FLOORING SYSTEMS

Section 5.4

Introduction

- A flooring system comprises the structural components and materials that form the floor of a building. This system supports the building's loads, separates different levels within the structure, and provides a surface for occupants to walk on.
- The structural components of the flooring system - the slabs - are typically rigid planar structures with depths that are small relative to their other dimensions. These slabs are supported either along their entire perimeter or at specific points by beams, columns, and walls.
- The flooring system is a significant contributor to the overall building cost. To minimize expenses, rectilinear arrangements of supports are often preferred, as they allow for simpler patterns of reinforcement and formwork.

Slabs for Steel structures

- Typical floor slab systems for steel frameworks include:

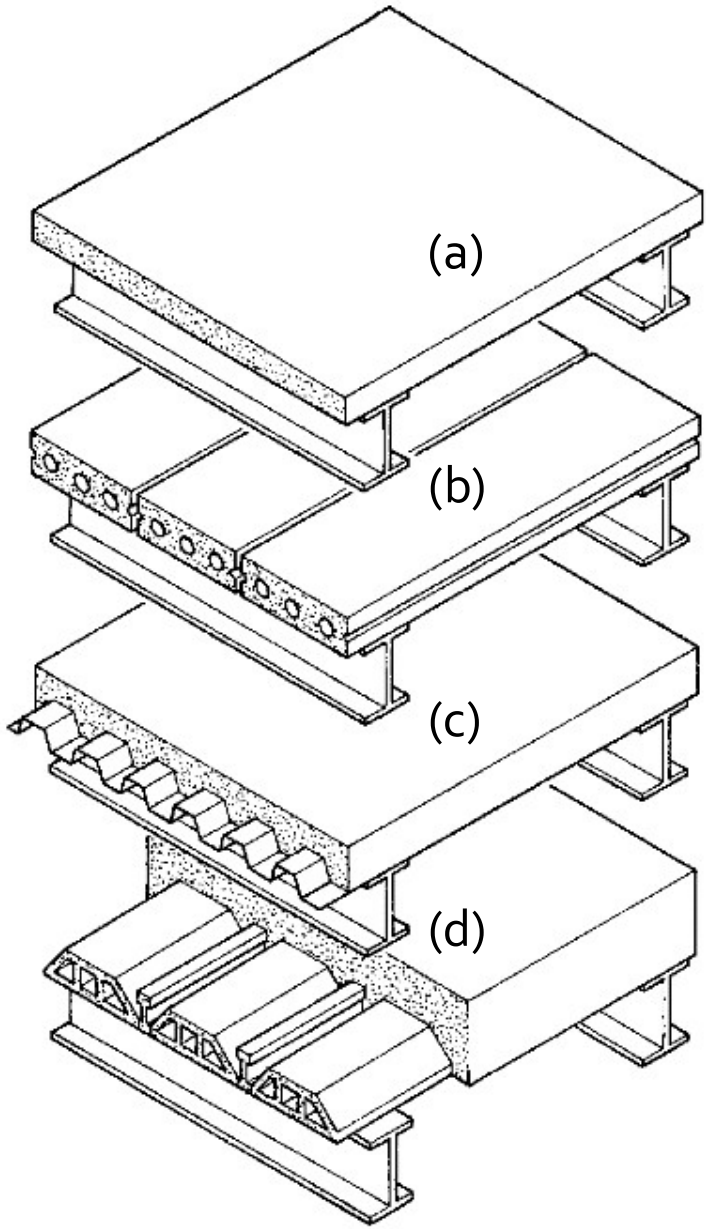
a) In - situ reinforced concrete flat slab.

b) Precast concrete floor units.

c) In situ concrete on profiled steel permanent formwork.

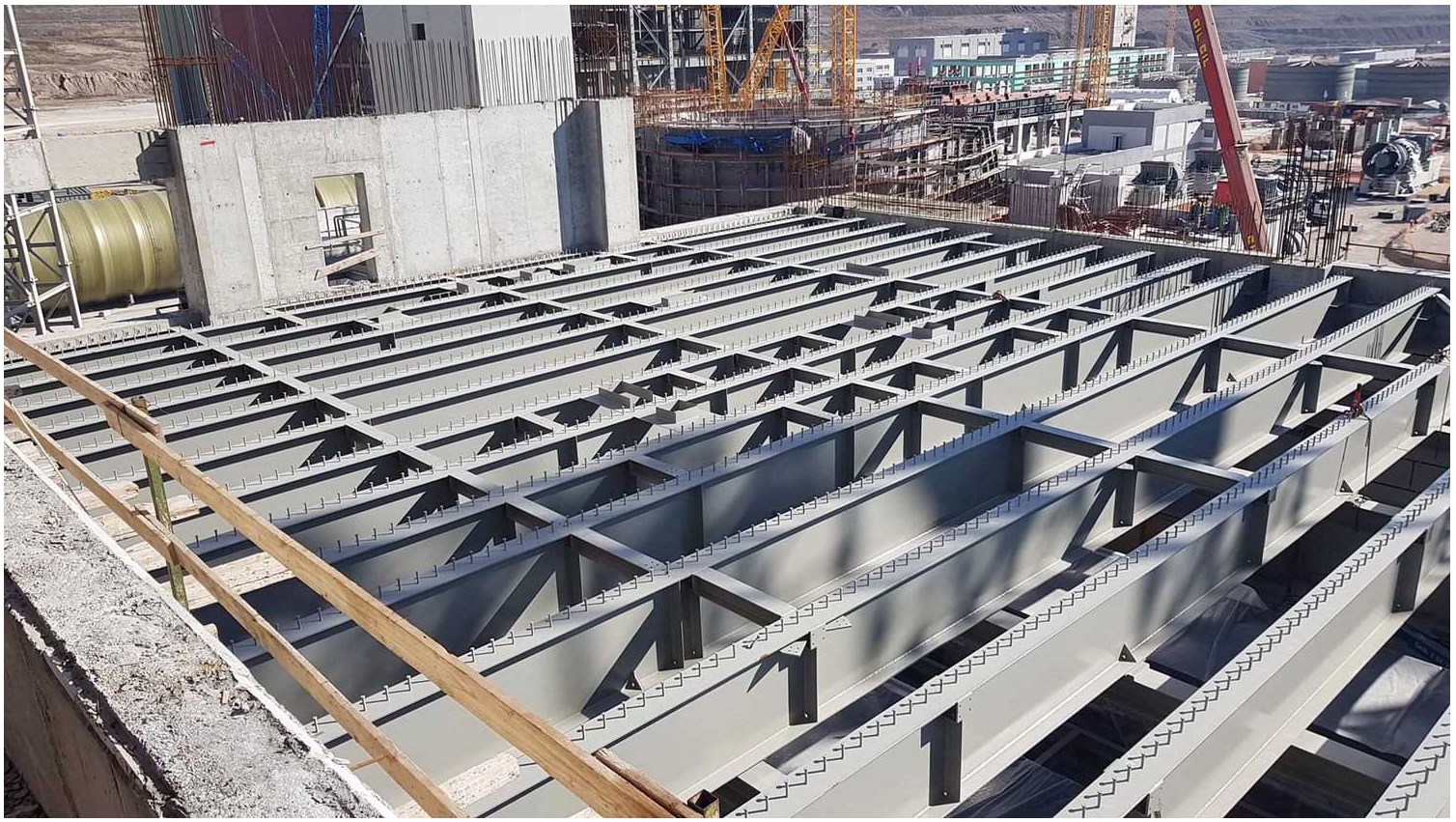
d) Composite precast and in situ concrete.

