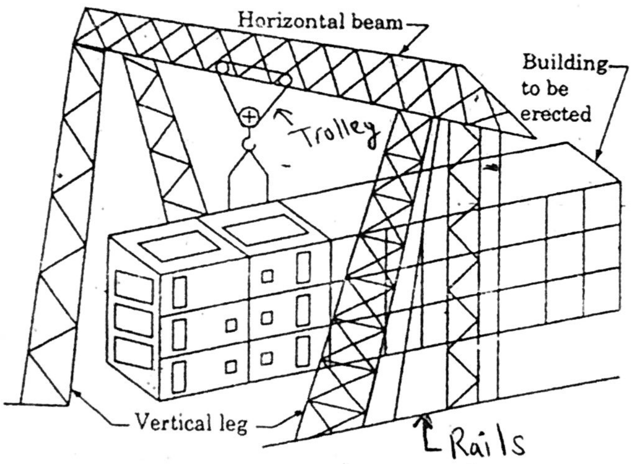
Tower crane with fixed base

These cranes are fixed at the base and braced horizontally to the building portion already completed. As the building rises up, the vertical mast can be hoisted up by special hydraulic jacks provided for this purpose. There is a provision for adding additional mast pieces. Buildings up to 100m height can be built up with this type of crane.

Cranes on Rails :-

1) Portal Crane

In storage yards and in Buildings where the travel distance is short, portal cranes are used. They consist of two vertical legs and a horizontal beam.



Portal Crane

A travelling trolley is attached to the bottom of horizontal beam. These cranes can pick up elements stacked along the side of track. The biggest advantage of such cranes is that they are very stable and can handle large loads. Since there is no counter balancing dead weights are added to the crane, these cranes are lighter in weight and therefore easy to assemble and dismantle without the help of another crane.

The disadvantage is restriction to longitudinal or horizontal movements. No circular motion is possible. Therefore for given operation, the movement of crane required longer construction time.

2) Tower Crane

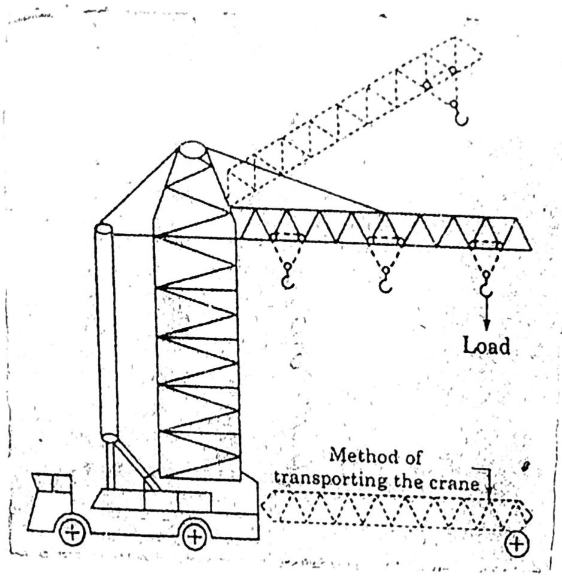
This type of crane is similar to 'tower crane with fixed base' except that it is run on rails. The serious drawback of this crane is that it requires heavy and lengthy crane track, ~~lengthly~~ and expensive assembling and dismantling. The component parts are heavy and therefore the erection of such crane will require the help of another crane. These cranes have a load carrying capacity limited to 6t.

The advantages of this crane is that long reaches of up to 30m can be achieved. Long straight rail tracks and curved tracks of radius of 5m can be used. The central mast will have one or two operator cabin to facilitate view of operator at high heights

Mobile cranes moving on ground :-

1) Truck mounted crane

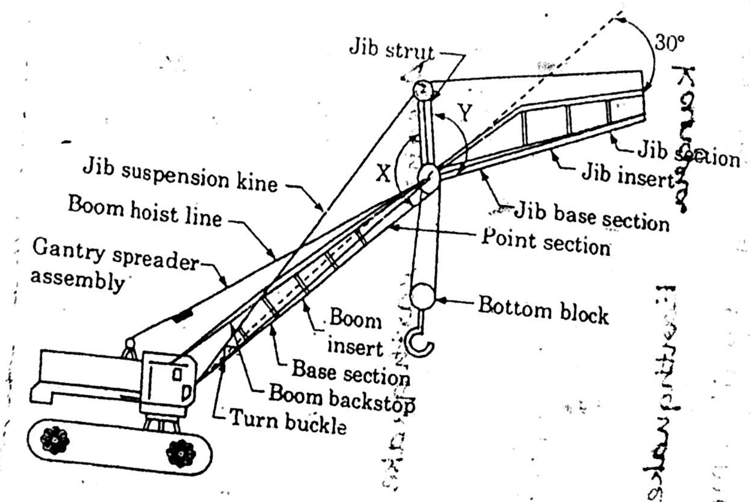
For very quick movements from place to place cranes are mounted on truck with its own operating cabin and a separate chassis. The chassis of the crane will have a generator and motor. Before operating the crane the truck should be checked for its lifting capacity



Truck mounted Crane

2) Crawler mounted crane

This is the most commonly available and vertical crane for all types of construction activities such as excavation, dredging and materials handling.



on hard and compact soil, such crawler cranes can be easily operated. On loose soil it is difficult to move the crane with load.

- dwelling houses and public buildings
- precast Concrete chimneys
- precast water tank elements
- retaining walls
- pavement floors
- underground tunnels
- mobile and radio towers
- highways and railways

Principles involved in prefabrication

The main advantage behind the method of prefabrication when compared to in situ concrete construction is that time and cost is saved. This advantage can be achieved by following the principles of prefabrication given below,

- Simplify and separate building systems
- Minimize building components and materials
- Simplify and standardize connection details
- Adopting proper construction, handling, transportation and erection methods
- Proper maintenance and checks for safety requirements

Building Systems:

Buidings systems may be a single unit or a collection of units arranged in specific manner. Units are defined as box shaped three dimensional units containing walls, floor and roof arranged with an interior

space, which are built in a factory, shipped to site, ins..
and connected into a complete building. These units may
be arranged horizontally or vertically to form a building.
The size, type, number, configuration (way in which arranged), orienation & location
of units depends on the building to be assembled
For efficient prefabrication all the building systems
should be a simple assemblage of units and similar in
size and shape. For conventional representation of dimensions
of buildings, a terminology called module is used.

Building Components and materials:

The building components of a unit should be standardized (ie) the components should be of uniform and regular size. The number of components should be reduced as much as possible and their size and shape should match the transportation, erection and handling limitations. In analysis stage the components comprising the unit are determined based on the components type, material, height, length, width, weight, units per truck and cost. The design of such components should be code based incorporating stress check, deflection check, crack width check etc.

Since the aim of prefabrication is to effect economy, improvement in quality and speed in construction, Lifting and handling - Lifting and handling positions shall be clearly defined. Special facilities like bolt holes or projecting loops should be provided while casting. The weight of the component should not exceed the capacity of lifting or handling equipment.

Transportation - Transportation of prefabricated elements inside the factory and to the site of erection is of considerable importance. Transportation must be done with extreme care so as to avoid any inducing of stresses in the component.

Proper maintenance and check for safety requirements

During construction - Workers must follow necessary safety precautions during casting, handling of prefabricated components.

After construction - Proper maintenance should be done especially joints should be checked for water tightness and corrosion resistance

- The structure must be prevented from fire attacks, chemical attacks and should be durable.

selection of proper materials for prefabrication is also an important factor. The use of locally available materials and materials with required characteristics like light weight, easy workability, thermal insulation and fire resistance is essential.

Connections / Joints.

Connection play a vital role in maintaining the integrity of the building. Their purpose is to transmit forces between structural members. The several different ways of achieving connections are by bolting, welding, grouting etc. The joints should be adequate enough to withstand abnormal loads due to fire, impact, explosions etc. Further a joint should prevent the ingress of water and air into the building.

Construction and Erection

Manufacturing (or) Construction - The manufacture process varies with the type of component to be manufactured, place of manufacture and the principle involved. Manufacturing involves

- Collection and storage of materials
- Preparation of moulds
- Casting of concrete into the moulds
- Demoulding
- Curing.

Materials used :-

The materials used in prefabricated components are many. The modern and common materials used are concrete, steel, aluminium, wood, glass and fibre. While choosing the materials for prefabrication, the following special characteristics are to be considered

- → Easy availability
- → Easy workability
- → Non combusibility
- → Durability in weather conditions
- → Thermal insulation
- → Sound insulation
- → light weight for easy handling, transportation and erection
- → Economy in cost

Concrete :-

- * Concrete used should be of highest possible quality, both in terms of strength and durability.
- * The concrete delivered to the mould should be free from segregation, honey combing and bleeding.
- * Concrete used has a requirement of good workability as the concrete is often transported automatically from an

batching plant to the mould and there is no possibility of performing workability tests.

* Common prefabricated concrete elements include beams, columns, girders, deck slabs, pier, abutment, footings and retaining walls.

* Concrete is also used for making connections between prefabricated elements. These connections offer require the use of high early strength concrete to allow accelerated construction processes.

Structural Steel :-

* Steel elements are well suited for prefabrication and accelerated construction.

* There is a high degree of control over fabrication tolerances and hence complex connections can be made using structural steel.

* Common elements include steel beams, steel girders, steel decks and steel railings.

* Other than elements, structural steel can be used for fabricating connections which can be rolled rectangular or hollow sections, channels, angles, plates, Tees, Bolts etc.

Reinforcement -

* Prefabricated elements are normally heavily reinforced
* High Yield Strength Deformed (HYSD) bars are used in 95% of the cases, even in shear links where mild steel would be suitable.
* Mild steel is normally used for tying wire, because it is easier to hand bend on site.
* Commonly used bar diameters are,
  - main flexural bars - 16, 20, 25, 32 and 40mm
  - Column ties - 8 and 10 mm
  - beam stirrups - 10 and 12mm
* For slabs and, walls, welded mesh is used as reinforcement.

Composites :

Nowadays composite materials and used in prefabrication industry as it incorporates full efficiency of all the materials involved in combination. Some of the composites used are,

-> sandwich wall panels
-> Structural insulated panels (SIP)
-> Insulating concrete forms (ICF)

Loads to be considered

- DL
- LL
- WL
- EL

Load Combinations

Steel members – For design of steel members which are designed based on working stress approach, full loads are considered

DL + LL

DL + WL

DL + LL + WL

DL + 0.5LL ± EL

Concrete Sections

1.5 (DL + LL)

1.2 (DL + LL + WL)

1.2 DL + WL

1.2 (DL + 0.5LL + EL)

Unit II - Prefabricated Components and Systems

Behaviour and types of structural components - roof and floor slabs - wall panels - shear walls - Beams - Columns - Skeletal system - Portal frame system - large panel systems - Block system

Structural Components

The various prefabricated structural components include,

- Roof and floor slabs (panels)
- Wall panes
- Frames
- Beams
- Columns
- Shear wall
- Large panel system
- Block system

Precast Frames

Precast frame involves fabrication of entire frame in factory before starting construction work, transportation to site of erection and erection of planned frame. The various types of precast concrete frames are,

- Skeletal frame
- H frame
- Portal frame

Skeletal frame

Skeletal frame is a frame of structure consists of network or system of colums and supporting or connecting beams which transfers loads from upper floors to foundation below. It also supports interior floors and exterior walls. Skeleton frame is often used in multi storeyed buildings. Use of skeletal frame lead to reduction of importance of masonry in construction (load bearing structure).

Types

(i) Skeletal Concrete Frame

This type of skeletal frame system consists of grid of beams and columns which is constructed on a concrete foundation

→ Columns are vertical members of the frame and are building's primary load carrying element. They transmit the load from beam to foundations

→ Beams are horizontal load carrying elements of frame

Beams are further classified as,

(a) Main Beams – Transmitting floor and secondary beam loads to columns

(b) Secondary Beams – Transmitting floor loads to main beams

(ii) Skeletal steel frame

→ Steel Skeletal frame refers to rectangular grid of vertical steel columns and horizontal I beams which are connected using proper connection. Steel beams around perimeter of structure is called spandrel beams on which walls are placed. Skeletal frame consists of

(a) Vertical Columns – Vertical load carrying members

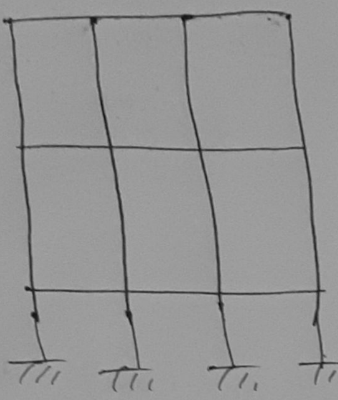
(b) Main or primary beams – Transmits load from ~~Column~~ slab to column

(c) Intermediate or secondary beams – Transfers load from slab to main beams

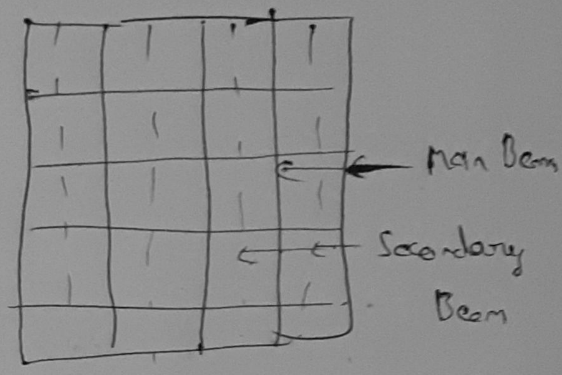
Spandrel Beams - Beams on perimeter on which ~~walls~~ walls are placed

-> Connections between column and beams are made using brackets, gusset plates, haunches using bolt, rivet or welding

-> Shims are used for elevation (height) adjustments



Cross section



Plan

Advantages

-> Construction can be done stage by stage.

-> Walls can be of light weight material

-> Can be used for high rise structures, parking garages etc.

-> Economic

-> Easier modification

-> The frame can be erected as individual components it offers flexibility in design, manufacture, transportation

Disadvantages

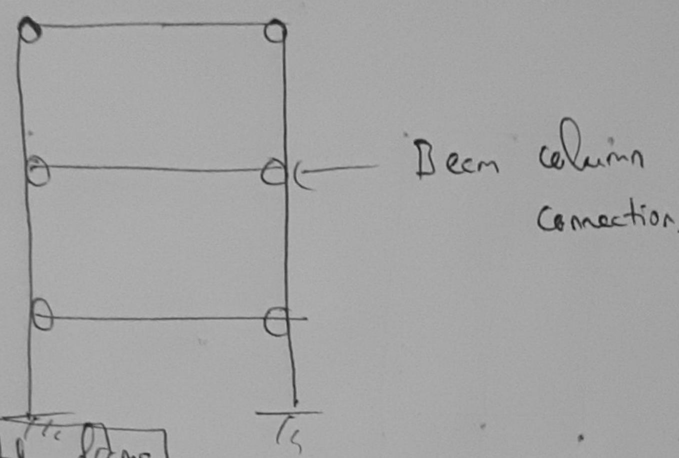
-> High maintenance cost

-> High initial cost

Portal

Connections

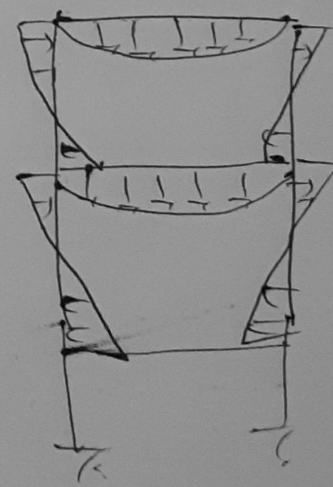
Connections in skeletal frame is formed near the beam column junction for case of precasting as shown below,

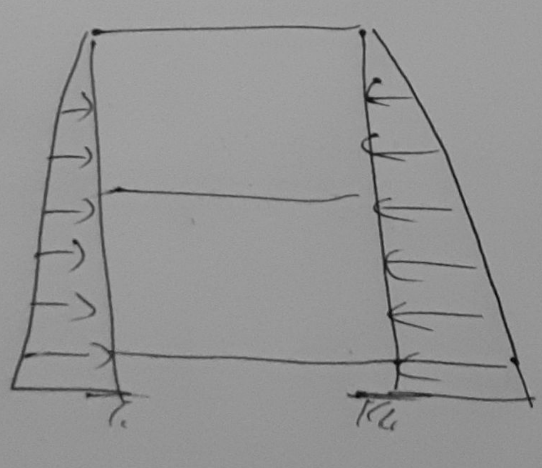


Behaviour of skeletal frame

These frames are designed as moment resistant frames combined with precast or cast in situ shear walls.

Under vertical loading, greater sagging moments are generated in beam. The column moment is much smaller and generated in column itself. Under lateral loading the column moments has increased and they are no longer distributed to beams





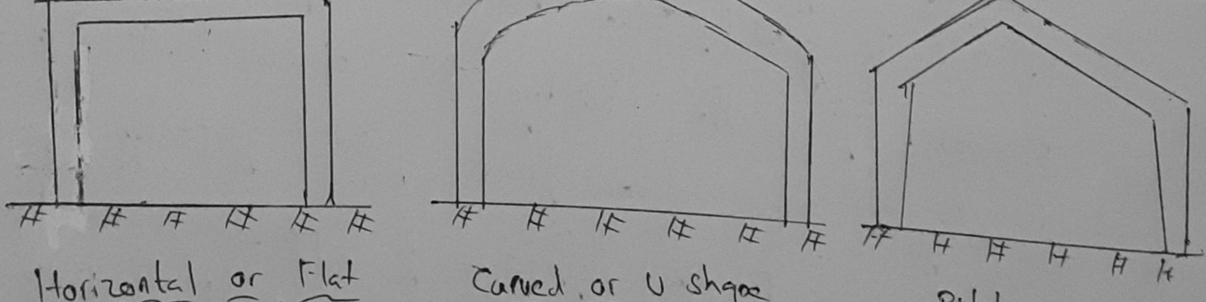
Portal Frame

Portal frame is a type of structural frame used in warehouses, garages, hangar buildings, agricultural buildings, sport venues, large retail shops where a large clear space uninterrupted by intermediate columns is required. Portal frames are used for single storey low rise buildings. Portal frames are generally fabricated from steel, reinforced precast concrete and timber. Building structure is formed by series of portal frames.

Types

(i) Concrete Portal Frame

Concrete portal frame are a combination of two vertical columns and a normal horizontal beam. The vertical and horizontal members are built monolithically and are rigidly connected. The horizontal top members may be horizontal or flat, curved or U shape, pitched.

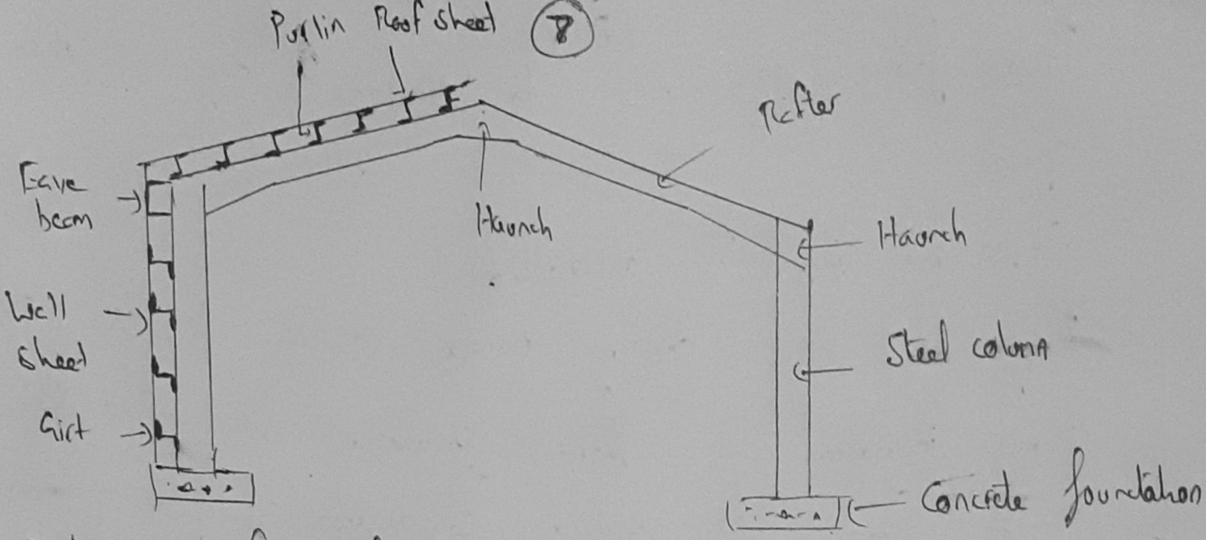


Horizontal or Flat — Curved or U shape — Pitched

In buildings (residential and commercial) The portal frames are spaced at suitable distance of 3 to 4 m. It supports the slab at top. The base of the portal frame may be hinged or fixed. In case of warehouses, sheds and workshop structures roofs are provided as pitched roof with purlins at top (steel b running along length) on which asbestos cement (AC) or galvanised iron (GI) sheet is fixed. In this type, frames are spaced at 6 to 8m.