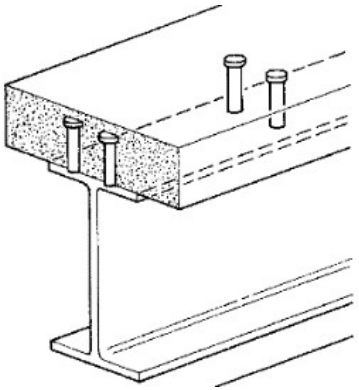
- All of these systems are normally one-way-spanning and require to be supported on a parallel arrangement of steel beams. However, system (a) can be a two-way-spanning structure.



Slabs for Steel structures

- To increase efficiency and therefore reduce the size of the beams, shear studs are usually welded to the floor beams which allow composite action to be developed between the beams and the floor slabs.



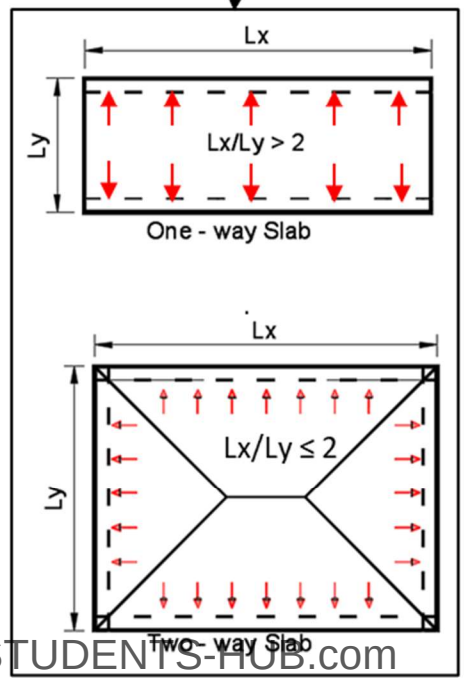


Concrete Flooring Systems

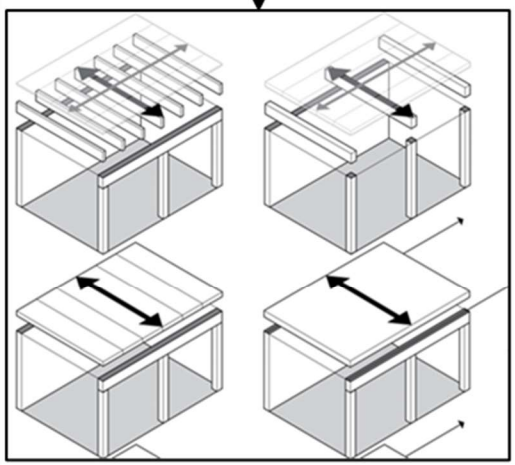
SLABS CLASSIFICATION

Load transformation (One-way/ Two way)