(ii) Steel Portal frame

Portal frames are generally made of steel as steel frames are cost effective. The steel portal frame consists of vertical steel columns and horizontal beam or rafters. The columns and rafters are generally I shaped and are called primary elements. Roof and wall elements are generally of steel and act as building envelope. Secondary elements called purlins (Z,C), girts (Z,C) and eave (C) beams are used to connect roof sheet to rafter, wall sheet to column and ~~wall~~ sheet to to point of intersection of column and rafter. These purlin, girt and eave beams provide lateral support for main primary elements. Height of steel portal fram varies from 4.5m to 9m in general. The maximum height of 12m may be provided if the building is provided with overhead travelling crane. The frames are generally spaced at 6 to 8m. Bending stiffness of members and rigidity of connections are increased by increasing the depth ~~of~~ ~~crane~~ rafter at connections (eaves and apex) called as haunches. Steel colums are supported on concrete foundations



Behaviour of ~~skeletal~~ portal frame

In portal frames, the joint between beam and column is rigid (fixed). ~~The~~ By using this form of joint bending moment in beam (rafter) gets reduced. This results in reduced sectional size and provision of large spans. Rigid joints are introduced in eave and apex by providing haunch or bracket. Use of haunches ~~or~~ reduces the depth of rafter by increasing the moment of resistance of the member (due to increase in cross section at eave and apex). The haunch also adds stiffness to the frame and reduces deflection. Length of haunch is generally 10% of span of frame and depth is generally 2% of span of frame. In addition to this bracings may be provided in roof and side walls to transfer lateral forces due to wind to the ground. The coloms are usually fixed at base.

Advantages

-> As size of rafter is reduced, portal frames are a very efficient construction technique

→ Portal frames are used to provide large interior space

→ Simple and rapid in construction

→ Roof and wall sheeting panels provide weather proof, acoustic insulation and thermal insulation to the structure

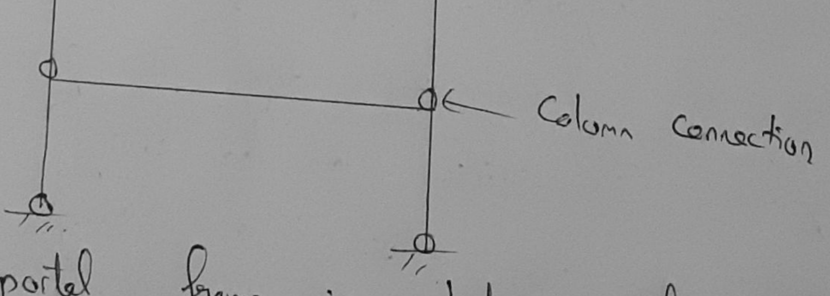
→ Portal frames are used in construction of ware houses, workshops, shopping complex ets.

<u>Disadvantages</u>

→ Though portal frame construction is economic and efficient, care must be taken while designing joints such that it prevents buckling.

→ Portal frames are relatively flexible than skeletal frame and hence ~~capable~~ of deformations (deflection) occurs

<u>Connections</u>



Connections in portal frame is between columns and between columns and foundation. Connections are generally moment resisting connections made using bolting or welding which is capable of ~~traf~~ transferring load and moments between members.

Prefabricated Beams

Precast beams and columns are key structural elements in constructing a structure. Beams are horizontal members that support slabs and other secondary beams. Precast beams can be reinforced either with prestressing tendons or reinforcement bars. The type of reinforcement depends on

-> span
-> loading condition
-> production methods.

Dimensions

Following are the dimensions of prefabricated beams,

-> Depth - 16 to 40inch - 400mm to 1000mm
-> Width - 12 to 24 inch - 300 to 600mm
-> Span to Depth ratios - 10 to 20

Connections

Connections between beam to beam, beam to columns is achieved by projecting reinforcement into sleeves of another member and grouting the sleeves or by using brackets or by welding of reinforcements.

Types

Following are the types of prefabricated beams,

-> Rectangular beam
-> L shaped beam
-> Inverted Tee beam
-> AASHTO beam (I shaped beam)

Rectangular beam

-> Rectangular beams got their name due to its rectangular

Shape

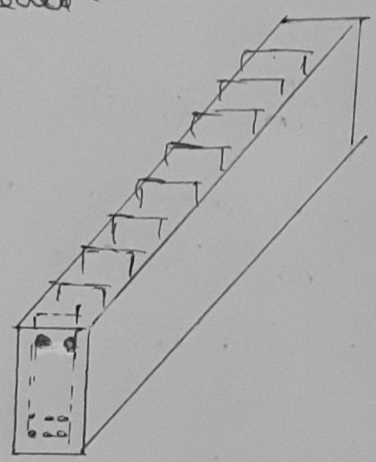
-) These beams are generally used for small clear

-) These beams may be reinforced and/or prestressed

-) These beams possess high strength and structural integ

-) Due to their rectangular shape, the beams have a greater surface area

-) Connections are achieved by reinforcement links projecting out of the top around with insitu concrete can be cast or beams have projections on which secondary beams or floor panels are connected.



-) Rectangular beams are commonly used for parking structures

-) Generally dimensions of rectangular beam are

* Width - 12" to 16"
* Depth - 24"
* Span - 50'

L shaped beam or Spandrel

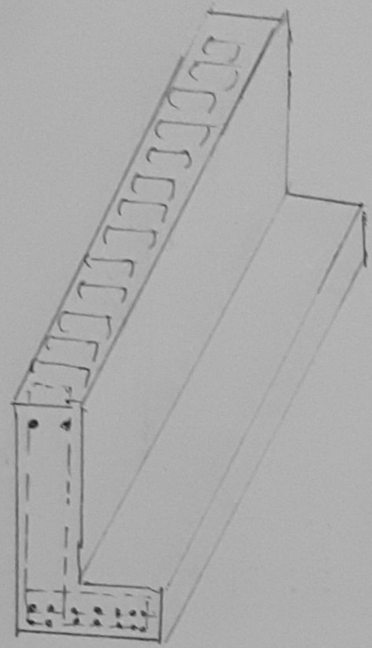
-) L shaped beam have 'L' shaped profile which provides a ledge (shelf like structure) for a precast slab to be placed over it

-) The beams are generally used for small clear spans

-) These may be reinforced and/or prestressed.

(11)

-) These beams possess high strength and durability
-) Normally used in construction of residential and commerical buildings.
-) Generally dimensions of L shaped beam are
~~* width~~ -



* Width - 18'' to 36''
* Depth - 18' to 36''
* Span - 40' to 100'

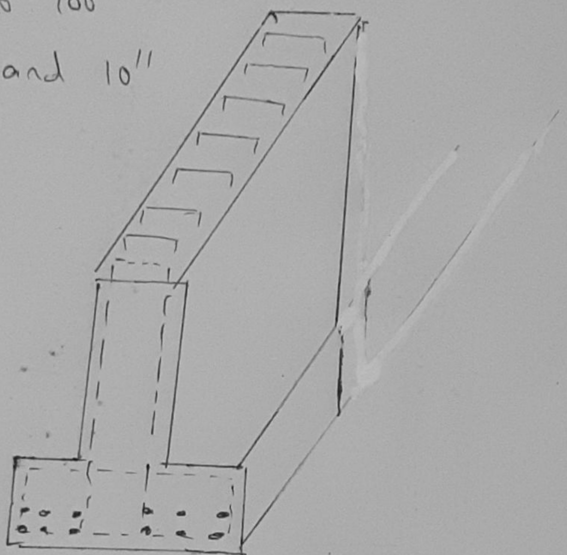
Inverted T beam or Ledger

-) Precast concrete inverted tee beams are highly used and provide many advantages
-) They are often used in parking structures
-) They are ~~dep~~ dependable in roof and floor systems
-) Can be used for high long spans and large buildings like gymnasium
-) Inverted Tee beams are durable and resistant to impact, wear and tear.
-) Inverted Tee beam used for high load bearing capacities and design to accomodate heavy and ~~unsual~~ unusual loads

-> Inverted Tee beams (single or double web) are offered and used in design of fire rated structures

-> Generally Inverted Tee beams are available in sizes

* Width - 18" to 36"
* Depth - 18" to 36"
* Length - 40' to 100'
* Thickness - 8" and 10"

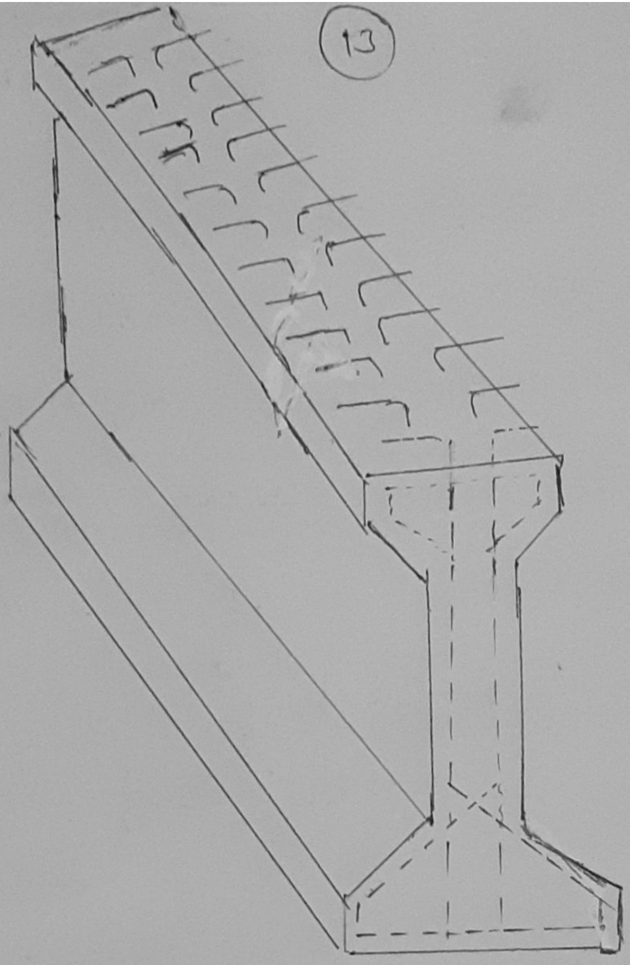


AASHTO Beam

AASHTO stands for American Association of State Highway and Transportation. AASHTO beam is a modified I cross section beam with increased width of lower and upper flange at junction of flange and web thereby forming a bulb shape at top and bottom. This has an advantage of being able to more effectively resist compressive forces also. This AASHTO beam section used as girder for medium to long length (span) bridges. (rail and road). AASHTO beams are widely used as they are efficient and cost effective. General dimensions of AASHTO beams are

-> Width of top flange - 12" to 20"
-> Width of bottom flange - 16" to 26"
-> Width of web - 6" to 8"
-> Depth or height of web - 11" to 23"
-> overall depth - 28" to 54".

(C) Intermediate or ---



Block system

The term precast blocks refers to cement concrete blocks formed or manufactured in factory and used for construction of walls. The blocks may be solid or hollow with hollow space more than 25%. These blocks are used for construction of compound walls and non load bearing walls. It can also be used for load bearing walls if specially designed. The ingredients of precast blocks are one part of cement to six parts of combined aggregate (sand and aggregate chips) with fineness modulus 3·6 to 4, size of aggregate chips being 6 to 12mm, combined aggregate being 60% fine aggregate (sand) and 40% ~~coarg~~ coarse aggregate (chips). The dimensions of precast blocks are

* Length - 400, 450, 500 or 600mm
* Height - 100, 200 mm
* Width - 50, 75, 100, 150, 200, 250 or 300mm

The minimum crushing strength of precast blocks are,

* Solid blocks - 4 N/mm^2 (load bearing wall)
* Hollow blocks - 2 N/mm^2 (load bearing wall), 1·5 N/mm^2 (non load bearing wall)

(c) Interlocking ...

Unit II – Prefabricated Components

Large panel Construction :-

This system is based on the use of large prefab. components. This system refers to system composed of large wall and floor concrete panels connected in vertical and horizontal direction

Behaviour of ~~wall~~ large panels in large panel construction :-

In large panel system the load from the floor is transferred to foundation through walls. The size of panel depends on the maximum size that can be lifted conveniently from casting bed without breaking, capacity of lifting equipment etc. The materials used are bricks, hollow clay blocks, concrete, light weight metal, gypsum, plastic, timber etc.

Systems :-

The structural solution of the large panel buildings are characterized by the orientation of the load bearing walls and whether the slab is one way or two way slabs. There are three basic structural solutions,

- → Cross wall load-bearing systems
- → Longitudinal wall load bearing systems
- → All wall load bearing systems

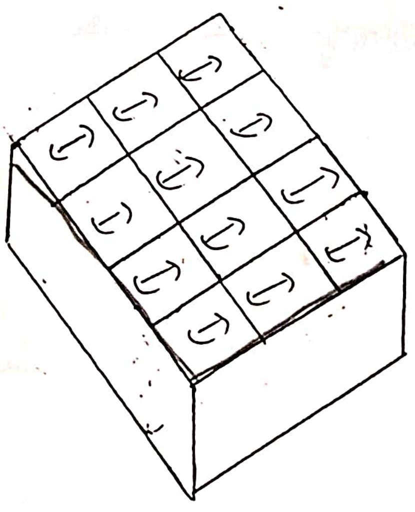
1) Cross wall load bearing system :

→ In this system only the external walls in the cross direction are load bearing while the external walls in the longitudinal direction are non load bearing.

→ This system has one way slab. The one way floor slabs have a span of 6 to 7m and 60-100 mm thick

→ The floor slabs are connected together with wall to form a diaphragm that transmits load from slab to wall and then from wall to foundation

→ Cross wall load bearing system is used for low rise buildings.

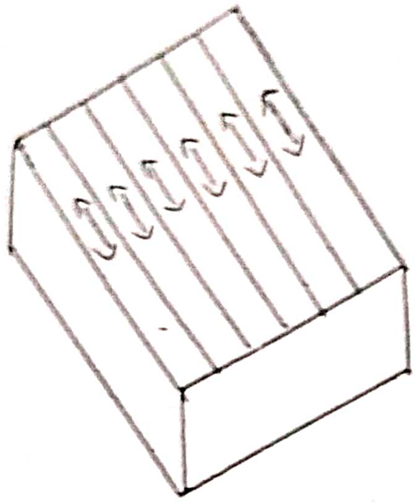


2) Longitudinal wall load bearing system

→ In this system only the external walls in the longitudinal direction are load bearing while the external walls in cross direction are non load bearing.

→ This system has one way slab. In this system the floor slabs can have a longer span of 9-12m. and 60-100 mm thick.

→ Suitable for high rise buildings.

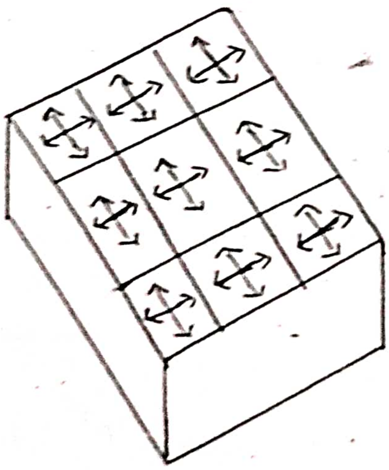


3) All wall load bearing systems

→ In this system the external walls in both cross and longitudinal direction are load bearing.

→ The slab are generally two way slabs. The slabs are generally room size sufficiently 4 to 4·5m with a thickness of 150mm

→ Especially suitable for high rise buildings as it is easier to achieve stability in both the directions.



Structural Integrity :-

Structural integrity means that the stress in the system normally carried in any one of the structural component can be safely transferred to adjacent components without overloading them and causing failure.

In large panel construction, it is more difficult to achieve structural integrity in case of cross wall load bearing system and longitudinal load bearing systems, because the one way slab will collapse. To overcome this special connections should be provided in between wall and slab. with all wall load bearing system, high structural integrity can be achieved.

Advantages of large panel construction :-

- → Mass Production
- → Speed
- → Less structural cost
- → Quality Control
- → Skilled Labour is not required
- → Low initial investment
- → Modularization
- → Durability and long term performance.

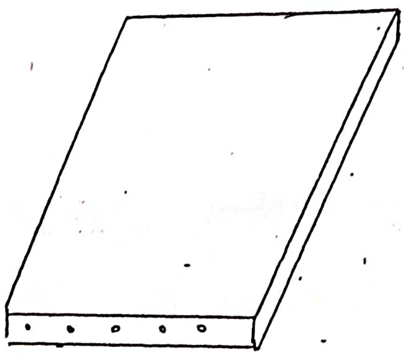
Types of roof and floor elements:

Prefabricated concrete slabs is an economic and versatile solution to ground and suspended flooring. Half of the floor slabs used in commercial and domestic building are prefabricated concrete. It offers both design and cost advantages over traditional methods such as cast insitu concrete, steel concrete composite and timber floors.

1) Solid Floor slabs

→ Solid floor slabs are mostly room sized prefabricated elements. Used extensively in residential and commercial buildings with short span

→ The floor slabs are supported on wall panels either along full length or by means of reinforced concrete or steel brackets if supported at certain locations.



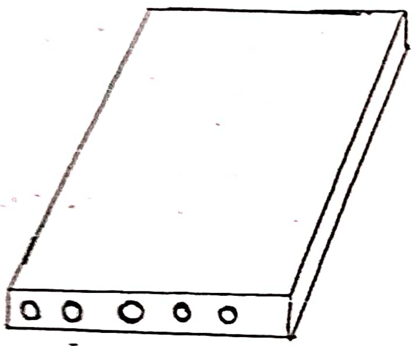
Solid Floor Slab

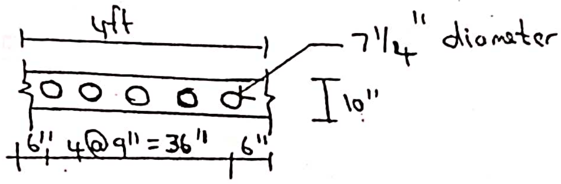
→ The topping is provided over the solid floor slab elements by placing steel mesh to achieve continuity and connection.

2) Hollow Core slab

→ The main advantage of hollow core slabs are the reduction of dead load due to the cores. The hollow cores also facilitate provisions for inserting electrical and mechanical appliances.

→ Slab panels are ordinary available in depths of 6 to 12 inch, and widths of 2 to 8 ft. Spans may range from about 15ft to 40ft. Panels of 4 ft width is common.





Hollow Core Slab

Manufacturing :-

There are two basic methods of manufacturing,

Dry cast or extrusion system – The cores are created by placing augers or tubes. Low slump concrete is forced through the space around the tubes. After filling, the concrete around the cores is compacted.

Higher slump concrete or wet cast - The sides of the hollow cores are formed with either stationary or fixed forms or with forms attached to the machine with the sides being slip formed. The cores in the slab. are formed with either lightweight aggregate fed through tubes attached to the casting machine, pneumatic tubes anchored in a fixed form or long tubes attached to the casting machine which slip form the cores.

Advantage :-

→ Most widely used economical, efficient floor and roof systems.

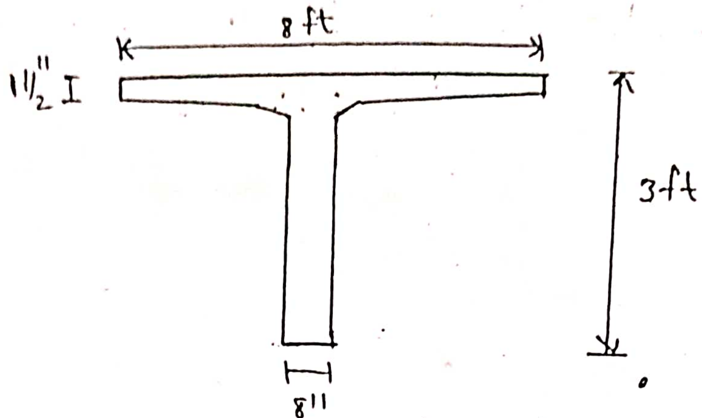
→ With proper alignment, the voids in a hollow core slab may be used for electrical or mechanical appliances.

→ Excellent fire resistance

3) Single T slabs

→ Single T slabs are employed frequently for longer spans and heavier loads in buildings such as parking garages, auditoriums, gymnasiums and dining halls.

→ It consists of single prefabricated rib and a connecting top slab. Topping can be provided over the slabs by placing steel mesh above the slabs.



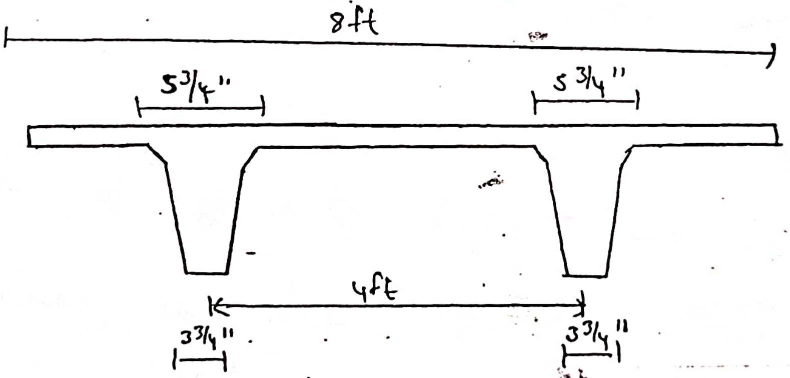
→ Stem width is 8 inch. and flange widths usually 8 or 10 ft
Depth range from 36 to 48 inch.

→ Floor and roof spans of up to 120 ft are common.

3) <u>Double T slab</u>

→ The double T slabs are highly functional because it not only meets structural requirements, but provides a flat surface for usage.

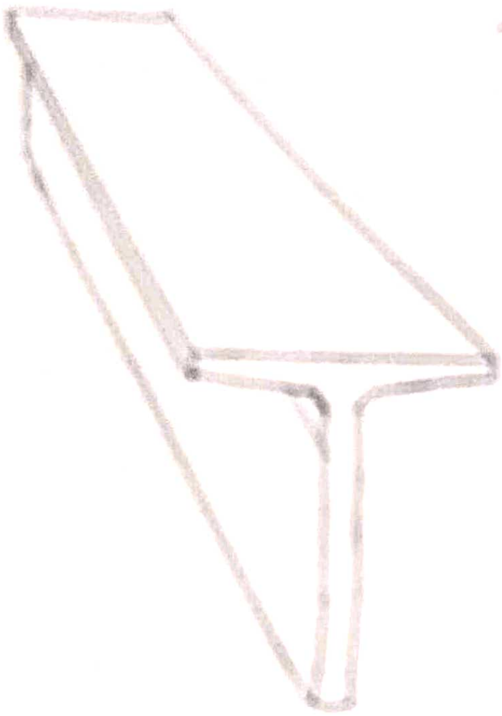
→ Double T slabs achieving greater span with reduced weights when compared to hollow core slabs.



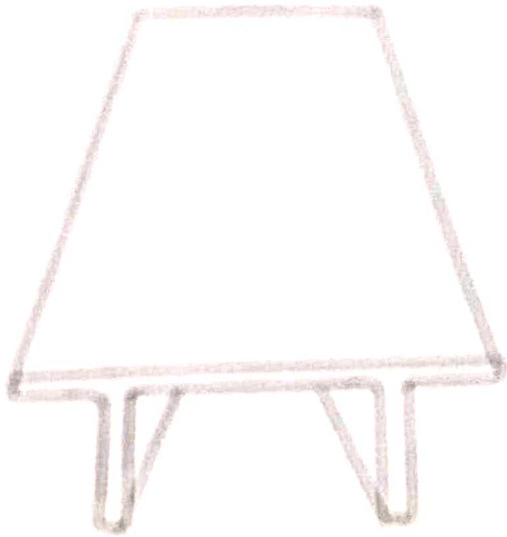
→ T slabs have high strength and stiffness.

→ Double T slab consists of two ribs and a connecting top slab and the dimensions are indicated in figure.

→ Double T slab can easily accomodate electrical & mechanical



Single T slab



Double T slab

Wall panels

→ Prefabricated concrete wall offer a wide variety of shapes, colour, textures and finishes

→ Precast wall panels offer the advantage of speed of construction, smooth surface finishing, acoustic insulation and fire resistance

→ Prefabricated wall panels can be classified as below

1) Based on their position

→ Interior wall – walls present in interior of building

→ Exterior wall – walls present in exterior of building appliances.

→ Double T slabs can span upto 32 m without intermediate supports.

→ The void ratio of the double T is 70% which allows the greater span with smaller mass when compared with the 60% void ratio of hollow core slab.

→ The deformation at the free edges of the flanges can be reduced by making the flange stiffer by welding angles to the flanges.

4) Bubble floor (or) Bubble deck

→ These composite slabs are made by introducing spherical bubbl in concrete.

→ By introducing the gap it leads to 30-50% lighter slab which reduces the loads transferred to columns, walls and foundations.

→ The bubbles are made by high density polypropylene. The material polypropylene does not react chemically with concrete or reinforcement.

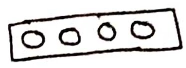
→ Around the bubble gaps, slab elements have a bottom and upper concrete part connected with vertical ribs that go around the gaps.

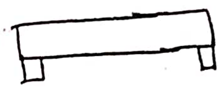
→ light in weight.

2) Based on Structural Composition:

Homogenous walls :-

Solid walls - Walls that are solid in nature. 

Hollow walls - This walls consists of hollow cores.
This type are walls are light in weight. 

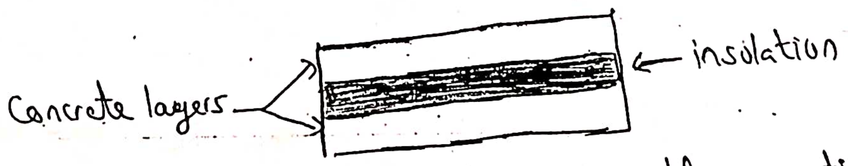
Ribbed walls - Walls provided with small projections called ribs at both ends. 

Non homogeneous walls :-

Sandwich panels

→ Two structural concrete layers which are separated by a distance which accomodate a layer of thermal insulating material like polystyrene.

→ Wythe connectors are used for connecting the concrete layers. The wythe connectors pass from one concrete layer to the other concrete layer through the insulating material.



→ Placement of connectors interrupts the continuity of the insulation layer. These interruptions are called thermal bridges which reduces the thermal insulating capacity of sandwich panel by 40%.

Classical Sandwich panels:

→ Classical sandwich panels consist of a single concrete layer with the insulation layer. located at exterior or interior

→ Wythe connectors are used for connecting the insulation with concrete layer.

3) Based on method of construction:

→ Large panels - They are an element primarily of storey height or partial storey height. Panels are designed to resist both vertical and horizontal loads

→ Blocks - Smaller wall elements weighing less than 2000 kg

4) Based on fuction:

→ Cladding or curtain walls - Cladding or curtain walls are most commonly used as a building envelope. They do not transfer any vertical loads but simply enclose the space. They are designed to resist wind and seismic forces. These panels can be removed individually if necessary.

→ Load bearing walls - These wall elements transfer loads from other elements. It cannot be removed as it affects the strength and stability of building.

2) Lateral Dimension.

Overall lateral dimension or diameter of column shall be multiples of M/4.

Design:-

The structural design of prefabricated column is similar to that of ordinary reinforced concrete. The main difference is that the ultimate failure load is a function of cross section of the prefabricated column and the type of connections, while it depends on cross section alone in case of reinforced concrete columns. An impact allowance of 50% should be considered while designing. Following are the points to be considered while designing the column section,

→ The size of the section should be predetermined in accordance to factory handling and transportation

→ Design should be carried out such that safety is ensured during frame erection and its stability

→ Ultimate limit state calculations should be carried out to satisfy the service requirements of each project.

Manufacturing :-

→ Most of the columns are manufactured horizontally.

→ Columns up to 3m length with complex profiles are cast vertically

→ The moulds are of steel with dimensional tolerance of <±3mm

→ Shear walls – These panels are used to provide lateral load resisting system by forming a diaphragm when combined with floor system

→ Skeleton walls – These walls carry loads through ribs or ends

Prefabricated Columns :

→ Prefabricated columns are the main vertical load carrying members in a frame of a structure

→ The prefabricated colums is cast with concrete and is square, rectangular and circular in cross sections.

→ The minimum cross section depends on the type of beam column connector employed, typically it ranges between 250 to 300 mm

→ Maximum dimension of prefabricated column is 600 x 1200 mm.

→ The characteristic compressive strength of concrete should be above 50N/mm² because of early strength required for lifting the prefabricated column in factory.

Dimensions of Prefabricated Columns :-

1) **Height** :

Floor to floor clear height of prefabricated column shall be,

→ Multiples of 1M – for height ≤ 2.8m

→ Multiples of 2M – for height ≥ 2.8M

-) Main bar diameter - Minimum - 12mm and Maximum - 40mm
-) Links - Diameter not less than 1/4th of diameter of main bars
- Spacing not more than 12 times diameter of main bars.

Lifting and Erection:-

-) Generally columns are manufactured in largest possible length that can be transported and erected in site.
-) Maximum lengths of 25 to 30m is possible
-) The maximum length to depth ratio suitable for lifting purposes is 50:1. But such slender columns should be prestressed axially to about $3N/mm^2$ to prevent damage due to flexural cracking.
-) The lifting points are positioned at 0.2L from the ends of column.

Connections:-

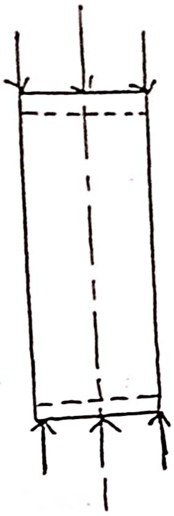
-) The connection between two precast columns and also between precast column and beam are designed according to the manner in which moments and shear forces are transferred through them.
-) The connection can be achieved by
* placing in situ concrete at junctions with overlapping reinforcing bars.
* providing steel inserts and connecting the joints thus formed.

Behaviour of Prefabricated Columns:

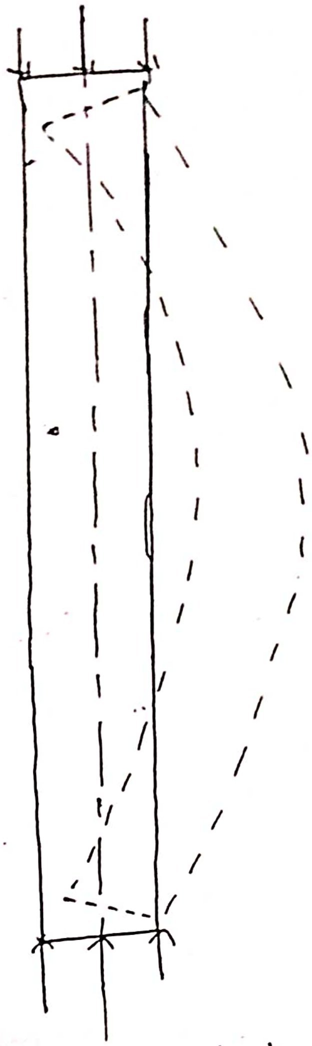
Columns are usually compression members whose lengths are considerably greater than their cross sectional dimensions. Columns are compressed by gradually increasing equal and opposite axial forces at the ends. Columns are classified as 'short' or 'long' depending on proneness to buckling.

If the column is 'short' the applied forces will cause a compressive strain, which results in the shortening of column in the direction of applied forces. Under incremental loading, this shortening continues until the column ~~yields~~ crush or yield squashes

If the column is long similar shortening is observed only at initial stages of loading. Thereafter as the applied forces are increased in magnitude, the column becomes unstable and develops a deformation normal to the loading axis and the axis is no longer straight. This type of failure is called buckling



Short column (fails by compression yield)



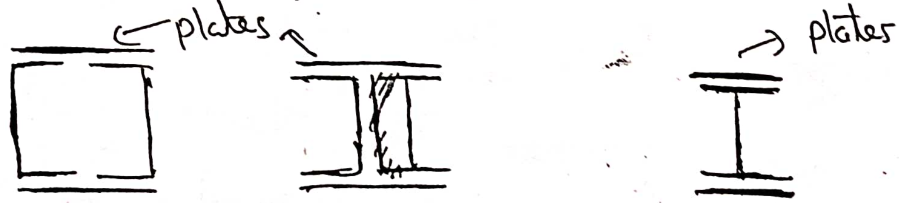
Long column (fails by buckling).

Prefabricated Concrete Columns:-

Prefabricated concrete columns are generally short. They are usually constructed for a storey height. Hence they behave like a short column when compared to slender steel columns. When the compressive axial load is applied axial shortening of column occurs leading to material failure (crushing of concrete and yielding of steel. This type of failure can be avoided by making composite columns with steel sheets bent in paticular shapes with concrete infilled between them called as Concrete Filled Steel Tubular Columns (CFST)

Steel Columns :

Steel Columns are usually slender and manufactured in largest possible lengths. When axial load is applied, deformation occurs followed by buckling failure. In order to avoid buckling, the steel columns must have high bending stiffness. High bending stiffness can be achieved by different cross sectional shapes. Conventional angle, tee, channel sections are built up together in different cross sectional shapes (usually box like structure) in order to attain high bending stiffness.



Built up channel section — Built up channel section — Built up I section

The stiffness of such built up sections can increased by providing suitable stiffeners in between them

Shear Wall :-

Shear walls are specially designed structural walls incorporated in the building to resist lateral forces that are produced in the plane of wall due to wind, earthquake and other forces.

Necessity of providing shear walls in precast structures :-

When the height of the multistoreyed buildings reaches certain limit, the possibility of load transfer both vertically and horizontally to foundations through columns starts reducing. This is because of larger deflections at the top storeys which add on to the moments on frame due to wind, earthquake and other forces. The bending moments resulting from these actions in a unbraced frame are large leading to an uneconomical design of columns. To eliminate this large moments some diagonal bracings are provided ... called shear walls which resists the moments in the frame by its axial diagonal force.

Comparison of shear walls with construction of conventional wall panels -

1) The conventional wall panels are brittle in nature while on the other hand the shear walls are designed

to be ductile. So stability is achieved with sh. walls in case of any lateral forces due to wind, earthquake etc.

2) Shear wall structural systems are more stable when compared to conventional RC frames with wall panels. as the wall panels are slender when compared to box like three dimensional structure of shear walls.

Types of shear walls:

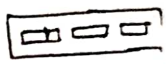
1) Precast concrete infill wall:

* This type of shear walls are provided in between two columns so that they act monolithically with columns. ~~The columns~~
* The columns at the two ends are then called boundary elements.
* This was the first and simple type of shear wall used in resisting lateral forces.
* This type of shear walls under action of vertical loads (self weight) and and lateral forces (wind & earthquake) are subjected to bending and shear respectively.

* This type of shear walls are designed in such a way that they never fail in shear but only by yielding of steel in bending as shear failure is brittle in nature.

2) Precast concrete / brick hollow walls

→ This type of shear walls are made with concrete or brick with some hollow spacer in between.



→ After transporting the hollow wall to the site, reinforcement bars are arranged in both directions into the hollow spaces and concreting is done at site.

→ This type of shear walls are designed to resist both self weight and lateral forces.

3) Brickwork infill wall:

→ This type of shear wall is similar to that of precast concrete infill wall except that,

* This type of walls are constructed by using brickwork

* Construction is done insitu in between already assembled frame composing of beam and columns

* They are light in weight.

4) Steel plate shear wall

* Steel plate shear wall consist of a vertical wall made of steel plate, columns on the boundary and floor beams on horizontal ~~direction~~ boundary

* The steel plate along with boundary columns act as vertical plate girder. The column act as flanges of the I section plate girder and the steel plate act as web of the I section plate girder. The horizontal beams act as transverse stiffeners.

* This type of shear wall provides high strength and stability.

5) Core type shear walls

→ In some buildings, the elevators and other services areas are grouped in a vertical core which may serve as device to withstand lateral loads

→ Cores with designed lintels at regular intervals as in elevator shafts have good resistance against torsion which usually occurs in core type shear walls

Unit III - Design Principles

Design philosophy - Design of cross section based on efficiency of material used - Problems in design because of joint flexibility - Allowance for joint deformation - Demountable precast concrete systems - Design for stripping, stacking, transportation and erection of elements.

Design of cross section based on efficiency of materials used

The cross sections of precast reinforced concrete structures can be rectangular, T, I, U and V shaped and the profile may be solid, hollow or divided fretted latticed and Virendeel structures.

Beams of various cross section

Precast beams may be of rectangular, I, T, U, V shaped. Among these cross sections, rectangular cross section is the most simple cross section and used for lighter sections. They are simple to manufacture and produced in smaller number. The disadvantages of rectangular sections is that they are uneconomical as well as hollow sections.

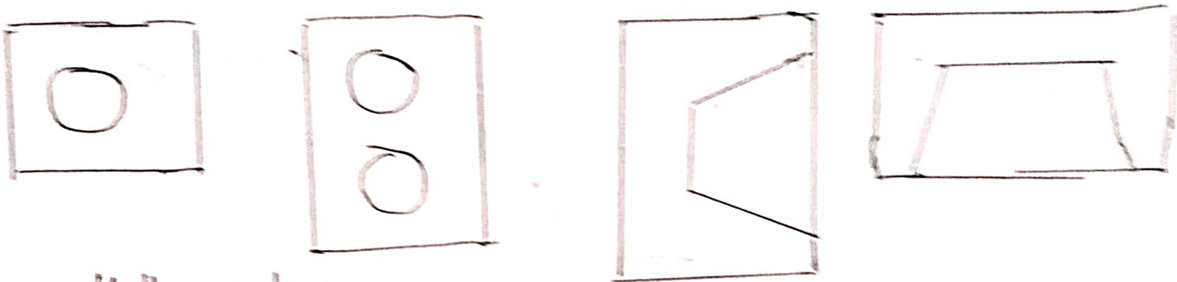
I, T, U and V shaped sections are frequently used in manufacturing precast sections. Compared to rectangular section, these sections provides material efficiency of 30 to 50 percent saving in concrete and 5 to 10 percent saving in steel. These cross sections also provide internal space.

Cross sections to be used for precast beams and columns

Following are the various cross sections to be used for precast columns and beams,

Rectangular   I Section   T Section

Double Tee section   Inverted U section



Hollow section   Channel Section

One of the great advantages of precast structures over reinforced concrete structures is that it is possible to form cross section based on theory of strength of materials.