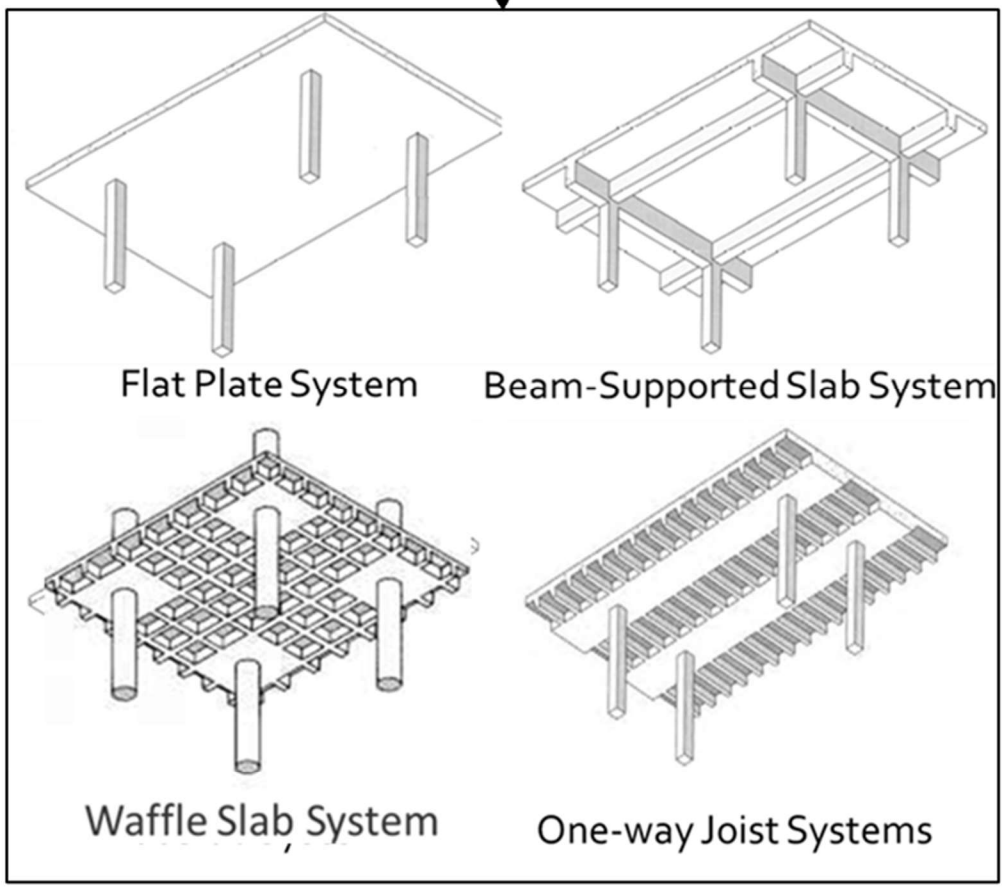
Geometry



Method of construction/ Material

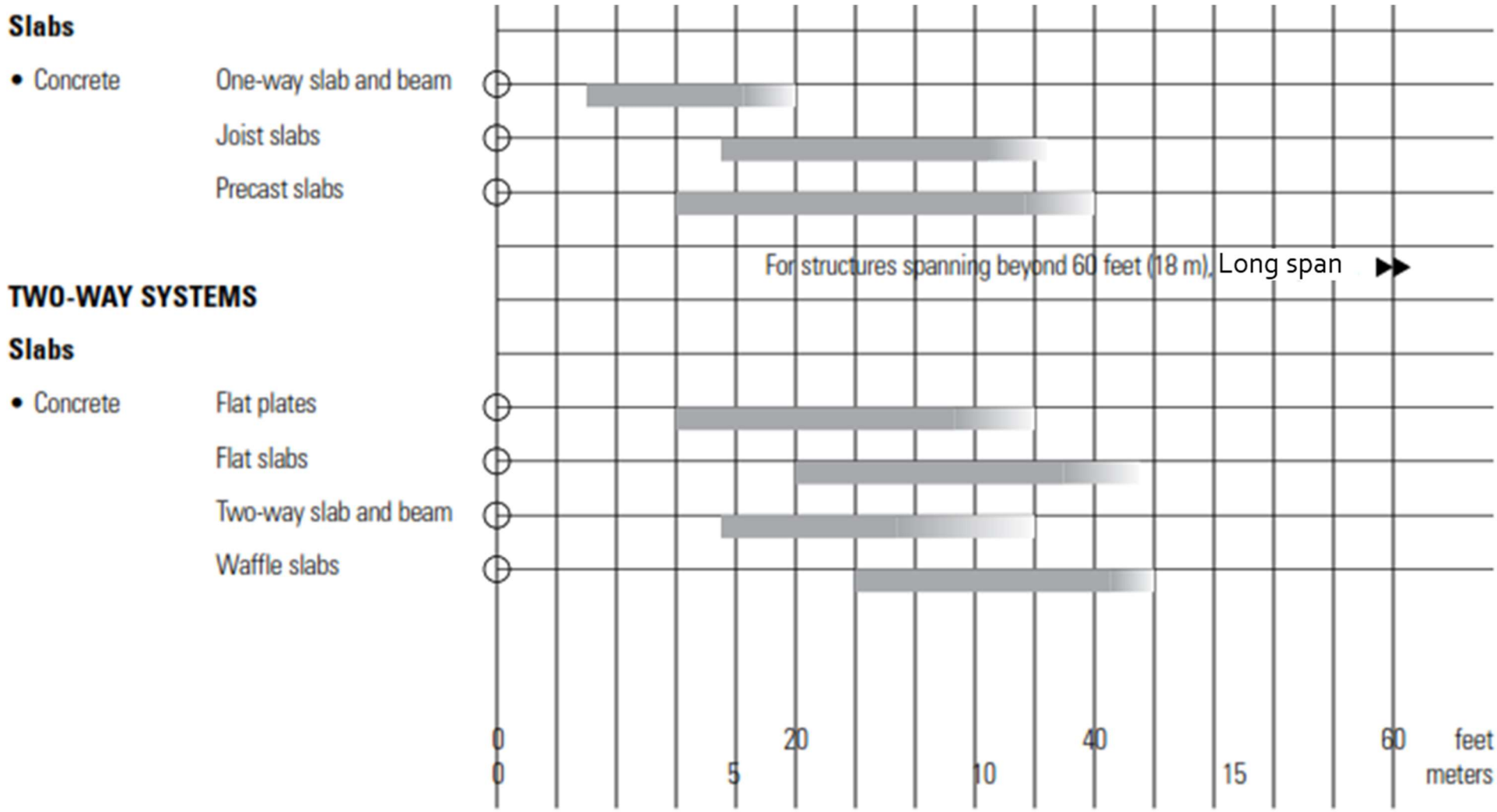


Slap Type



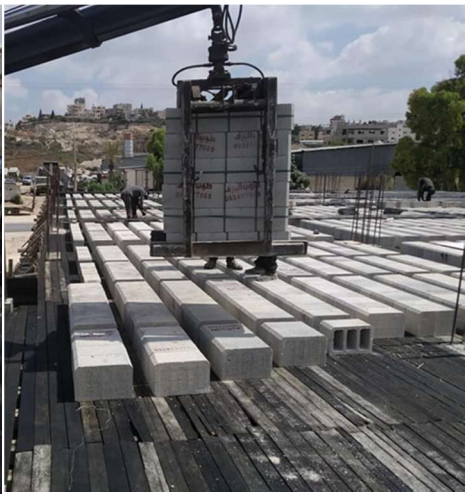
Economic spans

Appropriate span ranges for basic types of flooring systems



One-Way Joist System (rib slab)