The economy (or) efficiency of cross section is usually measured by form factor (ϕ) the value of which is given as,

$$\text{Form factor}, \phi = \frac{F}{F'} \quad \text{—(1)}$$

where $\phi \rightarrow$ Form factor

$F \rightarrow$ Area of investigated cross section

$F' \rightarrow$ Area of rectangular cross section of depth 'h' and width 'b'

(3)

For rectangular cross section, $F' = bh$ — (2) (bd)

Modulus, $k = \frac{bh^2}{6}$ $(bd^2/6)$

$h^2 = \frac{6k}{b}$

$h = \sqrt{\frac{6k}{b}}$

Substituting 'h' in (1) ⇒ $F' = b \times \sqrt{\frac{6k}{b}}$

$= \sqrt{b} \times \sqrt{b} \times \frac{\sqrt{6k}}{\sqrt{b}}$

$F' = \sqrt{6kb}$ — (3)

Substituting (3) in (2) ⇒ $\phi = \frac{F}{F'}$

$$\text{Form factor } \phi = \frac{F}{\sqrt{6kb}}$$

→ For rectangular cross section, $\phi = 1$

→ For I, T, U, V shaped cross section, $\phi < 1$

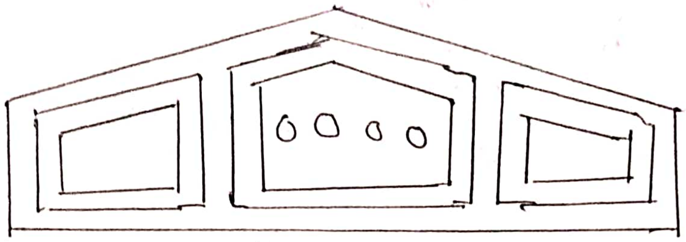
Smaller the value of ϕ, cross section is more economical. For reinforced concrete structures

The value of form factor for steel I section profile is $\phi = 0.31$ to 0.33. For prestressed concrete structures the value of ϕ is 0.45 to 0.50. For precast concrete, the value of ϕ is 0.5 to 0.6. Hence instead of rectangular cross section, I section of same material makes saving in material. This concept of is called design of different cross section based on efficiency of material used in prefabricated structures

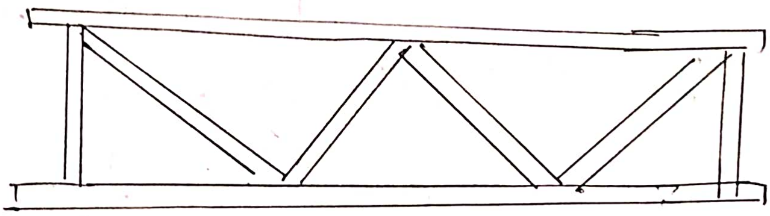
(4)

Fretted, latticed and virendeel structure

There is generally no difference in construction methods between fretted and solid beams. Fretted, latticed and virendeel structures have openings to obtain savings in material and decrease in dead load



Fretted reinforced concrete girder



Latticed structure (truss)

Choosing

These structures Choosing various type of above structures is called as design of different cross section based on efficiency of material used.

Joint flexibility

Flexible joints are joints that holds two parts together so that one can swing relative to each other. Flexible joints means a pinned connection which fully transmits forces but not moments between the connected members or elements. Therefore there may be a difference in the rotation of the connected elements at the point of connection

Problems in design because of joint flexibility

- In design pinned frames (frame with flexible joints) are ~~designed~~ designed only with ~~reg~~ regard to strength requirements while fixed frames are designed in regard to stability and deformation limits.
- Connections made with flexible joints (pinned connections) leads to uneconomical cross section of members like beams and columns resulting in larger self weight.
- Elements made with pinned connections are ~~into~~ indeterminate (ie) the equilibrium equations are insufficient for determining the internal forces on elements during design. Hence special design procedures should be adopted.
- It is not Ideal to predict the actual behaviour of flexible joints.

Allowance for joint deformation

Joint deformation means expansion or contraction of joint when subjected to stresses. When the element is stressed beyond its strength it cracks leading to failure. The stresses may be due to external loads, moisture and temperature variations.

Reason for providing allowance

If this expansion or contraction movements of joint are restricted partly or wholly by any means it will lead to bulging or shortening of elements. Hence to minimize this, restriction should be avoided by providing certain allowance for the joints to deform. Hence the allowance for deformation of joints should be provided with reasonable care during design, location, detailing and selection of materials.

Evaluation of allowance for joint deformation

For evaluation of allowance, following points have to be considered.

1) Temperature Variations

Allowance for joint deformation is determined in relation to the movement which will occur due to temperature changes. In estimating these movements, the ~~time~~ temperature at time of construction may be considered. If concrete is laid in summer, the main movement will be contraction and in such case deformation will be more. If construction is in winter, the main movement will be expansion and in such case deformation will be less.

2) Moisture Variation

Brickwork and concrete contract on drying and expand when wetted again and the process of construction may continue even for a long time after construction depending upon humidity conditions.

For dense concretes, contraction due to shrinkage due to moisture vary from 0.5 to 0.8 mm/m

3) Loading

Deformations may also be caused as a result of loading. Allowance of deformations in joint shall be provided to accomodate deformation with loading particularly to allow the following factors,

- The difference in compressibility of various materials used in individual sections of building
- Unequal loading of different parts of building
- Differential settlement due to unequal settlement due to unequal bearing capacity of soil

Allowance for members to incorporate joint deformation

The admissible dimensional deviation of prefabricated elements are

(a) Blocks

Thickness → 0 to 5mm
Width → -5 to 8 mm
Length → -15 to 10mm

(b) Panels

Thickness → 0 to 5mm
Width → -5 to 10mm
Length → -15 to 12mm

(c) Beam and Columns

Thickness → -3 to 5mm
Width → -5 to 5mm
Length → -15 to 15mm

Demountable precast concrete systems

Demountable precast systems are precast building systems which can be demounted or disunited (removing of elements of building system without any damage so that elements can be reused). The connections between the elements of precast building systems are made such that the elements can be easily demounted when needed and reused.

Need for special care during demounting

Demounting of any building system is more hazardous than erection of prefabricated structure. Adequate attention and safety measures should be followed in planning and execution of demounting work in various stages so as to minimize risk of accidents and injuries, Care should be taken in such a way that it causes least damage to members while demounting.

Precautions while demounting

- Types of lifting equipments (crane) should be selected considering size and weight of elements
- Danger signals should be provided
- Emergency exits should be provided
- Entry of unauthorized persons should be avoided
- Demounting should not be carried out during storm or heavy rain
- Safety arrangements should be available (safety shoes, gloves, first aid tools etc)

Sequence of demounting

→ Demounting should be done storey by storey in descending order. Demounting of upper floors shall be completed before demounting of member in lower floors

→ All windows and doors should be demounted before demounting roof and walls

→ Roof or floors are ~~defo~~ demounted first

→ After demounting of roof, walls are demounted. Care should be taken so that they won't fall as a single mass on floors.

→ Finally the structural members, beam and column are demounted. Demounting of beam is done followed by columns.

Methods of demounting

→ Systems consisting of linear members disunited at joints

→ Disuniting of ~~ed~~ entire rigid frames

→ Straight members disunited at points of minimum moments

→ Disuniting of two hinged and three hinged arches.

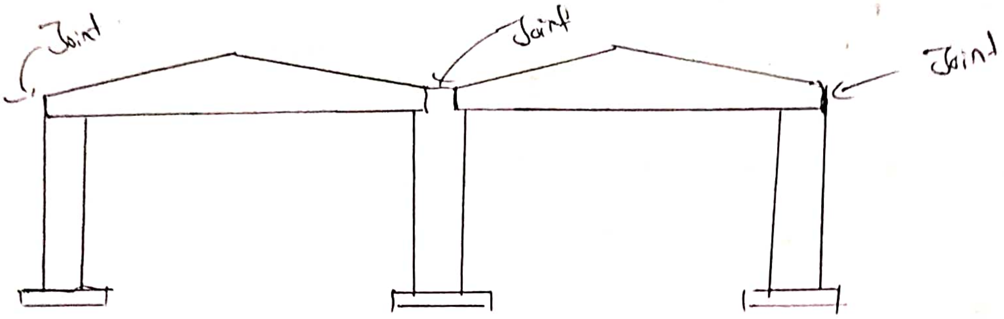
1) Systems consisting of linear members

→ Disuniting of linear members ~~are~~ have advantage in point of view of manufacture, assembly and demounting

→ Temporary supports are not essential during erection and demounting.

→ As joints are located in corners or ends it is difficult to in placing joints

→ Cross sections of precast members are large and hence material requirement is high.



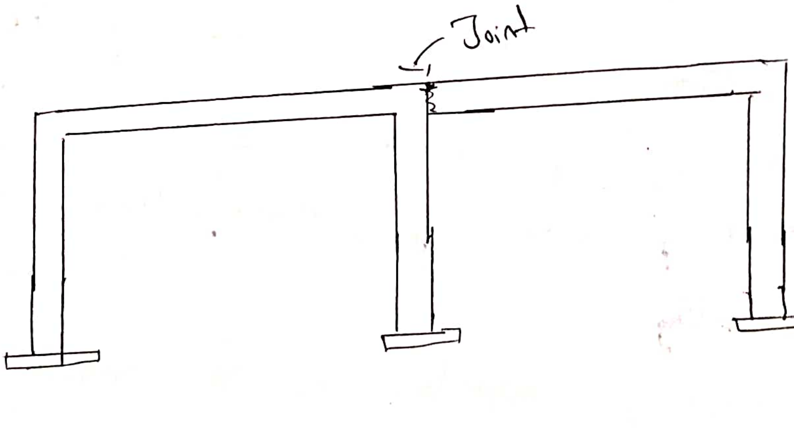
Members of frame disunited at joints

2) Disuniting of entire rigid frames

→ In order to reduce number of joints and to manufacture larger precast members, precast frames are fabricated as entire frame.

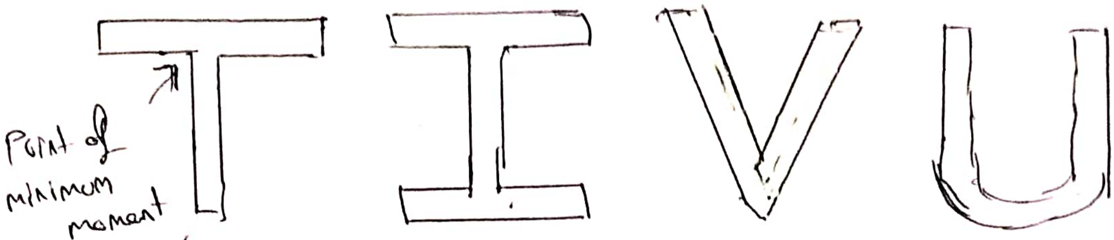
→ These frames are disunited or demounted at base and at junction between frames

→ Care should be taken which while lifting of frame after demounting. The frame should be lifted at two or more points



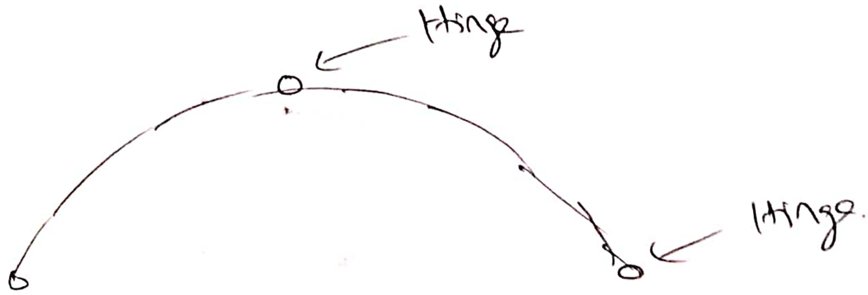
3) Straight members disunited at points of minimum moment

In this method point where moments are minimum are found out and disuniting is done at such points. Following are the members which can be easily disunited at points of maximum moment.



4) Disuniting of two hinged and three hinged arches

Arch structures are normally used for bridges with span more than 20 to 25 m. Their placing and demounting are difficult. Arches are normally demounted at hinges



Design philosophy

The design concept of precast structures is based on manufacturing and erection, economy and standardization of precast components.. In design of precast elements and its connections, all loading conditions and restraint (support reactions) should be considered for initial period of casting to final connection of structures. Special attention should be given to methods of stripping, stacking, transportation and erection of precast elements. Design of connections to transmit forces due to shrinkage, creep, temperature change, elastic deformation, wind forces and earthquake forces require special attention. Precast members and connections should be ~~meet~~ designed to meet tolerance requirements. Design should incorporate adverse effects also

Unit III - Joints and Connections in Structural Members

Types of joints - based on action of forces - compression joints - shear joints - tension joints - based on function - construction joints - contraction joints, expansion joints - Design of expansion joints - Dimensions and detailing - Types of sealants - Types of structural connections - Beam to column - Column to Column - Beam to Beam - Column to Foundation

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Joints and Connections

The design and construction of joints and connections is the most important consideration in prefabricated structures. Their purpose is to transmit forces between structural members and to provide stability to structure. The different ways of connecting a structure is by bolting, welding or grouting

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Joints

Joint is the interface between two structural elements or between an element and some other portion of structure through which any one of forces (tension, shear or Compression) takes place. Joint provides physical separation between components of structure

Requirements of an ideal structural joint

-> It shall be capable of transferring the imposed load and moments with a known margin of safety

-> It shall occur at logical locations in the structure at which it may be easily analyzed and easily reinforced

-> It shall accept the load without any displacement or rotation and avoid stresses.

Factors to be considered in provision of joints

- Feasibility
- Serviceability
- Fire and water proofing
- Appearance

Recommendations of water tightness of joints

Following are the points to be considered for water tightness of joints

- A free flowing, self compacting and non shrink grout should be used at the interface of joints with prefabricated elements
- Joints should be prepared in accordance to specifications
- The fire resistance and durability requirements should be similar to that of members to be connected

Classification of Joints

Based on load or force transmission, joints are classified as,

- Compression joints.
- Shear joints
- Tension joints

As a general classification, joints commonly used are,

- Construction joints
- Contraction joints
- Expansion joints
- Isolation joints

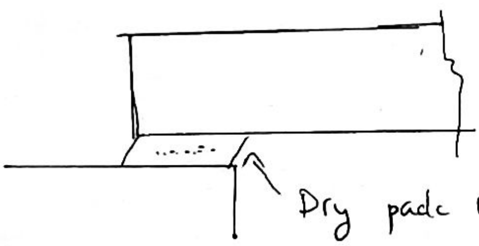
Based on method of connection at site, joints are classified as,

- Dry joint
- Wet joint

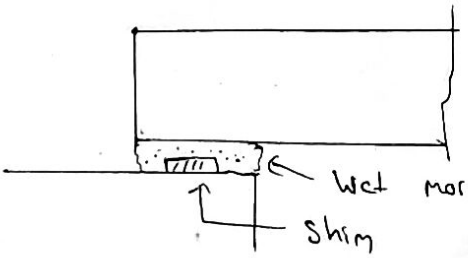
Compression joint

Compression joint should be designed to resist compressive forces and moments in the structure. Compressive forces can be transmitted between adjacent prefabricated components by direct bearing or an intermediate medium such as insitu mortar, fine concrete, grouting, bearing pads or other bearing elements. Direct contact between the elements should be used when a great degree of accuracy in manufacturing and erection needs to be achieved and bearing stresses are small. Intermediate medium such as insitu mortar, fine concrete or grouting are often used in the joints between colums and walls as well as beam and floor elements. The nominal thickness is about 10 to 30mm for mortar and grout and 30 to 50mm for fine concrete. The bedding is usually provided without reinforcing bars. Failure of compression joint occurs by either crushing of mortar or splitting of prefabricated components in contact with it.

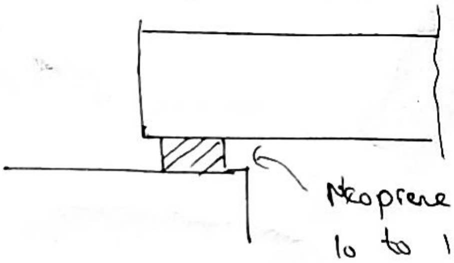
Dry packed bearing →



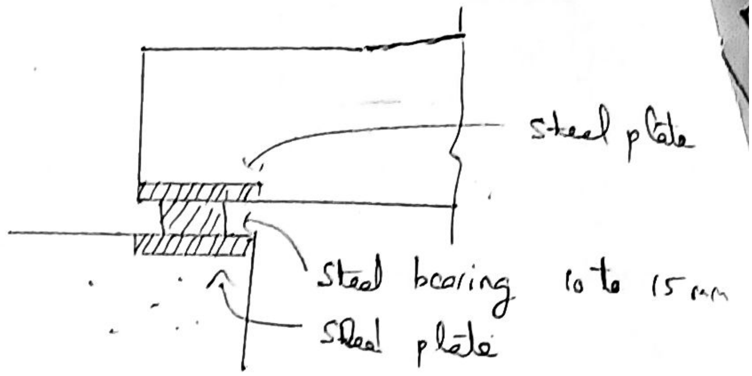
Wet packed bearing →



Elastomeric bearing →



Steel bearing using steel plates or structural steel sections →

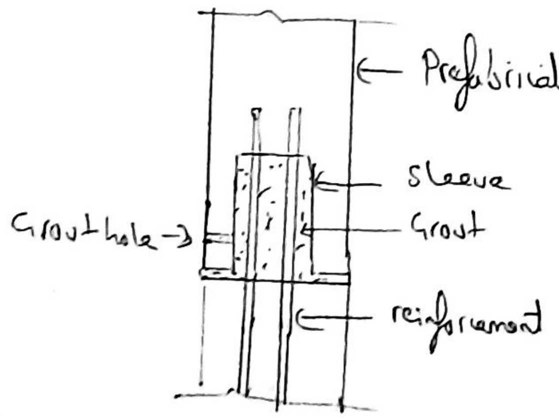


Tension Joint

Tensile forces are transmitted between adjacent prefabricated components by means of steel connectors, by achieving continuity by overlapping of steel bars, dowel action, bolting or welding. The tensile capacity of the connection can be determined by either strength of steel elements or by anchorage capacity of connectors.

By overlapping steel bars

The prefabricated elements are overlapped by projecting the reinforcement bar in one unit while having a metal conduit or sleeves to receive the projecting reinforcement bar. Pressurized grout is inserted through the gap between the reinforcement bar and sleeve. The gap (annulus) should be atleast 6mm on all the sides of the bars. The grout should be non shrinkable and be sufficiently flowable. Normally 2:1 sand cement mix having 24 hour strength of 20 N/mm^2 and 28 day strength of 60 N/mm^2 should be used.



Bolting

Bolting is also used to tranfer tensile forces. Anchorages such as bolts, threaded sockets, captive nuts are attached to plates which are fixed in prefabricated units. The tensile capacity of bolted connections is due to yield strength of bolt.

Shear joint

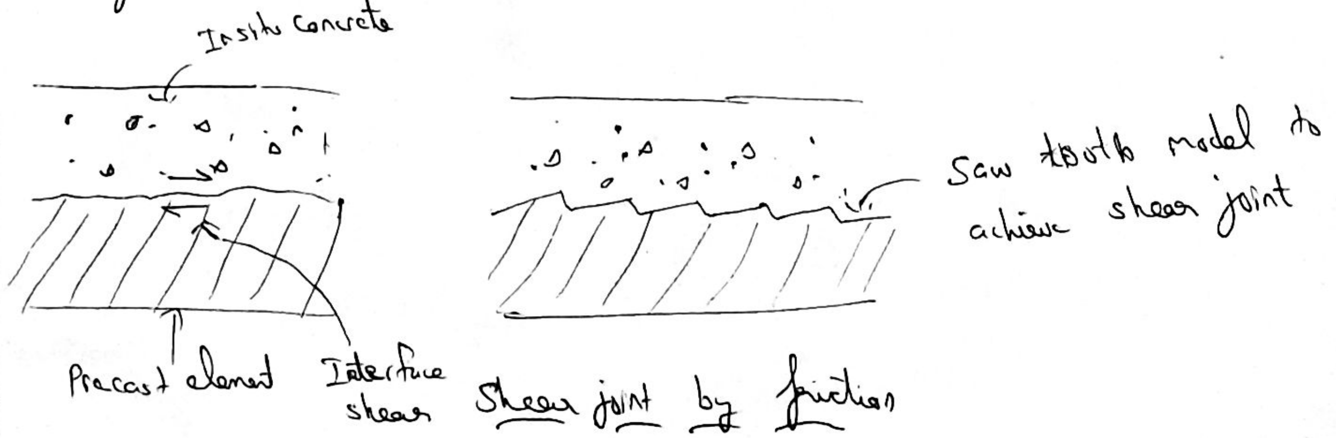
Shear force can be transferred between concrete elements by,

-> Adhesion
-> Friction at joint interface
-> Shear key
-> Dowel action of steel bars, pins and bolts

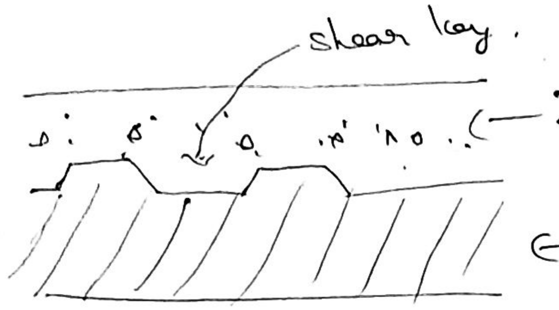
Shear joint by adhesion is obtained when cast insitu concrete is placed on a precast surface adhesive bond develops between cement paste in cast insitu fresh concrete and tiny pores in precast concrete.

Shear joint by friction is achieved between precast and insitu element by roughening the surface of prefabricated which serves as shear joint.

Shear key for transfer of shear force between elements are obtained by cast in situ concrete or grout in joints between the elements with surface castellations. Shear keys work as mechanical keys thereby preventing significant slips at interface

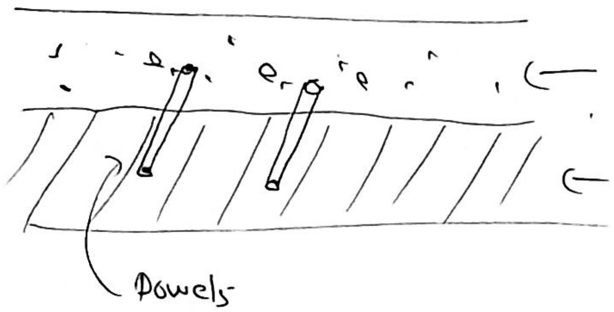


Shear joint by friction



Shear friction by shear key

Shear force can be transferred between elements by using special reinforcing bars called dowels.

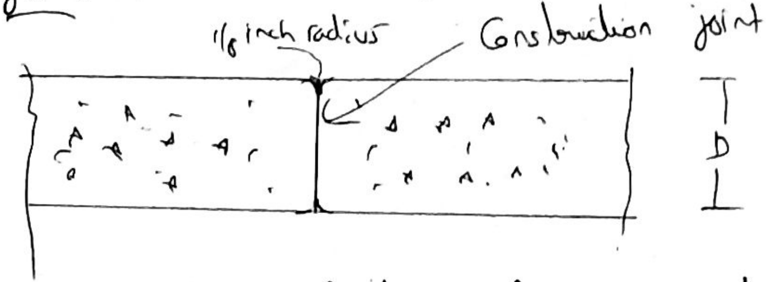


Construction Joints

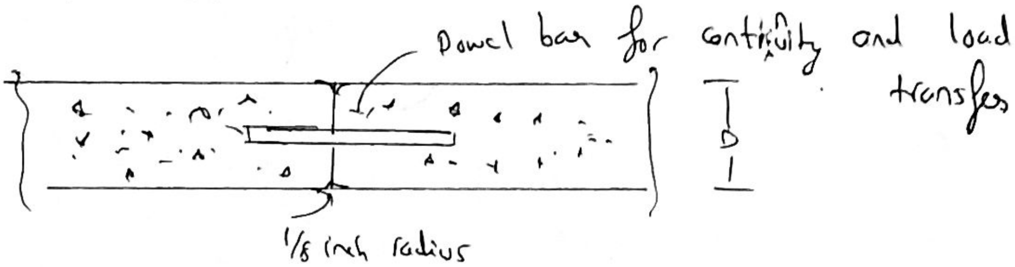
The construction joint is the separating plane between old (parent) concrete and new concrete batch. Construction joints are provided when the time available for batching, mixing and placing of concrete in prefabricated moulds is less. A spacing of 20 to 30 feet (6.1 to 9.1m) for construction joints is recommended in prefabricated walls and floors. Also the spacing of construction joints must not interfere with flexural and shear ~~capacity~~ continuity through the interface between old and new concrete. To achieve continuity, the hardened concrete (old concrete) should be clean and milky and powdery layer of cement dust.

Following are the types of construction joints

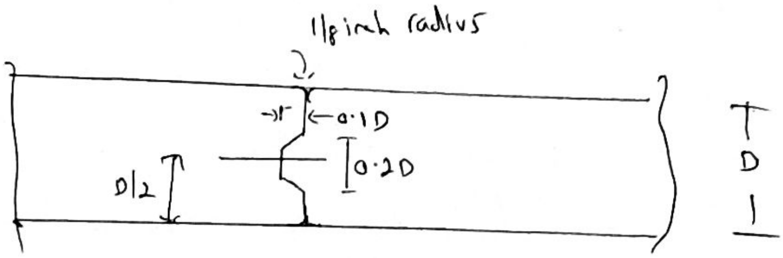
→ Butt joint (structural wall and slabs)



→ Butt joint with dowels (Structural wall and slabs)



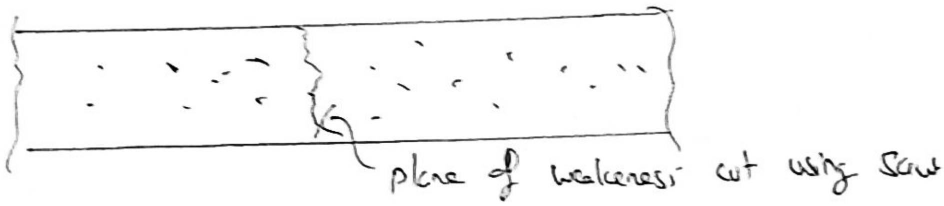
→ Tongue and groove joint (liquid retaining structure)



Contraction joints

Contraction joints are placed in precast concrete to control random cracking. Contraction joints is introduced in concrete by introducing a straight line weakened plane in which cracks are induced at predetermined locations. As precast element (slab) shrinks due to cooling and drying, shrinkage movements and due to ambient temperature tensile stress occurs. Due to these stresses cracks form at contraction joints thereby preventing cracks at other sections as joints are weaker than other places. Due to nature of preventing cracks, contraction joints are also called as control joints

Contraction joints are introduced by jointing tools the concrete is fresh or by sawing with saw after the concrete is hardened



Contraction joints are commonly used in slabs and pavements Depth of joints are generally between $1/3^{rd}$ to $1/4^{th}$ the depth of the slab and typically spaced every 3.1m to 15m

Expansion Joints

Expansion joints are joints that separate or divide a structure and which are provided to relieve stresses induced in building due to

→ Change in volume of concrete due to temperature changes

→ change due to variation in moisture content

This joints permit movement of structure due to above changes and hence also called movement joints

Evaluation of temperature changes

1) Temperature variations

Spacing of expansion joints is determined in relation to the movement which will occur due to temperature changes. In estimating these movements the temperature at time of construction may be considered. If concrete is laid in summer the main movement will be contraction and in such cases the expansion joints can be placed apart. If construction is in winter the main movement will be tension and the expansion joints are provided nearer.

2) Variation in moisture content

Brickwork and concrete contract on drying and expand when wetted again and the process of contraction may continue even for long time after construction depending upon external humidity conditions. For dense concrete contraction due to drying shrinkage vary from 0.2 to 0.5mm/m, for light weight concrete shrinkage vary from 0.5 to 0.8mm/m and for ~~autoclaved~~ aerated concrete shrinkage is in order of 3mm/m.

3) Due to loading

Deformation (movement) may also be caused as a result of loading. Allowance for movements in joint shall be provided to accomodate deformation due to,

→ Difference in compressibility of various materials used in building

→ Unequal loading of parts of structure

→ Differential settlement due to difference in load bearing capacity of soil

Width of expansion joints

The width of expansion joint varies between 1 and 6 inches (25 and 150mm), with 2 inch (50 mm) being common. because such joints serve additional function of construction joints

Spacing of expansion joints

In general spacing of expansion joint should not be greater than 120ft (36m). Following are the recommended spacing of expansion joints,

Walls - 30M

Balconies and parapets - 6 to 12M

Roofs - 20 to 30M

Frames - 30M

__Joint filler__

Joint filler is a compressible material used to fill the expansion joint in the structure. The main function of joint filler is to permit the joint to expand without developing compressive stress. The joint filler should satisfy the following performance requirements,

- It must be cellular
- Ability to recover 75% of its original thickness when pressure is released
- Durability and resistance to decay due to termite and weathering.
- Sufficient rigidity during handling and placing.

Joint filler may be produced from variety of materials like bitumen, cork strips, cellular rubber, expanded plastics, mineral fibre, polythene foam, coconut pith

__Sealing Compound__

Sealing compound is a material of plastic consistency applied to the joint in the form of liquid or paste. The function of sealing compound is to prevent entry of water, grit or foreign matter. To protect the joint filler from damage. Sealing compound should have good characteristics like adhesion, resistance to flow, resistance to oil, fuel and resistance to weathering.

Isolation joints

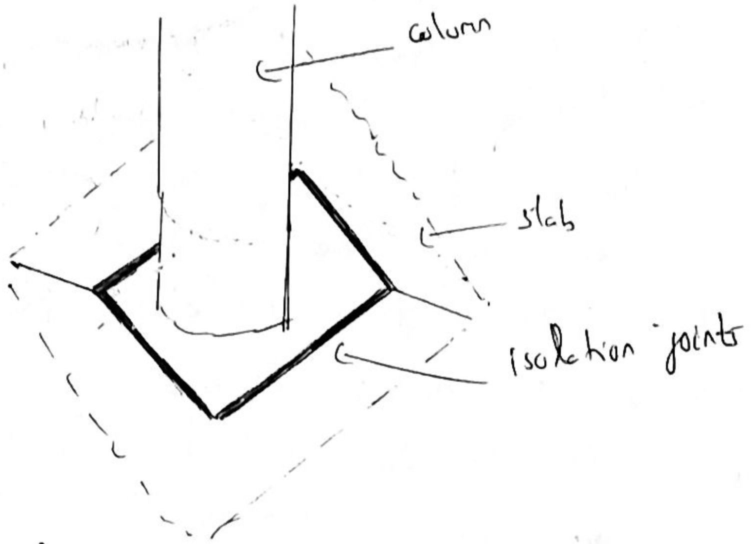
Isolation joint is a separation between adjacent sections of a concrete structure to allow relative movement in all directions. Isolation joints should be located at junction of slabs and walls, column, footing, equipment foundation etc. The materials used for isolation joints are foam insulation, plastic, cork, rubber, neoprene or asphalt. Absence of isolation joints create cracks in elements due to movement thereby creating weak point resulting in structural or maintenance issues.

Following are important points to be considered.

- → Isolation joints should be designed and placed in desired location
- → Reinforcement provided should not continue through the joints and should be stopped
- → Isolation joint fillers should extend for full depth in concrete and should not exceed at top
- → Width of expansion joint should be between 1/2 to 1 inch. Greater width may cause excessive movement

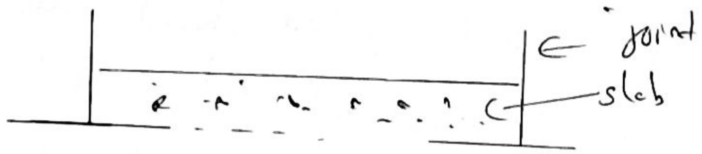
Isolation between column footing and surrounding slab

Isolation joint is used to separate column footing and surrounding slab because if settlement occurs in column footing, the slab around column will be undisturbed or won't crack. Similiarly the slab is allowed to undergo expansion or contraction due to temperature changes



Isolation between slabs

Isolation joints are ~~provided between~~ placed in desired location before concrete slab is poured. The slab is then cast with isolation joint material acting as formwork between slabs and the joint remains permanently within the slab.



Connections

Connection is the assembly of one or more interfaces (assembly of joints) that transfers forces (shear, tension, compression) and moments (bending, torsion).

The transmission of loads between connections is affected by several criteria like,

- magnitude of load
- Span of unit (beam or column)
- material used for connection

philosophy of prefabricated Connections concerns both the structural requirements and the method of construction. The design philosophy depends on several factors given below,

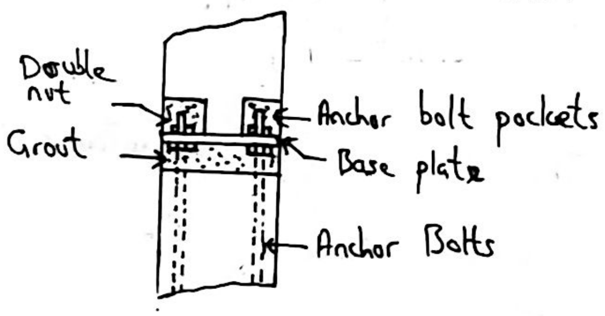
- The stability of frame
- The structural layout of frame.
- Moment continuity at ends of beam
- Fire protection to important bearings and rebars
- Appearance of connection.
- Site access

Following are the main types of connection,

1) Column to Column connection

(a) Anchor bolt system

Figure shows a detail using anchor bolt pockets and a double nut system with anchor bolts.



→ Before erection of upper column, a base plate is fixed on the top of lower column using anchor bolt and single nut (bottom). Base plates may be slightly smaller than the external column dimensions to suit architectural aspects.

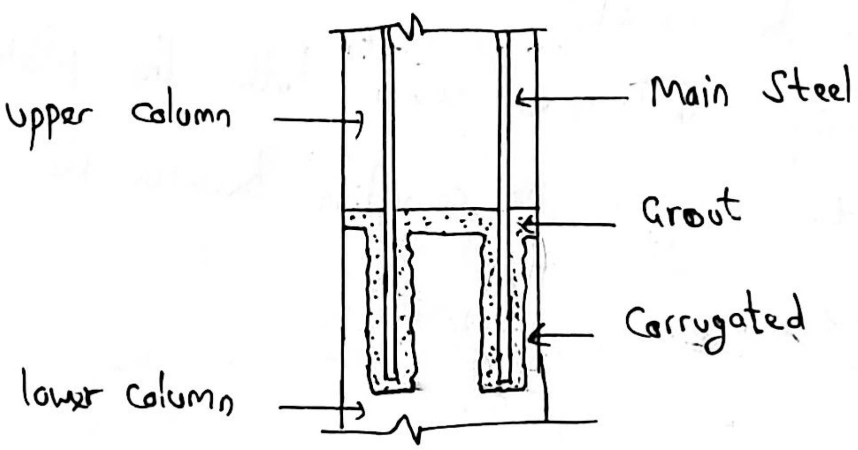
-> Upper column is provided with recess which consist of provisions (a small hole) for receiving the bolt.

-> After placing the upper column on position, the anchor bolt from lower column fits to the recess of upper column

-> Single nut (top) is placed such that it connects the bolt with both lower and upper column

-> Finally the place around anchor bolt and base plate (recess) is grouted

(b) Protruding reinforcement bars



-> The top portion of the lower column is provided with corrugated metal conduit (channel) on all possible sides of column so as to receive the reinforcement bar of upper column.

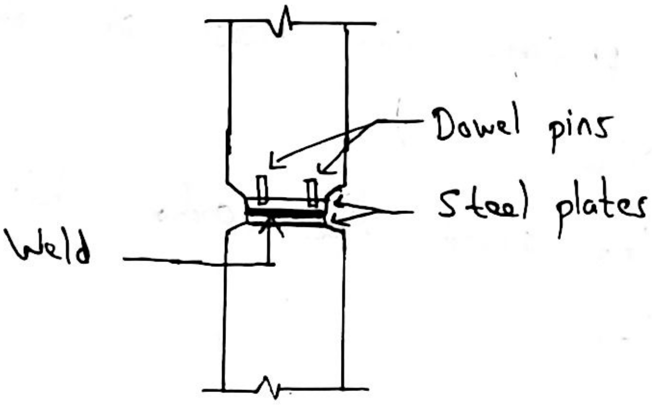
-> The bottom portion of the upper column is casted such that the reinforcement bar is projecting out.

-> After placing the upper column on the lower column

~~such that~~ the reinforcement bar ~~projects~~ gets fixed into corrugated metal conduit

→ Finally grouting is done.

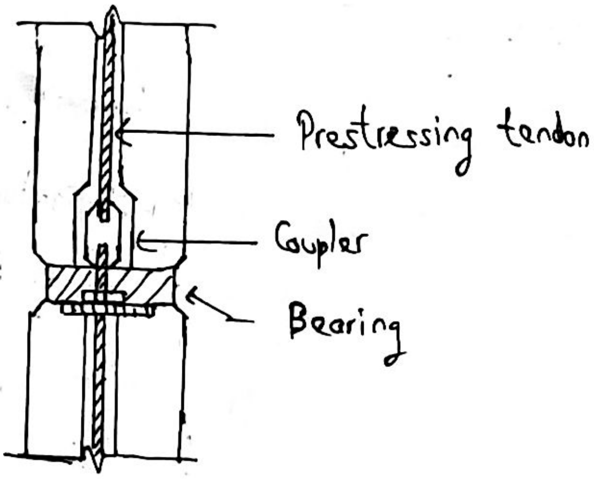
(c) **By welded steel bearing faces:**



→ Steel plates are connected to the two column sections to be connected

→ After erecting the upper column, both the plates are welded to form a connection between the columns.

(d) **By post tensioning (or) prestressing**



This connection is used only in exceptional areas such as large eccentricities of loads or tensile forces acting on the connection. Following is the step by step procedure.

→ ~~Placing (or) erecting of the column.~~

→ Lower column is stressed prior to placing. After stressing, the column is erected

→ Erecting of upper column and placing in position

→ Tendons are threaded through the upper column and coupled with the tendons of lower column using couplers.

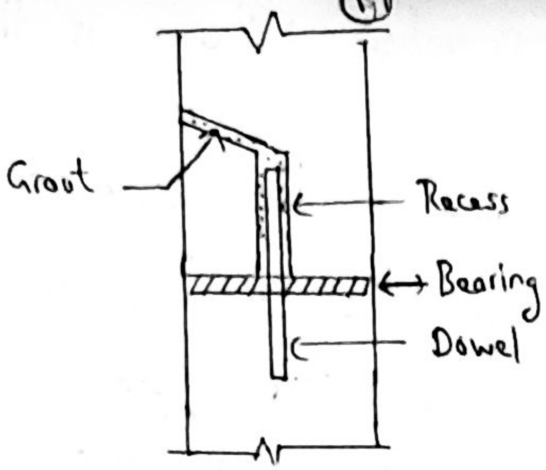
→ Upper column is adjusted for level and the joints at the interface is filled with mortar

→ After the mortar has hardened the tendons at the top of upper column are stressed.

→ Finishing of anchorages.

(e) Hinge Connection (or) Dowel Connection

This type of connection mainly transfers vertical loads and no bending moments. The connection acts as a hinge and called as hinge connection



Following is the procedure of construction of column to column connections by means of dowels

-> Recess is provided in the upper column
-> Temporary covers are used to keep the recess clean.
-> Lower columns are casted with dowel pins which act as a hinge.
-> When the upper column is erected and placed over lower column, the dowel pin from the lower column fits into the recess of upper column
-> Grouting is done in the recess to achieve stability of dowels
-> The grout hole is closed.