Rib slab during construction

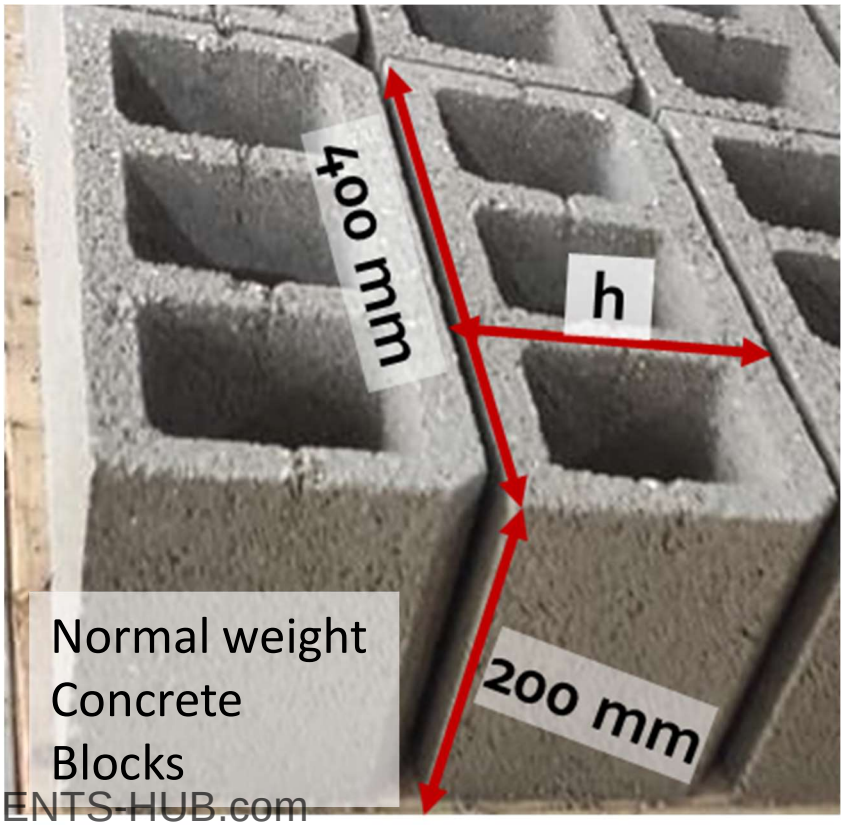


Rib slab from bottom after pouring

A one-way joist system consists of evenly spaced concrete ribs (joists) spanning in one direction, a reinforced concrete slab cast integrally with the joists, and beams spanning between the columns perpendicular to the ribs.

One-Way Joist System (Rib Slab)

- Ribs can be formed using normal weight concrete blocks; light weight blocks (Ytong); Polystyrene concrete blocks; clay block; removable metal or plastic forms.
- Available block size
  - Normal weight concrete blocks: h= 170, 200, 240, 300, 320
  - Ytong blocks: can be fabricated as required



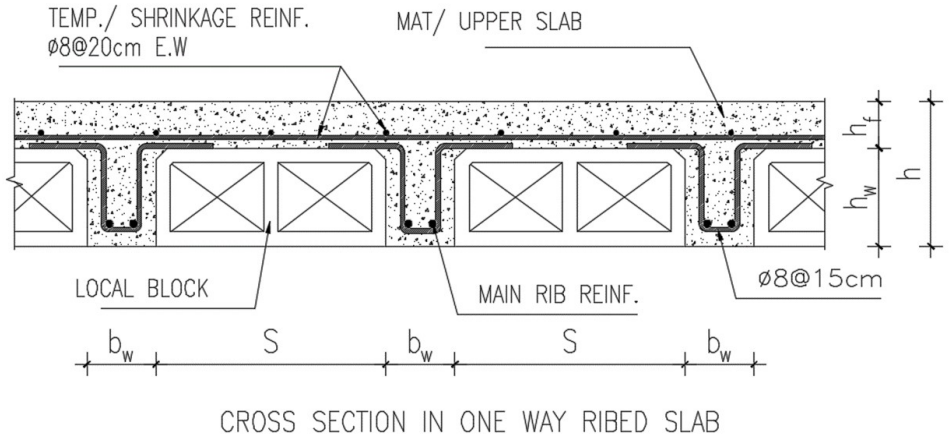
Normal weight Concrete Blocks

Polystyrene concrete blocks

Clay Block

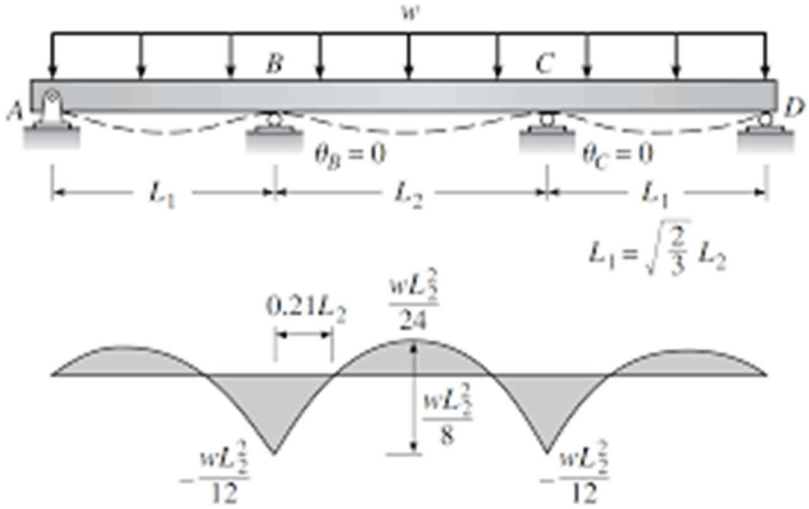
One-Way Joist System (Rib Slab)

- Dimensional requirements
- $b_w \geq 100mm$;
- $h \leq 3.5\ b_w$;
- $S \leq 750$ mm;
- $h_f \geq 50$ mm and $\geq S/12$

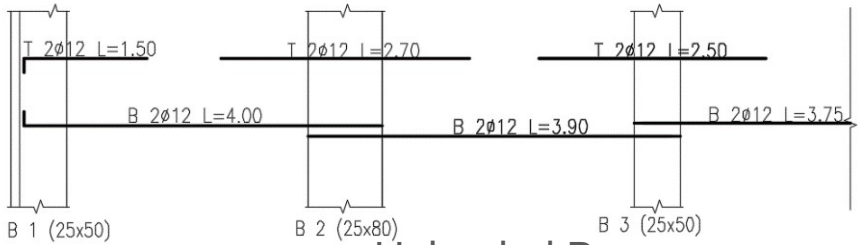


CROSS SECTION IN ONE WAY RIBED SLAB

- Ribs are modeled as continuous beams in knife supports.



- Typical Reinforcement



One-Way Joist System (Rib Slab)

- Advantages

1. Use less concrete and reinforcement steel than traditional solid slabs, thus reduce weight.
2. Thermal and Acoustic Insulation: The voids in ribbed slabs can improve thermal and acoustic insulation properties.
3. Ease of construction – widely used in the local buildings.
4. Structurally Flexibility and Preferable by the architects– the hidden beam concept.

- Limitation

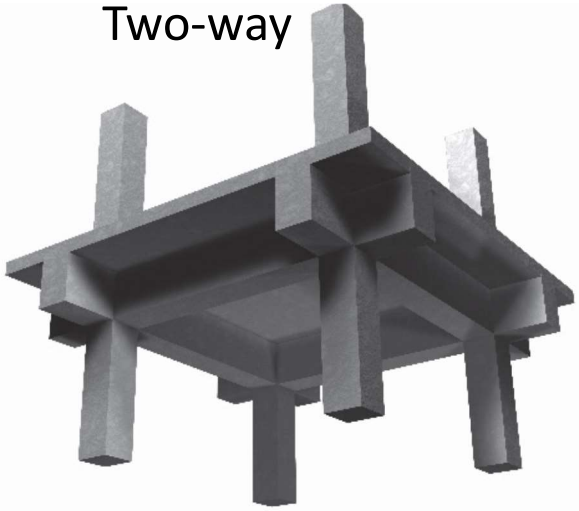
- Integrity: the connection between the blocks and concrete is questionable, especially under lateral loads.
- Advantages 1 and 2 are questionable

Beam-Supported Slab System

- The slab system supported on beams was the original slab system in reinforced concrete. Usually reinforced in two directions and cast integrally with supporting beams and columns.
- The slap panels can act as a one-way or two-way slap based on panel dimensions or supporting conditions.
- A principal advantage of concrete slab-and-beam systems is the rigid frame action made possible by the column-beam interaction.

One-way

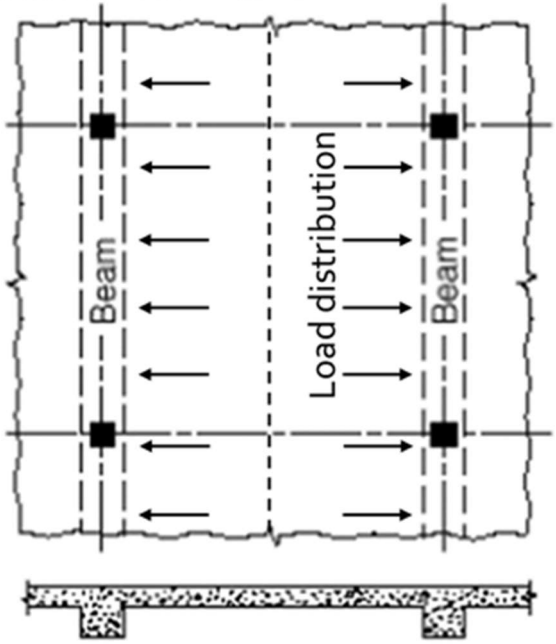
Two-way

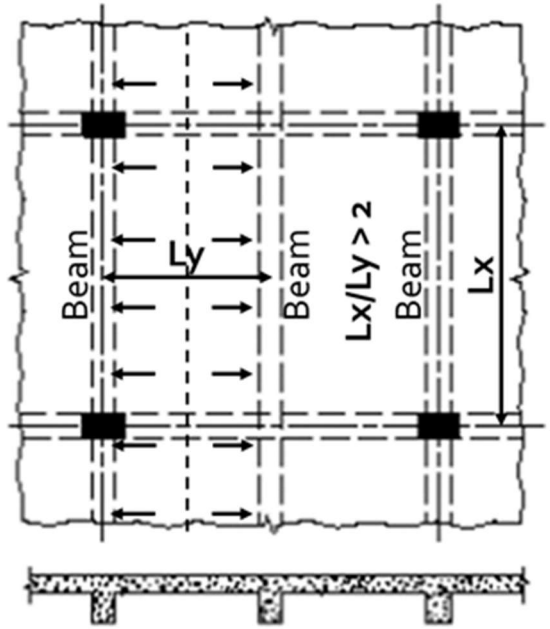


- The principal disadvantages are the increased cost of formwork and greater construction depth, mainly when mechanical ductwork must run below the beam structure.