2) Beam to Column Connection

Beam to column connections are the most important connections in prefabricated frames. They are difficult to specify, design and construct, especially those which are hidden within the beam. They describe the manner in which beam behaves in flexure by controlling the deflections and moments, and of the column in their terms of frame stability and column buckling capacity

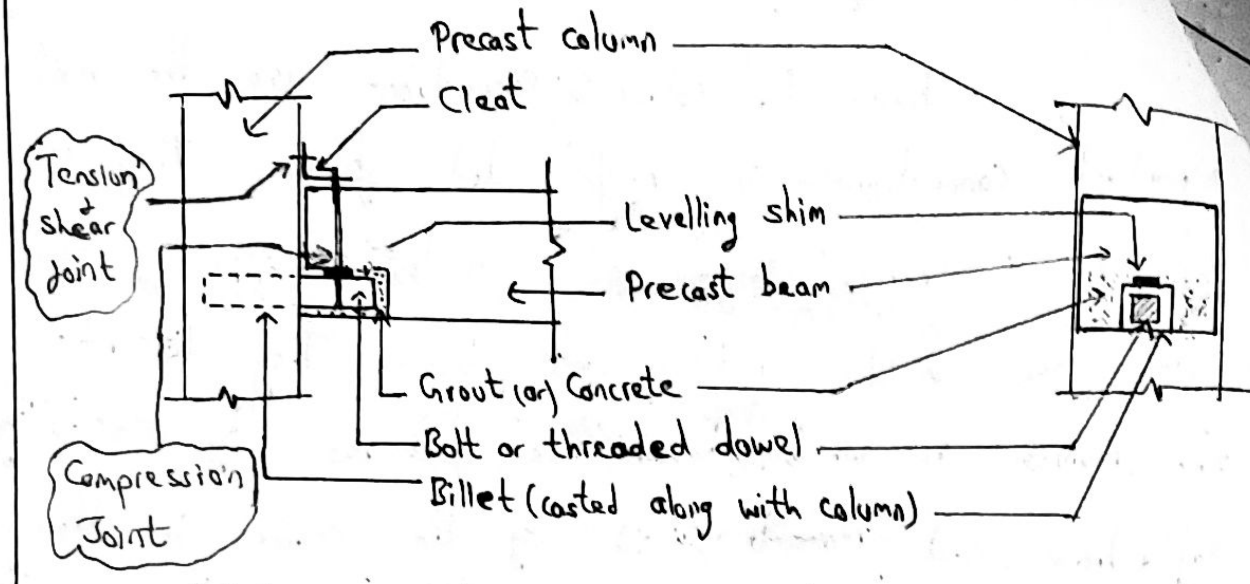
(a) Steel 'billet' connection:

This type of connection is one of the common type of hidden connection employed in prefabricated building construction. Billet connectors consist of the following,

- Solid or hollow steel section called billet is fixed into the column while casting. The billet project outs for a sufficient distance
- A threaded portion in billet to receive a bolt or dowel
- Cleat (angle section) to connect beam and column on top

Following is the procedure,

- Column is cast with billet and beam is cast with a recess for holding billet.
- The beam is lifted and placed on the billet of column.
- Bolt or dowel is ~~threaded~~ inserted through the billet
- Cleat (angle section) is placed on top connecting beam and column along with it through bolts.



Billet Connection

(b) Welded plate connection:

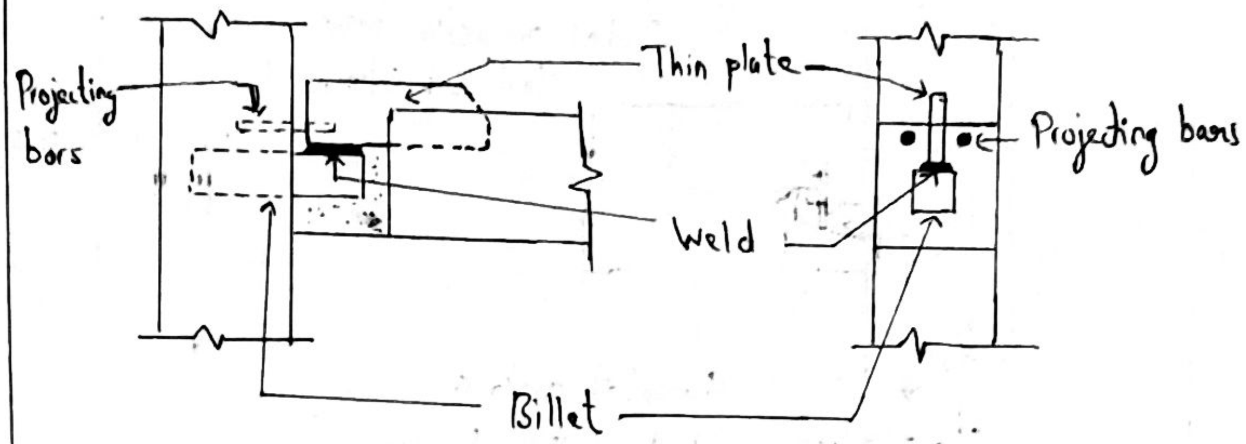
This is another type of hidden connection in which the beam and column are joined by welding a plate. Following is the procedure,

-) Solid or hollow steel section called billet is fixed into the column while casting. The billet projects out for a sufficient distance

-) A thin plate is attached to the prefabricated beam unit at its mid width.

-) Once the beam is lifted and placed on the billet of the column, the joint is fillet welded.

-) For temporary stability bars from the beam are projected into the column



Welded Plate Connection

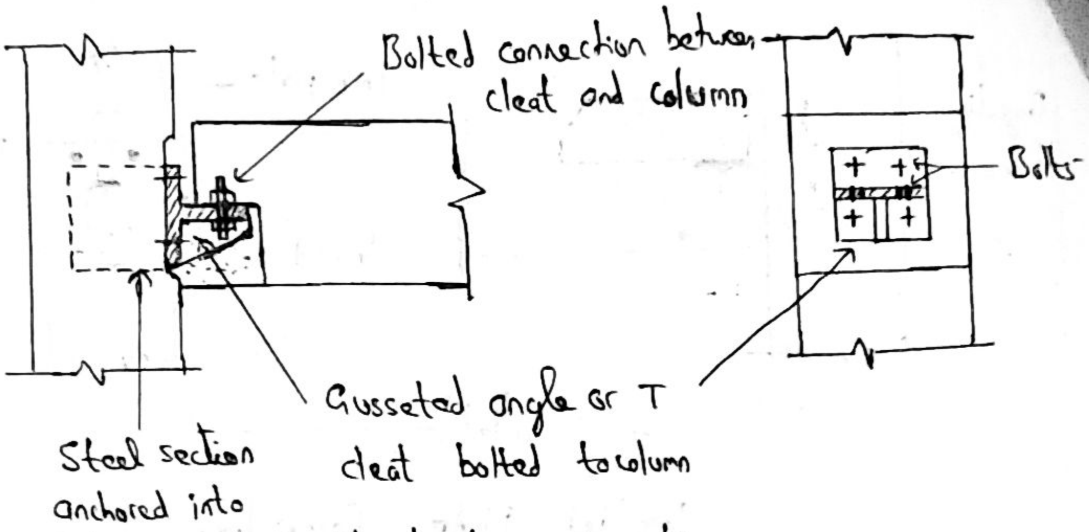
(c) Cleat type connection

This type of connection is a hidden connection in which rolled steel sections are drilled into beam and/or column for making connections.

→ Columns are cast with rolled structural steel section like Tee section, angle section drilled with holes to receive a bolted connection.

→ Once the beam is lifted and placed, the beam is bolted with the structural steel section

→ After bolting to beam, the place around the beam is filled with grout or concrete.



Cleat type connection

(d) Sliding notched plate connector: (For fig refer pg 17)

In this type of hidden connection, sliding plate is used which is provided with notch for connecting beam and column.

→ A steel box is anchored into the column. There ~~are~~ are two narrow plates with lip on either side of the steel box. The narrow plates are capable of sliding along its longitudinal axis

→ The beam is provided with a sliding plate with notch on both sides, one of which is fitted to lip on the narrow plate on beam

→ After lifting the beam and placing it in required position, the notch on the other end of sliding plate gets fitted over ~~the~~ the lip on column.

-> Once both the notches of sliding plate gets connected with the lip of narrow plate of beam and column, the sliding plate of the beam is pushed into the column till the notch on the sliding plate of beam fits on the tip of narrow plate on other end of the column.

(e) <u>Corbel (or) bracket connection</u> (For fig refer pg 17)

Bracket connection is a visible connection

This type of connection is used in industrial construction where the projecting bracket is not architecturally unpleasant.

-> Reinforced concrete corbel is casted monolithic with column

-> Levelling and bearing material is placed on the top of corbel to receive the beam.

-> A tube like structure is formed on the beam by grout.

-> Place the prefabricated beam on corbel of the prefabricated column.

-> After placing the beam, angle section is placed on the top of beam near the column face.

-> Finally reinforcement bar is projected through grout such that it connects the angle section and corbel.

3) Column to foundation (or) base connection

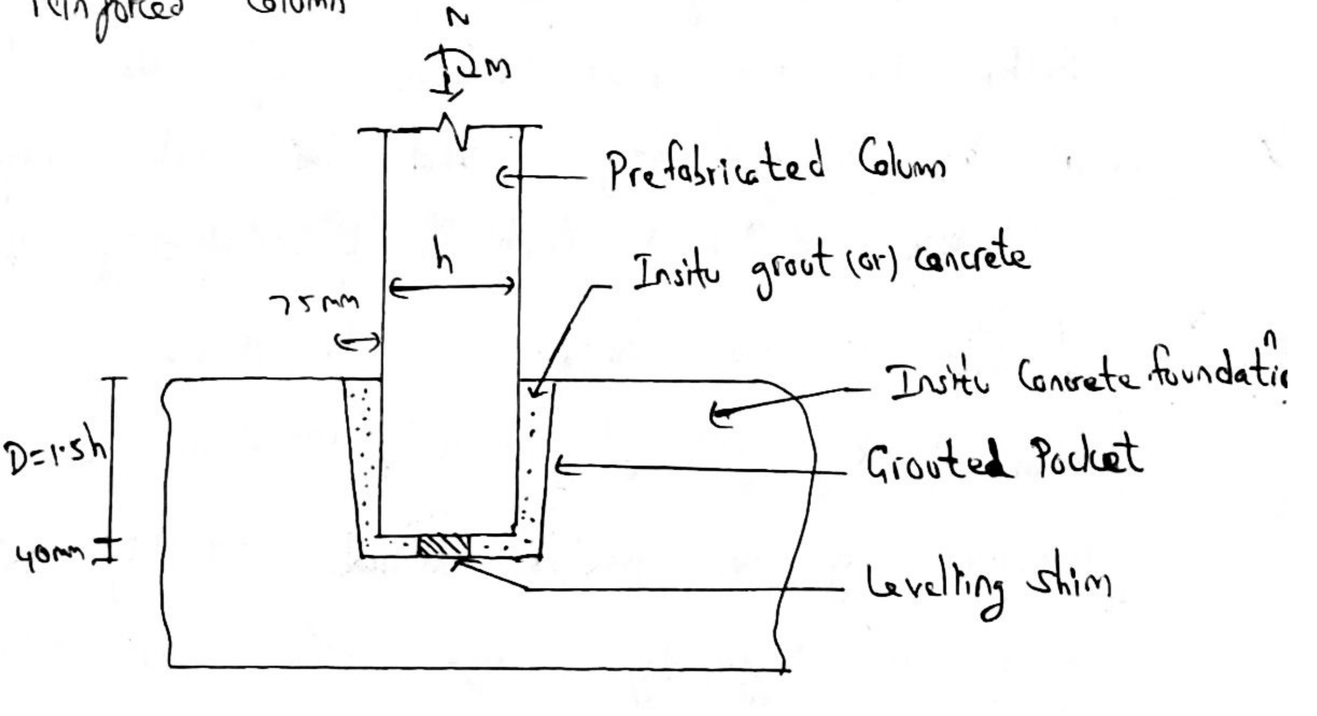
All Column foundation connections may be designed as either as pinned or moment resisting connections depending on the choice of designer in achieving overall stability requirements. Following are the three main types of column to foundation connections.

(a) Colums into a grouted pocket.

This is the normal method providing a moment resisting connection and most economical on point of view of prefabrication but its use is restricted to situations where large insitu concrete pad footings can be easily constructed.

The concrete foundation is cast insitu using a tapered box shutter to form the pocket. The prefabricated column is fixed into the pocket thus formed. The gap between the fixed colum and the outer of the pocket is filled with insitu concrete or grout. The gap should be at least 75mm at the top. The pocket is usually tapered at 5° to the vertical for facilitating easy placement of concrete or grout into the gap

Vertical loads are transmitted to the foundation by skin friction and end bearing. If overturning moments are present half of the skin friction is ignored due to possible cracking in all faces of the prefabricated structure. Ultimate load design considers vertical load transfer by end bearing based on strength of the gross cross sectional area of reinforced column



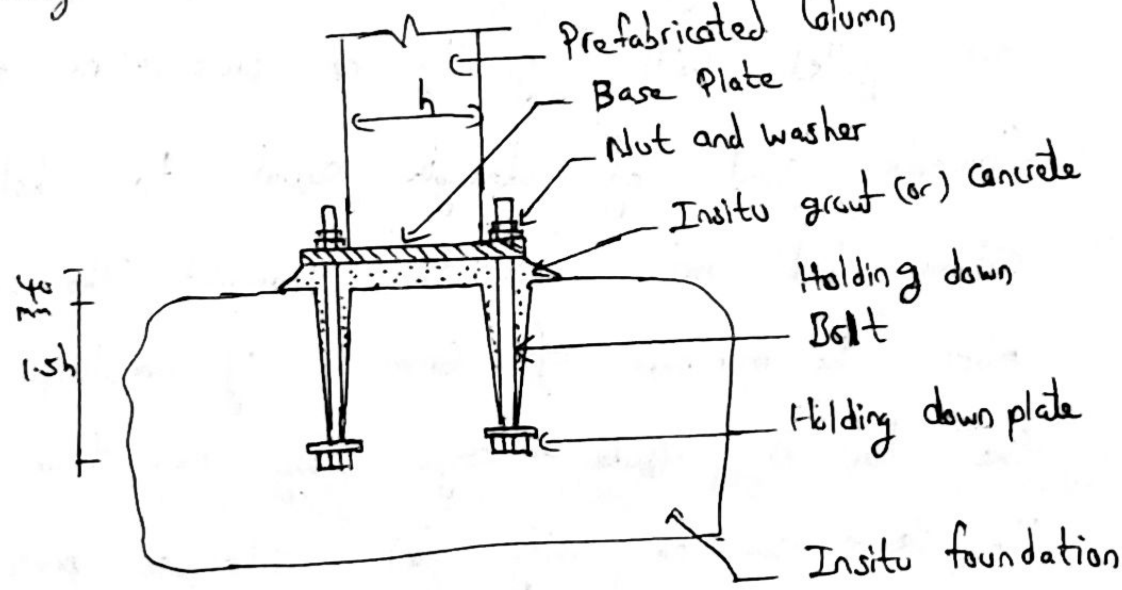
Column into a grouted pocket

The recommended minimum depth of pocket is equal to 1.5 times the breadth of column. The depth ~~should~~ of pocket should not be less than depth of column 'h'.

(b) Columns on base plate

The size of base plate can be either greater than the size of the column or less than the size of column. Although the base plate method is the most expensive of the three options it has the advantage that the column may be immediately stabilized vertically by adjusting the level of nuts of the bolts. This is paticularly important when working in soft ground conditions where temporary propping may not provide adequate stability. This connection requires a sufficiently large lever arm between the bolts and centroid of the compression zone. To achieve this the base plate is usually greater than size of column. To fabricate the base plate, reinforcing starter bars are fitted through holes in the plate and welded at both sides. The maximum projection of the plate beyond the column is restricted to 100mm. The bolts (26) are of 4:6 or 8:8 grade with 375 to 450 mm length and 20 to 32 mm diameter.

The design of base plates and bolts is done by considering equilibrium of vertical forces and overturning moments.



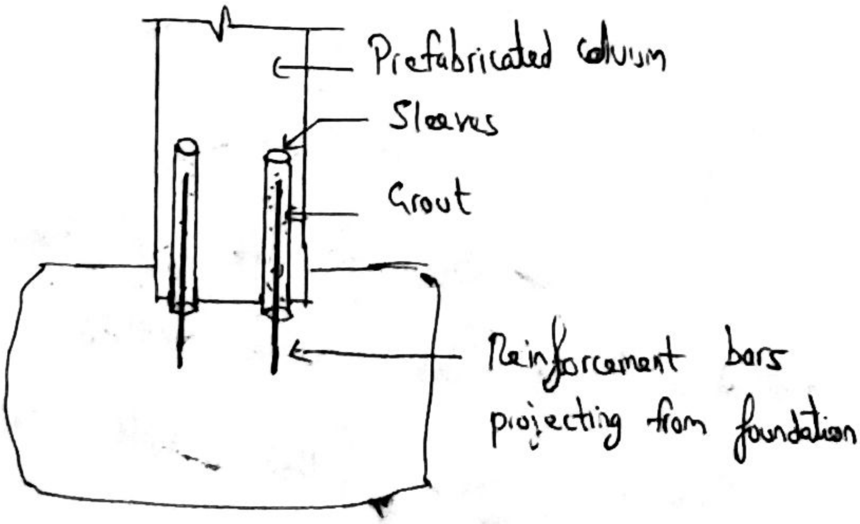
Column on base plate.

(c) Columns on grouted sleeves

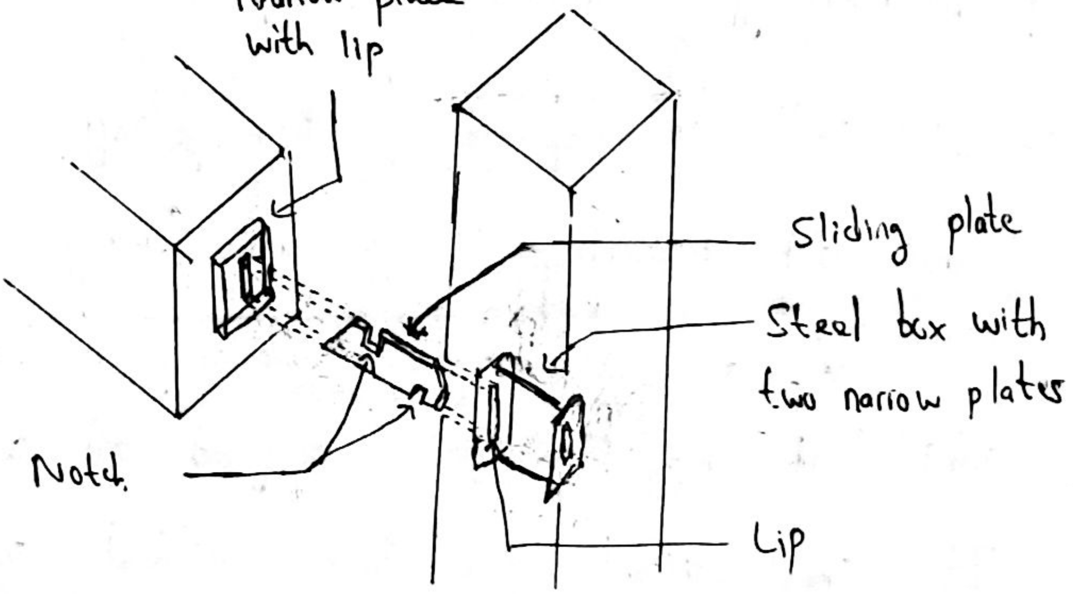
One of the most popular, easier and economical method is the grouted sleeve method.

→ Columns are fitted with sleeves usually circular sleeves at their bottom.