One-way solid slab

- The one-way slab is a plate with uniform thickness supported by concrete/ masonry-bearing walls, or more typically, cast integrally with parallel supporting beams, which, in turn, are supported by girders, bearing walls, or columns.
- The thickness of the slab is initially determined in compliance with serviceability requirements of the design code.
- They are suitable for light to moderate load conditions over relatively short spans of 2 to 5.5 m.



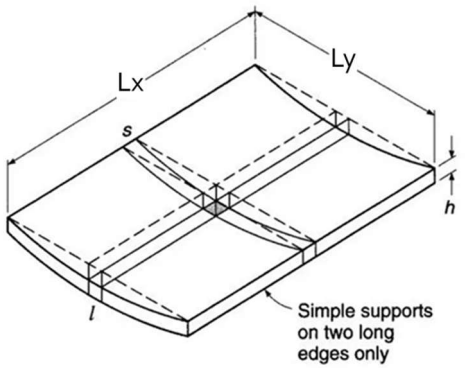


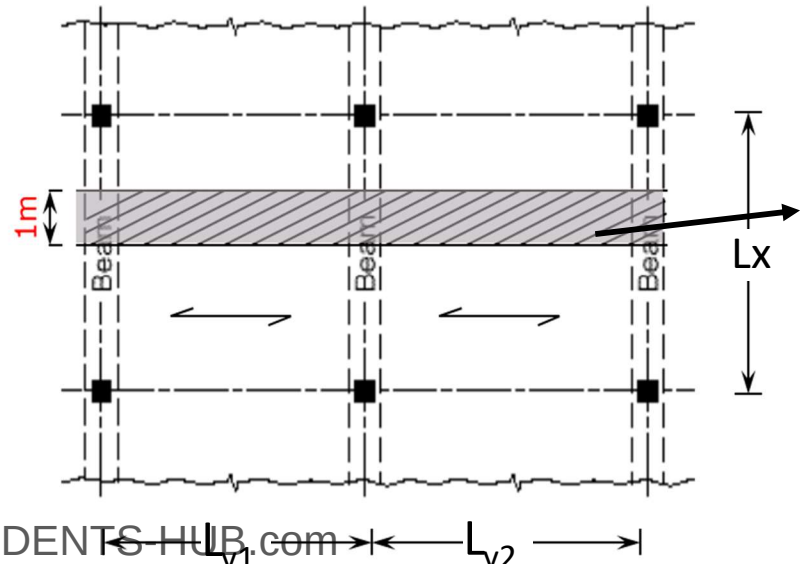
One-way solid slab

- Serviceability requirements of ACI-318 is shown in the table.
- The deflected shape of a uniformly loaded one-way solid slap panel is shown in the figure below. The shape indicates that slap loads are mainly distributed to the long sides of the slap panel.

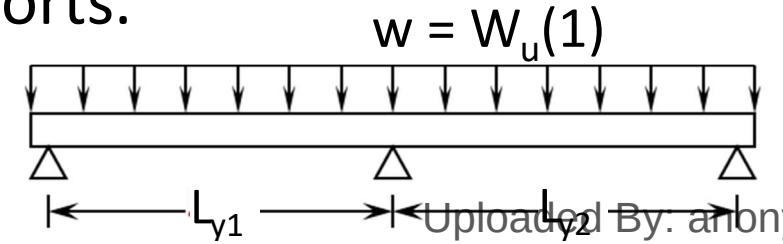
Table 7.3.1.1—Minimum thickness of solid nonprestressed one-way slabs

Support condition	Minimum h[1]
Simply supported	$\ell/20$
One end continuous	$\ell/24$
Both ends continuous	$\ell/28$
Cantilever	$\ell/10$



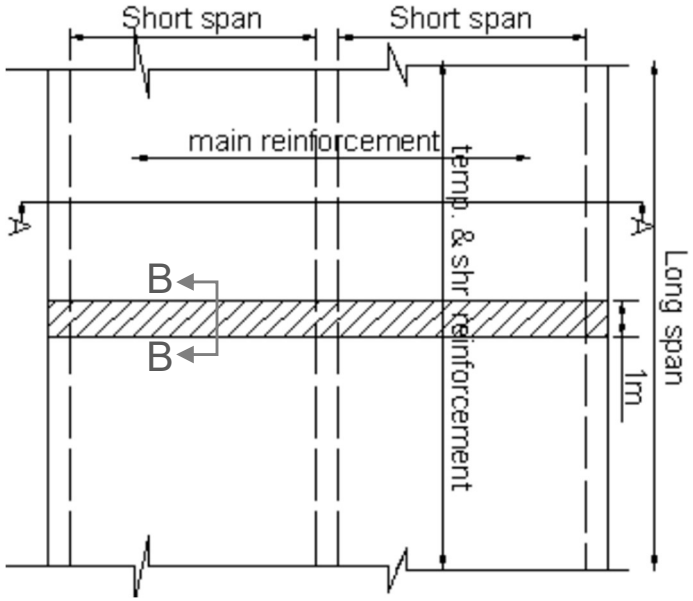


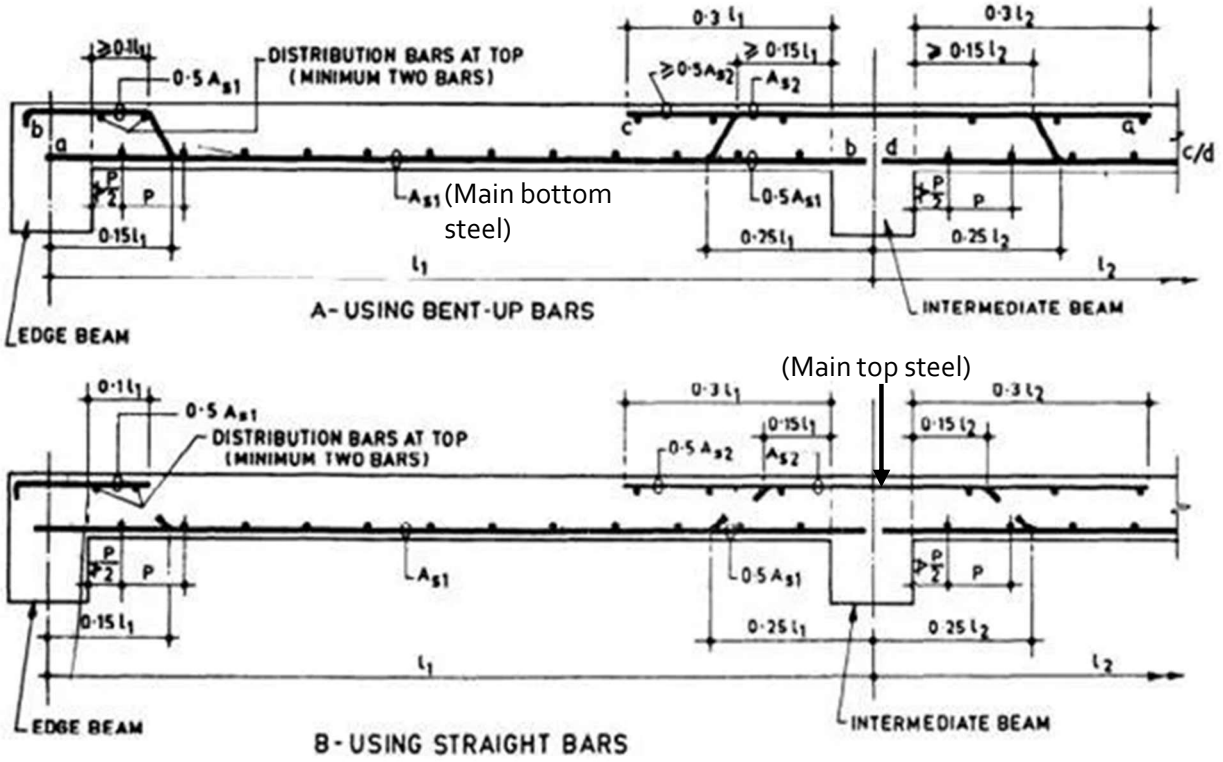
- Analysis. A strip - one meter wide - in the direction of the slab is analyzed as a continuous beam in hinge supports.



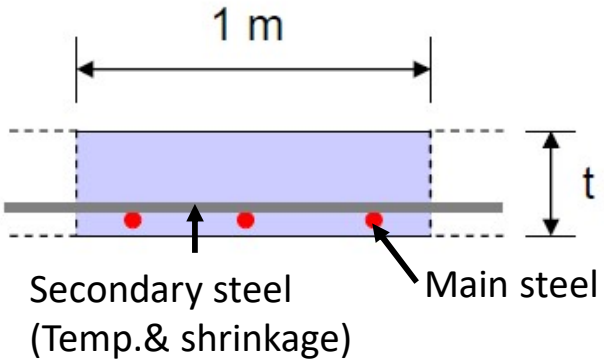
One-way solid slab

Typical Reinforcement





Section A-A



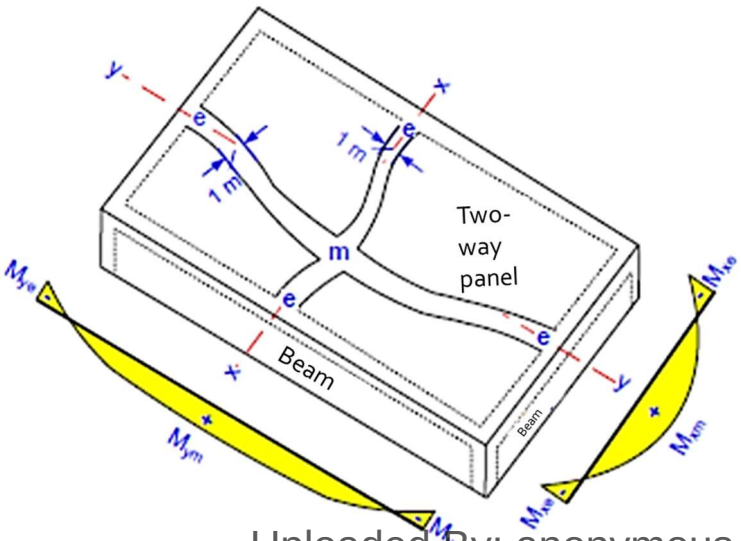
Section B-B

- A minimum area of flexural reinforcement, $A_{s,min,}$ of $0.0018A_g$ shall be provided.