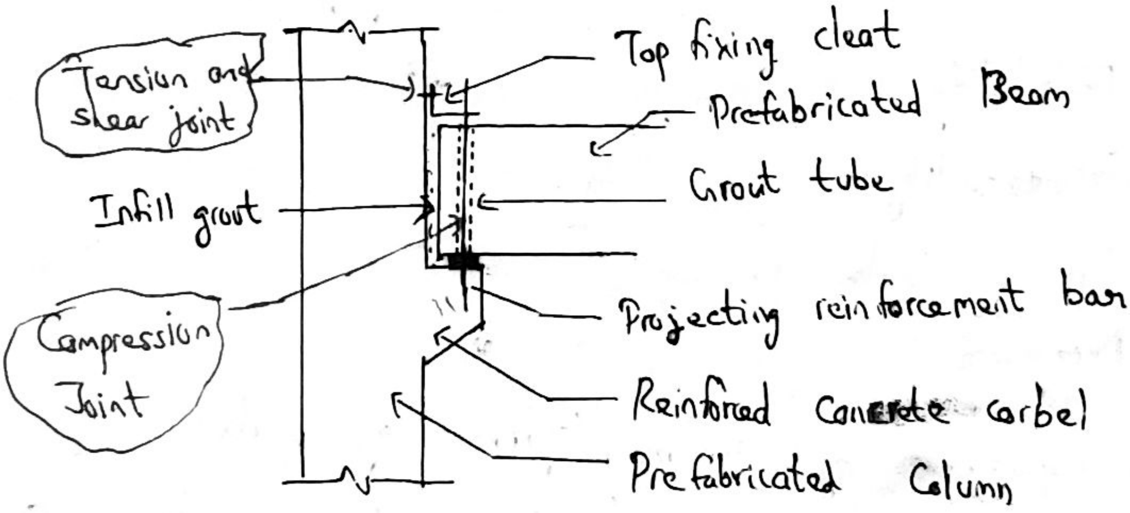
- The reinforcement bars running vertical in foundation are left projecting at the top of foundation.
- Column is erected so that the bars projecting from foundation pass into the sleeves of the column.
- The annulus (space) around the bars and sleeves are filled with gravity or pressurized expansive flowable grout of strength equal to that of Column but not less than 40N/mm². The annulus must be minimum of 6mm. If annulus around the bar is quite large say more than 10 to 15mm, the sleeve can be gravity fed, otherwise pressure grouting must be used.
- The column must be propped until the grout has hardened. However props usually remain in position until the first floor beams and slabs have been placed.



Column on grouted sleeves



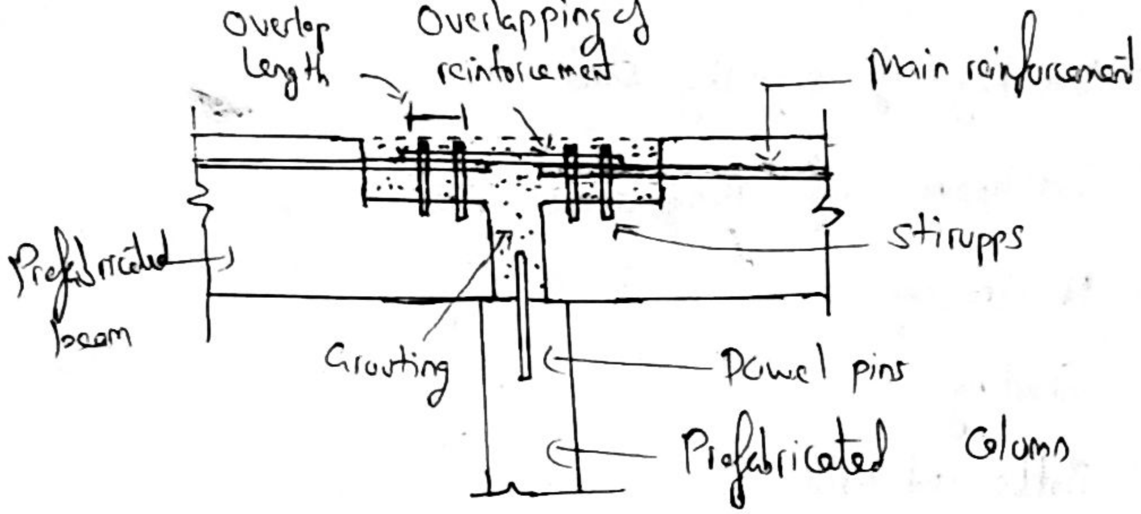
Sliding notched plate connector (Theory pg)



Bracket Connection (Theory pg)

4) Beam to Beam Connection

Overlapping reinforcement bars



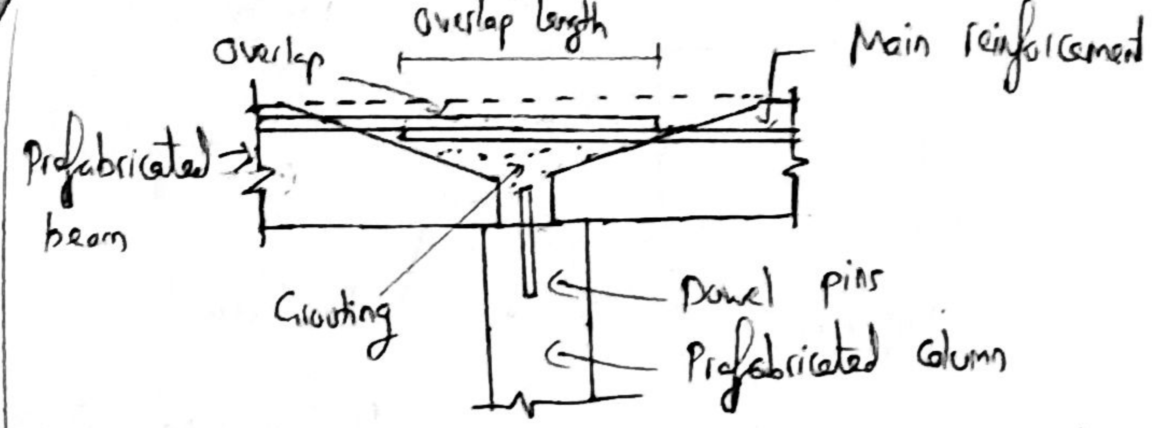
-> In this type of connections, the beams are cast with corbel like structure at their top and their top reinforcements are left projecting out.

-> The beams are lifted and placed on top of column

-> After placing beams the projected reinforcement of both the beams are lap welded using a small piece of reinforcement.

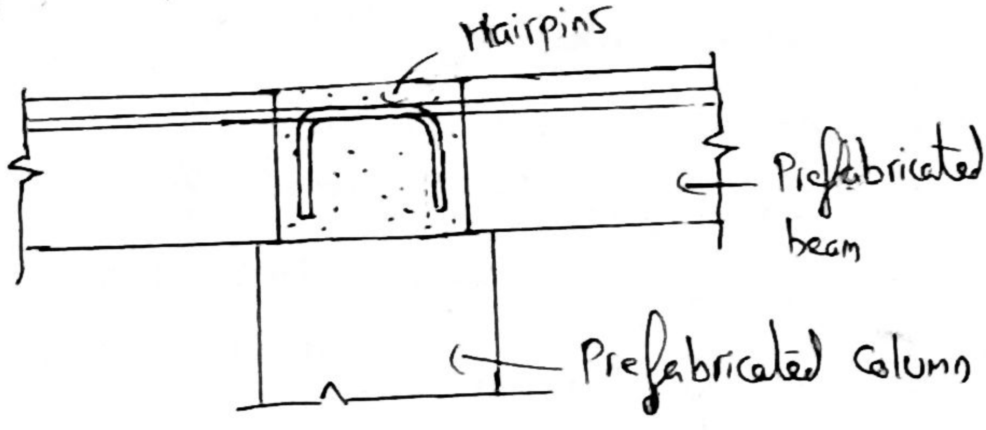
-> The place around connection is grouted

In case of requirement of high overlap length, the width of support (width of column) needs to be increased. Same solution is possible ~~without~~ without the need of enlarging base width, the ends of the beam are tapered and the top reinforcement of the beams are projected out for more distance. as in figure below,



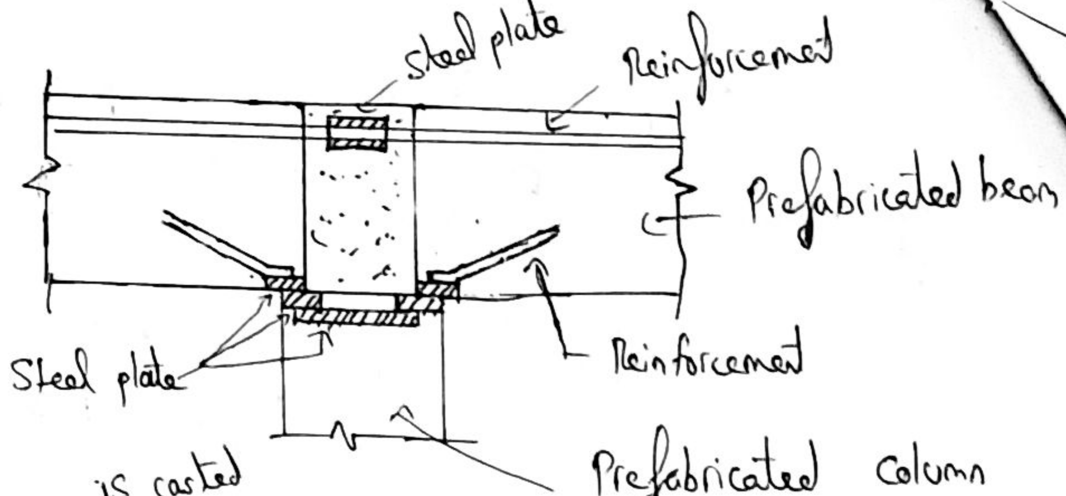
The main problem in above connection is that, it is difficult to provide stirupps in the zone of overlap to ensure proper functioning of overlap

In case of requirement of less overlap, length, enlargement of support width is necessary. The top reinforcement of the beams are projected out and bent in the form of hair pins as in figure below,



Welded rigid bottom connection

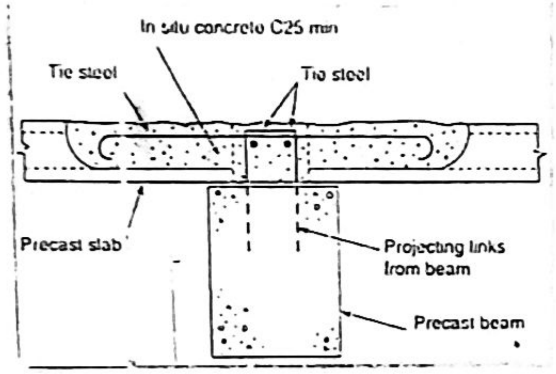
Welded connections are often provided at the bottom of beam as in figure below.



- Column is ~~erected~~ is casted with steel plates inserted at its top ends and another plate connects both end plates. ~~is erected~~
- Beams are provided with steel plates at its bottom ends connected with bottom reinforcement by welding
- Top reinforcements of beam are left projecting out
- After placing the beam on top of column, the bottom plates of beam are welded with plates on top of column
- The projecting top reinforcement of beam are connected by welding with steel plate
- Finally the place around the connection is ~~welded~~ grouted.
- By welding the plates, a rigid connection is made.
- Such connections are provided where rotations are large and spalling of concrete occurs.

5) Beam to Slab Connection

Connection between beam and solid slab (or) bubble deck slab



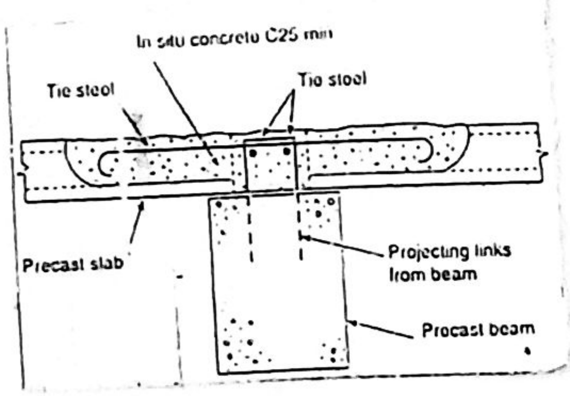
-> Beams are casted such that stirrups are projecting out at the top of beam

-> Solid slab or bubble deck slab are cast such that reinforcement bars are projected along its sides

-> Slab is erected and placed in position and hence a connection is formed between the stirupps of beam and the reinforcement bars of slab

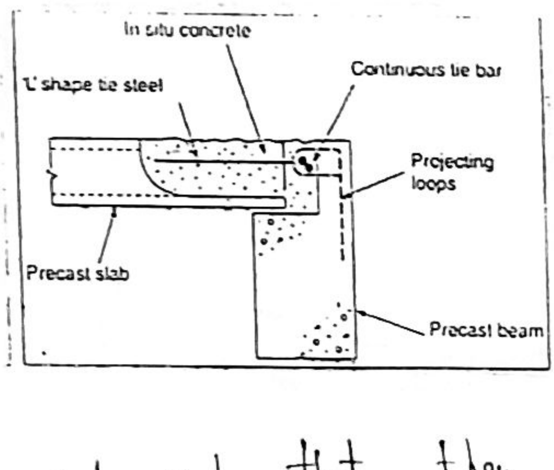
-> The place around the connection is grouted.

Connection between beam and hollow core slab



- Beams are cast such that stirupps are projecting out at the top of beam
- Hollow core slab is made with keys (groove) on its sides such that it receives reinforcement.
- Hollow core slab is erected and placed in position
- Reinforcement is fixed such that it connects the keys of the slabs on either side. Reinforcement can also be placed in hollow cores.
- Hence connection is formed between the stirupps of beam and the reinforcement connecting keys of slab.
- The place around the connection is grouted.
- Insitu topping of slab is done.

<u>Connection between beam and T slab</u>



- Beams are cast such that they have corbel shaped structure.
- T-Slabs are cast with L shaped tie reinforcement at its end such that it passes through the flange and rib of the beam and projects out at bottom through ribs.

- A hole is drilled on the corbel portion of the beam ~~and the reinforcement of the T-slabs are~~ to receive
- The reinforcement of T slab projecting through the rib
- The T slab is erected and placed such that the reinforcement of T slab fits into the hole on corbel portion of beam thus forming the connection
- The place around reinforcement is grouted.

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6) <u>Connection between panels</u>

Following are the types of connections between panels classified based on their location,

Horizontal Connections – Between slab panels
– Between slab panel and wall panel

Vertical Connections – Between wall panels

<u>Horizontal Connections between slab panels</u>

1) <u>Looped bars</u>

- The connections between slab and slab can be achieved by connecting the looped bars projecting from slabs by transverse reinforcement
- This connections are able to transfer tensile force, bending moments and shear forces.

→ Slabs are cast with loops projecting at its sides.

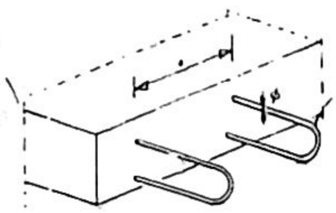
→ The slabs are placed in position such the loops from adjacent slabs gets interconnected.

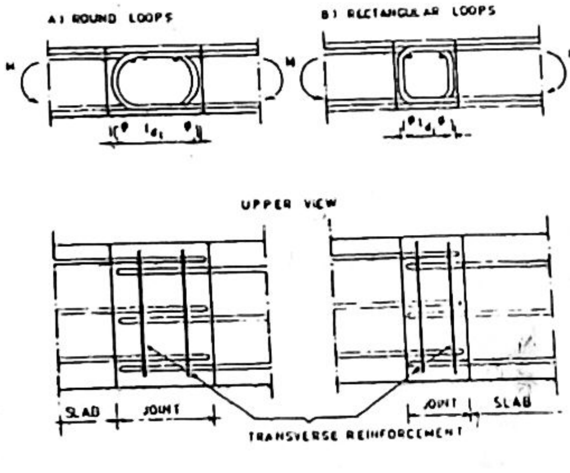
→ Transverse reinforcement are provided to connect all the loops of on one side slab. Transverse reinforcement serves two purposes

(a) Connects the loops and maintains alignment.

(b) To avoid cracks when the insitu concrete within loops hardens.

→ Loops may be round are rectangular in shape. Diameter of loops vary between 8mm to 10mm.



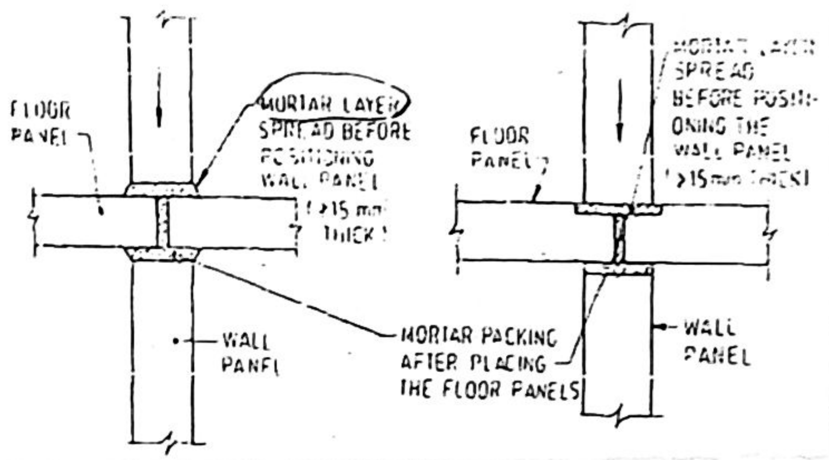


Horizontal Connections between slab and wall panels

1) <u>Grouting</u>

Following is the procedure,

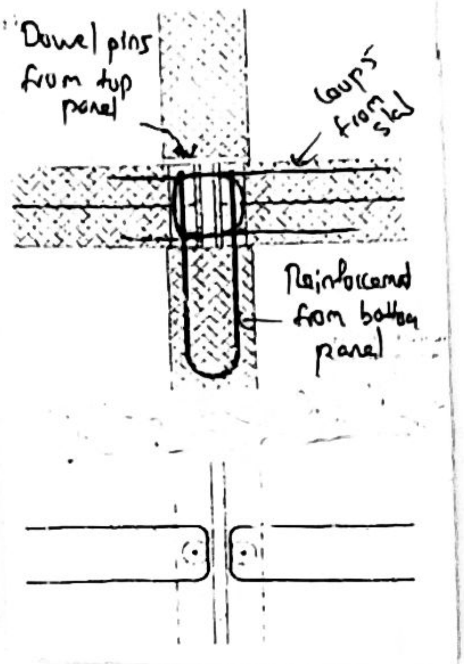
-> Grouting is done on top of bottom wall panels
-> Slabs are erected above the wall panels
-> After erecting the slab, positions of top wall panels are marked on the slab
-> A thin layer of grouting is placed spread on marked positions of slab
-> Top wall panel is placed



-> <u>Instead</u> of spreading grout directly on floor, a groove may be produced in slab and then grouting is done. This ensures proper compaction of grout.

2) Looped bars

(38)



-> Bottom wall panels are placed such that its reinforcement projects out at the top

-> Slabs are erected above the wall panels with loops projecting out along its sides and interconnected by laying transverse reinforcement.

-> Once the slabs are placed, the reinforcement from bottom wall gets projected through the loops of the slab.

-> Top wall panels casted with dowel pins are erected on the slab

-> The place around the connection is grouted

Vertical Connections between wall panels

Grouting

-> Wall panels are cast with grooves on either side along its height.

-> After erecting the wall panels the gap between the grooves are filled with grout

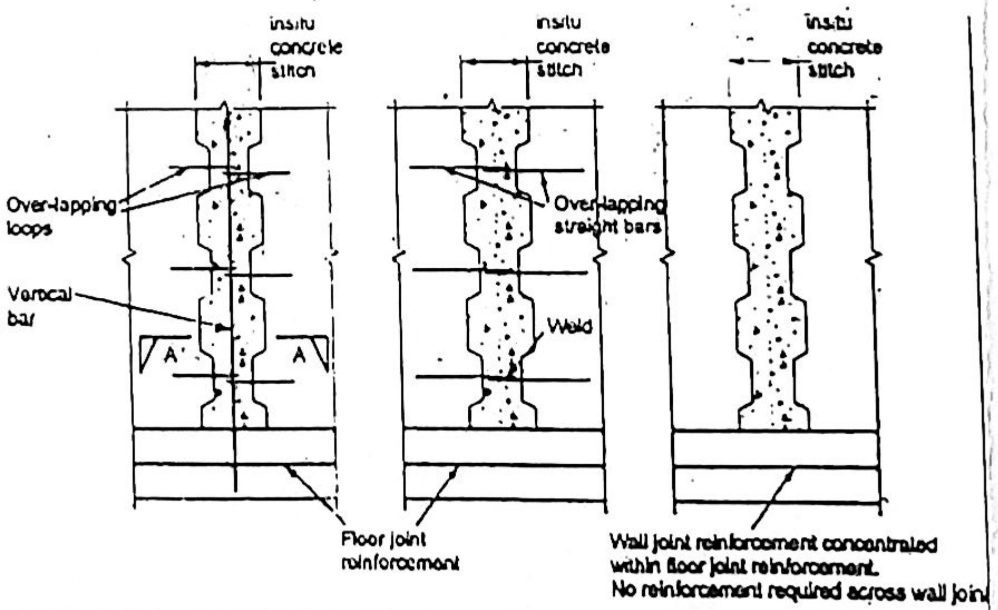
Welding of reinforcement bars

-> Wall panels are cast with grooves on either side along its height

-> Reinforcement bars from adjacent wall panels are projected out along its sides

-> After erecting the wall panels, the reinforcement from both the adjacent panels are connected by welding.

-> The gap between the grooves are filled with grout



Looped bars Welding Grouting

Looped bars

- Wall panels are cast with grooves on either side along its height.
- Reinforcement bars from adjacent wall panels are projected out along its sides in the form of loops
- After erecting the wall panels, the loops from adjacent wall panels are interconnected by using transverse reinforcement.
- The gap between the grooves are filled with grout.

Unit V – Design for abnormal loads

Progressive Collapse – Codal provisions – Equivalent design loads for considering abnormal effects such as earthquakes, cyclones etc – Importance of avoidance of progressive collapse – Case study

Progressive Collapse

A building undergoes progressive collapse when a primary structural element fails, resulting in failure of adjoining structural elements which inturn causes further structural failure. The resulting damages are disproportionate to the original cause, so progressive collapse can also be called as disproportionate collapse.

Causes for progressive collapse

A number of abnormal load hazards which cause progressive collapse are,

Pressure loads – Gas Explosions
- Bomb Explosions
- Fire
- Wind (or) Cyclones

Impact loads – Overload due to occupant misuse
- Vechicular collision
- Aircraft impact
- Transportation and storage of hazardous materials
- Earthquakes

Design or Construction Errors

Gas Explosions

Gas related explosions are potentially hazardous to building structures. Mainly gas explosion occurs in structures where natural gas is stored. The mean rate of occurrence gas explosions are 1.8×10^{-5}/year. A number of studies should be conducted on model structures to determine the pressure developed on the structure from an explosions of natural gas.

Bomb Explosions (or) blast loading

Bomb explosion usually involve planned activities that are focused on special target for socio political activities. The mean occurrence rate is 2×10^{-6} per building. The primary cause of occupant's death was building collapse and occupant's injuries were due to flying debris due to bomb explosions. Bomb explosions create shock waves at a velocity of the order 1km/s. The structural effects of large exterior explosion can be summarized as follows,

- → The pressure wave acts on exterior of building and may cause breakage of windows and failure of exterior wall and exterior column
- → As the pressure waves continues to expand into the building, upward pressure is applied to roofs and downward pressure are applied to floors.
- → Failure of interior column, interior wall elements and floor leads of progressive collapse.

The structural effects of smaller interior explosion can be summarized as follows,

- → Failure of floor system below detonation
- → Possibility of failure of floor system above detonation
- → Possibility of failure of nearby walls
- → Failure of non structural elements like windows, doors, partitions etc.

Fire

Fire hazard: lies in between normal and abnormal loads. Traditionally structural engineers have been rarely including structural fire protection, while fire protection is achieved using thermal insulation. The ignition of fire is related to floor area. The rate of fire occurrence is $0.2 \times 10^{-6}\ m^2/year$ to $1 \times 10^{-6}\ m^2/year$.

Wind or cyclone

The wind generally blows horizontal to the ground at high wind speeds: Very strong winds (greater than 80 km/hr) are generally associated with cyclonic storms and called as cyclones. These winds move rapidly around and over the building. This lowers the pressure on the outside and creates suction on the walls and roof, effectively causing effects equivalent of an explosion finally leading to progressive collapse.

Overload due to occupant misuse

No information could be described on the intensity or number of occurrence of this hazard. The nature and building contents should be determined and checked for overload. Progressive collapse due to overload is not huge.

Vehicular collision

Vehicular collision with building occurs mainly in urban areas due to single vehicle leaving the roadway. Suggested annual frequency of impact of motor vehicles with buildings was approximately 6×10^{-4} per dwelling unit per year. Impact force due to such collisions may be obtained from analysis of velocity of vehicle, distance of building from traffic way (road), direction of impact etc.

Aircraft impact

Majority of aircraft accidents occurs in take off and loading operations. Half of accidents occur at airport sites and only 30% occurs at distance greater than 8km from airport. Hence construction of building at some distance near to airport may be avoided though the probability of occurrence is less.

Transportation and storage of hazardous materials

Sources of transport of hazardous materials are pipelines, motor vehicle transport, railways and water carriers. There are potential of fire or explosion of hazardous material due to unconfined vapours of liquids and gases arising from them.

Earthquake

Earthquake loading can generate strong lateral forces and stress reversals. This load can overload structural members which result in the loss of one or more load carrying members, which may then lead to failure of additional structural members in other parts of the system and then progressive collapse of entire system. Observations of earthquake damage in past earthquakes show that seismic loads can cause structural damage.

Design or Construction Error

A majority of structural failure in ordinary buildings occur as a result of errors in planning, design, and execution (construction)

- Some errors in concept, analysis and execution by unqualified personnel.
- Some errors occur due to lack of communication and misunderstandings.
- Human errors may occur in representing data.

These errors can be minimised by using proper load and resistant factors, safety checks in site, design checks, proper communication etc.

Characteristics of structure required to resist progressive collapse

In order to withstand abnormal loading that can cause progressive collapse, several characteristics are required in the structural design and layout of a structure that can have significant influence on its collapse resistance. These structural characteristics are summarized as follows,

Robustness

Robustness is structural ability to survive the event of local failure. A robust structure can withstand the loading, so it will not cause any disproportionate damage

Integrity

Integrity is the condition where the structural members remain together as a single unit even after the presence of abnormal events. In other words the structural system will not become separated apart during its lifetime.

Continuity

Continuity is the interconnection of structural elements in a structural system. In reinforced concrete building as per design codes and standards, continuity is used to express the continuity of steel reinforcement across the elements.

Ductility

Ductility is the structural ability to sustain additional deformation after the yield condition

Redundancy

Redundancy is the capability of other structural members to carry extra load in case other member fail or collapse. This implies if there is a failure in one of the elements, other elements and the remaining structural system as a whole can still withstand the load.

Avoidance of progressive collapse

The main objective of avoiding progressive collapse can be achieved by adopting proper guidelines in design. The following procedure provides some ideas in avoiding progressive collapse. At a starting point an abnormal event 'E' is considered, which acts on the structure and causes an initial failure thus shifting the structure from normal stage to an initial damaged stage 'D'. This initial damage makes a serious reduction in the load carrying capacity (sectional weakening) or a complete loss of load carrying capacity (component failure) in limited area of damage. This state or condition in limited area of structure spreads to other areas leading to collapse of the structure. Probability of progressive collapse due to abnormal event 'E' can be represented as,

Probability of progressive Collapse $= P(C|D) \times P(D|E) \times P(E)$

In this equation,

$P(E)$ - denotes the probability of occurrence of an abnormal event 'E' that threatens the structure

$P(D|E)$ - denotes conditional probability of initial damage state of local damage D as a result of the abnormal event E

$P(C|D)$ - denotes conditional probability of the collapse C of the structure as a result of damage state D.

Design strategies for avoiding progressive Collapse

The different appropriate design strategies to limit the probability of a progressive collapse could be identified by the ways to reduce the value of partial probabilities,

Design Strategy	Prevent collapse progression	Prevent Collapse initiation	
	Influencing global system behaviour	Influencing local element behaviour	Influencing abnormal events
$P(C)$ =	$P(C\|D)$ ·	$P(D\|E)$ ·	$P(E)$
Collapse Resistance	Robustness Integrity	Local resistance or protection	Event Control

Prevent the occurrence of abnormal events

This strategy focuses on reducing the probability of occurrence of abnormal events by control (ie) P(E). Events like gas explosion, bomb explosion, fire, overload, accidents can be controlled while events like earthquake, wind and cyclone cannot be controlled.

Prevent the occurrence of initial local damage

This strategy focuses on reducing the probability of ocurrence of abnormal events by event control

Prevent the occurrence of initial local damage due to the occurrence of abnormal events. The structure should possess

→ enough protection by wrapping or confinement (or)

→ local resistance by increased cross section

to withstand specific abnormal events without suffering any damage. This depends on the behaviour of structural element. The goal is to reduce the probability of local significant structural failure following given abnormal events (ie) P(D|E)

Prevent the collapse of structure

Prevent the progression of collapse of the structural system due to initial local damage. The structural system should be designed to provide effective measures to limit the spread of initial local damage by an internal property of structural system called structural robustness or structural integrity. This depends on the behaviour of whole structure. The goal of this strategy is to reduce the probability of structural system collapse following a given local failure (ie) P(C|D)

Design for avoiding progressive collapse

Indirect method

Indirect method is the primary method used to enhance the robustness thereby reducing the risk of progressive collapse. This can also be accomplished by incorporating general structural integrity measures like choosing proper structural system, proper placing of walls and columns, appropriate member proportioning and accurate detailing of connections. Provisions for general structural integrity may be in the form of providing continuous and inter-member ties that will provide a robust, stable and economical design of buildings. The indirect design approach has the advantage of being easy to apply and provides uniformity among all projects.

1) Tie Force method

In the tie force method, the building is mechanically tied together by means of reinforcement by threaded couplers, lapping or welding reinforcement, by using by using anchors. The three types of ties used are,

- → periphery ties
- → internal floor or roof ties
- → vertical ties.

Periphery ties

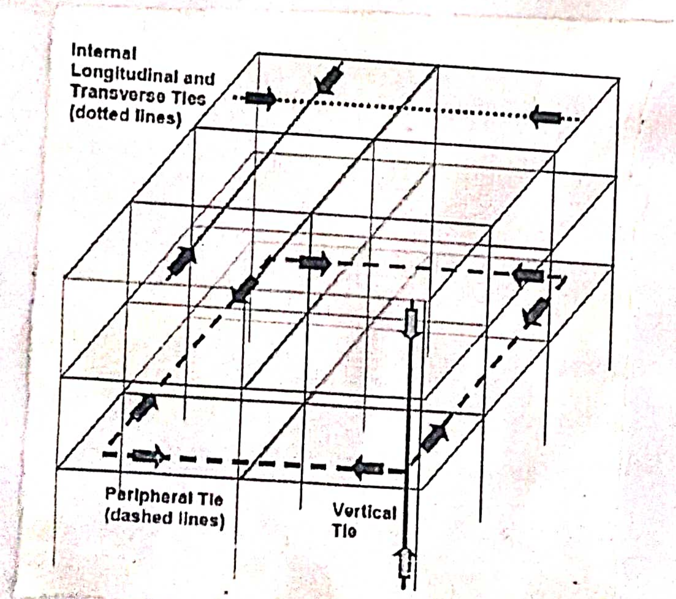
Every load bearing external column and external walls should be tied horizontally into the structure at each roof or floor level. The tie is designed for the total load of the upper storey above the floor level at which the tie is located.

Internal floor or roof ties

Internal ties at each floor and roof level be in two perpendicular directions. The ties should effectively continuously throughout their length and should be anchored to the peripheral ties at each end. The ties may be spread evenly in the slabs at spacing not greater than 1.5 times the spacing of columns, frames or walls supporting any two adjacent floors in the direction of tie.

Vertical ties

Each load bearing column and wall should be tied continuously from foundation to roof. The tie should be designed for the maximum load on the column or wall from upper storey.



Direct method

In the direct design method, resistance from progressive collapse is made by increasing the strength of main structural elements to avoid the failure under abnormal loads

loads or making the (11) structure so that it can cover the local failure area. The disadvantage of direct design methods is that the analysis is complicated compared to ordinary horizontal and lateral load analysis used in regular design. Direct method includes alternative path method and specific load resistance method.

Alternative path method

In the alternate path method the structure is designed to carry or redistribute loads by means of an alternate path in the event of the failure of a load bearing element. This is often interpreted as the removal of one load bearing element from the structure. For this the designer should make a complete study on the behaviour of the structural system. The advantage of this method is that it supports structural systems with ductility, continuity and energy consuming properties that are suitable in preventing the progressive collapse. This method is also dependable with the seismic design approach used in many building codes throughout the world.

Specific load resistance method

In specific load resistance method, some structural key elements which are prone to abnormal loads are designed with extra care. Due to this key structural elements develop full resistance to failure of itself and supporting members. This approach avoids progressive collapse of structures. The key elements should therefore be detailed to develop the ultimate capacity of the materials in shear, flexure and ax... load by means of confinement and continuity of reinforcem... for reinforced concrete construction and stiffeners for rolled steel construction.

Design Considering cyclone

Cyclonic storms form far away from the sea coast and gradually reduce in speed as they approach the sea coast. Cyclonic storms generally extend upto about 60km after striking the coast. Cyclones associated with high speed winds followed by heavy rain causes huge damage.

Cyclonic wind speed

Cyclones are high speed winds in the atmosphere having a core of extreme low pressure and light winds, surrounded by strong winds having nearly circular contours of equal pressure called isobars. The radial distance from the centre of core to the region where the maximum wind velocity occurs is called the radius of maximum winds (RMW). The appropriate wind velocity distribution among the cyclone is given in IS 15498 : 2004 (Guidelines for improving the cyclonic resistance of low rise houses and other buildings / structures) as,

$$V(r) = V_0 \left(\frac{r_0}{r}\right)^{\alpha}$$

Where $V(r)$ → Velocity of wind at a radial distance 'r'

V_0 → Velocity of maximum wind

r_0 → Radius of maximum wind (RMW)

α

$\alpha \rightarrow$ a power law exponent varying between 0.4 to 0.6

Design

It is known that higher wind speed occurs during cyclones compared to non cyclonic storms. Further there is a greater degree of turbulence in such storms and the probability of occurrence during the life time of structure is also large. To account for the enhanced risk, an enhancement factor 'f' is considered in design. As per IS 15948 : 2004, the design wind speed is given by

Design wind speed, $V_d = f k_1 k_2 k_3 V_b$

Design wind pressure, $P_z = 0.6 V_z^2$

Wind force, $F = (C_{pe} - C_{pi}) \cdot A p_z$

where $V_b \rightarrow$ Basic wind speed

$k_1 \rightarrow$ Risk coefficient

$k_2 \rightarrow$ Terrain factor

$k_3 \rightarrow$ Topography factor

$C_{pe} \rightarrow$ External pressure coefficient

$C_{pi} \rightarrow$ Internal pressure coefficient

$A \rightarrow$ Surface area of contact

$f \rightarrow$ Enhancement factor

The values $V_b, k_1, k_2, k_3, C_{pe}, C_{pi}$ is calculated as per IS 875 (Part 3) : 1987 (Code for practice for wind loads for buildings and structures)

Basic wind speed

In general, wind speed in the atmospheric boundary layer increases with height from zero at ground level to a maximum at a height called the gradient height. The variation with height depends primarily on the terrain conditions. However the wind speed at any height never remains constant.

Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 seconds and corresponds to mean heights above ground level in an open terrain. Basic wind speeds have been worked out for a 50 year return period. Basic wind speed is given in m/s.

Risk coefficient (k_1)

This coefficient indicates the risk involved due to the wind for different types of buildings. The risk is considered in design by provision of a factor called risk coefficient (k_1) which includes the importance factor for different types of buildings

Terrain factor (k_2)

Selection of terrain categories shall be made with due regard to the effect of obstructions which constitute the ground surface roughness. The terrain category used in the design of a structure may vary depending on the direction of wind under consideration.

Topography factor (k_3)

The basic wind speed V_b takes account of the general level of the site above sea level. This does not allow for local topographic features such as hills, valleys. etc. which can significantly affect wind speed in their vicinity. The effect of topography is to accelerate wind near the summits of hills and decelerate the wind in valleys.

Pressure coefficients

Pressure coefficients are always given for a particular surface or part of the surface of a building. The wind load acting normal to the surface is obtained by multiplying the area of that surface or its appropriate portion by the pressure coefficient (C_p) and the design wind pressure at the height of the surface from the ground. In order to determine the maximum wind load on the building, the total load should be calculated for each of critical ~~section~~ directions shown from all quadrants. Where considerable variation of pressure occurs over a surface it has been subdivided and mean pressure coefficients given for each of its several parts. In addition, areas of high pressure concentration frequently occurring near the edges of walls and roofs are separately shown in code. Coefficients for the local effects should only be used for calculation of forces on these local areas affecting roof sheeting, glass panels and individual cladding unit including their fixtures. They should not be used for calculating force on entire structural elements such as roof, walls or structure as a whole.

Design considering earthquake

General principles

The characteristics (intensity , duration) of seismic
ground vibrations expected at any location depends upon
the magnitude of earthquake, its depth of focus, distance
from the epicentre, characteristics of the path through which
the seismic waves travel and the soil strata on which
the structure stands. The random earthquake ground motions
which cause the structure to vibrate can be resolved
in any three mutually perpendicular directions. The predominant
direction of ground vibration is usually horizontal and hence
~~earthquake generated vertical inertia forces are to be considered~~
~~in design unless~~ horizontal acceleration due to earthquake
and horizontal inertia forces should be considered. Earthquake
generated vertical inertia forces are to be considered in design
unless checked and proven by specimen calculations to be
not significant. Vertical acceleration should be considered in
structures with large spans, those in which stability is
criterion for design or for overall stability analysis of structures.
Vertical component of ground motions can be particularly
harmful in cases of prestressed horizontal members and of
cantilevered members as they reduce gravitational force.
Hence special attention should be paid to the effect
of vertical component of the ground motion on prestressed
or cantilevered beams, girders and slabs

Design Assumptions

The following assumptions shell be made in the earthquake resistant design of structures,

→ Earthquake causes sudden ground motions which are complex and irregular in character changing in period and amplitude each lasting for a small duration. Therefore resonance of the type as visualized under steady state sinusoidal excitations will not occur as it would need time to buildup such amplitudes.

→ Earthquake is not likely to occur simultaneously with wind or maximum flood or maximum sea waves

→ The value of elastic modulus of materials wherever required may be taken as for static analysis unless a more definite value is available for use in such condition.

Load Combinations

The following are the load combinations adopted in the earthquake resistant design of structures,

For concrete structures

→ 1·5 (DL + IL)

→ 1·2 (DL + IL ± EL)

→ 1·5 (DL ± EL)

→ 0·9 DL ± 1·5 EL

For steel structures

→ 1·7 (DL + IL)

→ 1·3 (DL + IL ± EL)

→ 1·7 (DL ± EL)

Where DL → Dead Load

IL → Imposed Load

EL → Earthquake Load

Design

The design horizontal seismic coefficient (A_h) for a structure shall be determined by the following expression,

$$A_h = \frac{Z}{2} \times \frac{I}{R} \times \frac{S_a}{g}$$

Where Z → Zone factor

I → Importance factor

S_a/g → Average response acceleration coefficient

A_h → Design horizontal spectrum value.

The total design lateral force or design base shear (V_B) along any principal direction shall be determined by the following expression,

$$V_b = A_h \times W$$

Where A_h → Design horizontal spectrum value

W → Seismic weight of the structure.