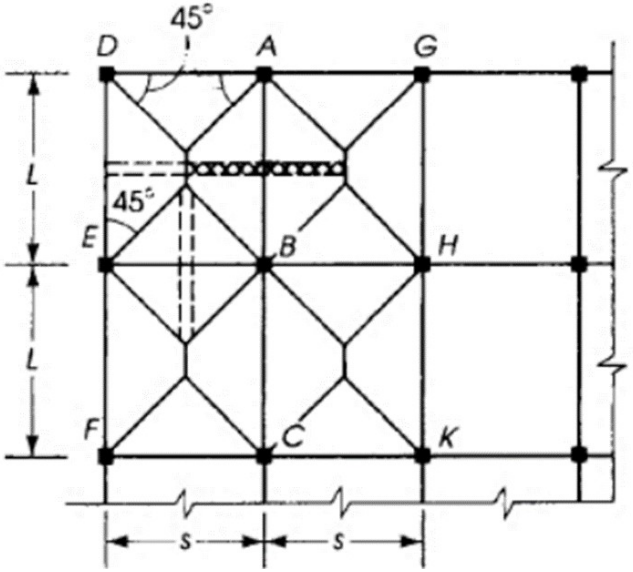
Two-way beam-supported slabs system

- A solid slab supported on beams on all four sides as shown in the photo.
- As a two-way system, the load is transferred in both orthogonal directions.
- Rule of thumb for estimating beam depth: span/16, including the slab depth; slab depth: slab perimeter/180.

Deflected shape



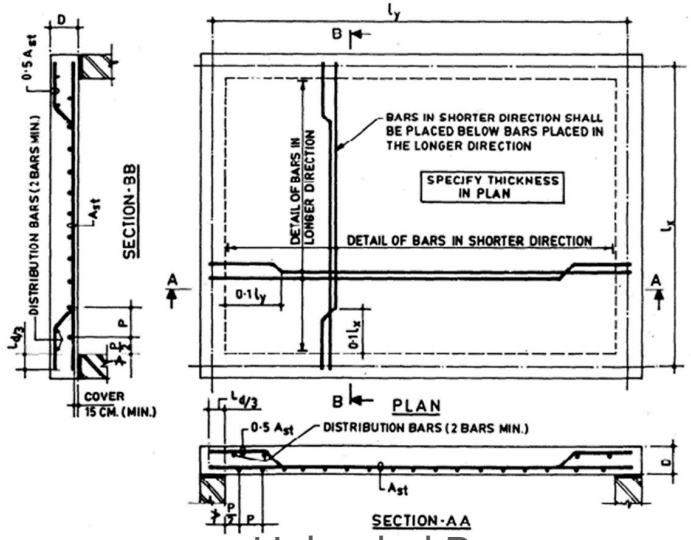
Distribution of slab load into supporting beams



Two-way beam-supported slabs system

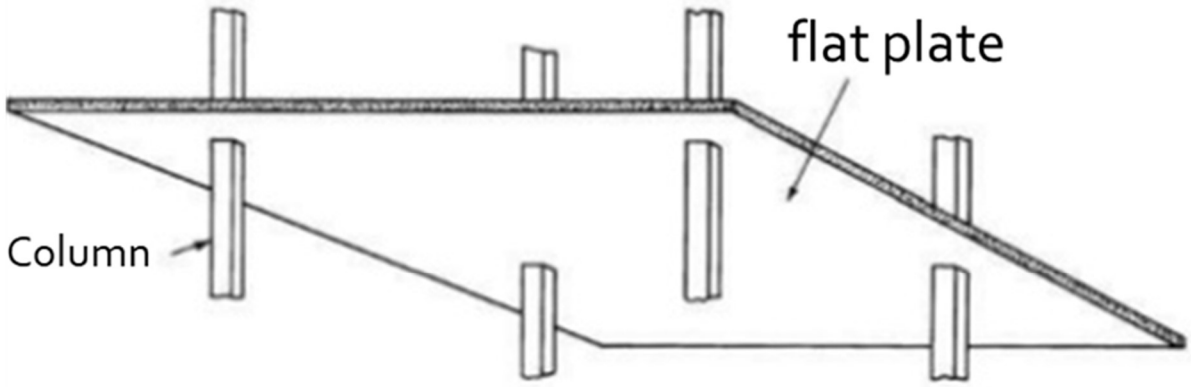
- Two-way slabs are most efficient when spanning square or nearly square bays, and suitable for carrying intermediate to heavy loads over 4.5 to 9 m spans.
- The system is not as economical as other two-way systems with similar span and loading conditions. As such, the system is not used as often, except in cases where the demands for lateral force resistance are relatively large especially where the moment-resisting frames are used as the seismic force–resisting system.

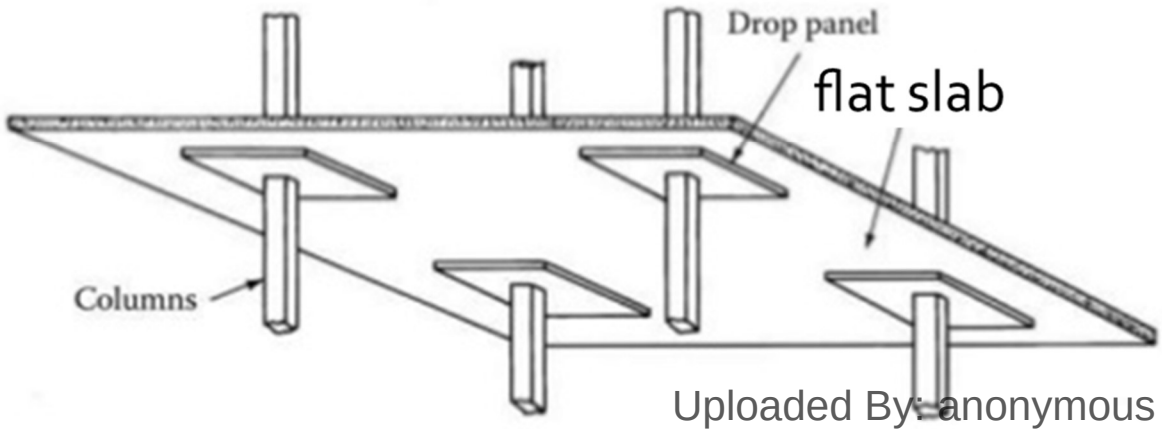
- Typical Reinforcement – the Panel is reinforced by orthogonal bars in tow directions



Flat Plate and Flat Slap System

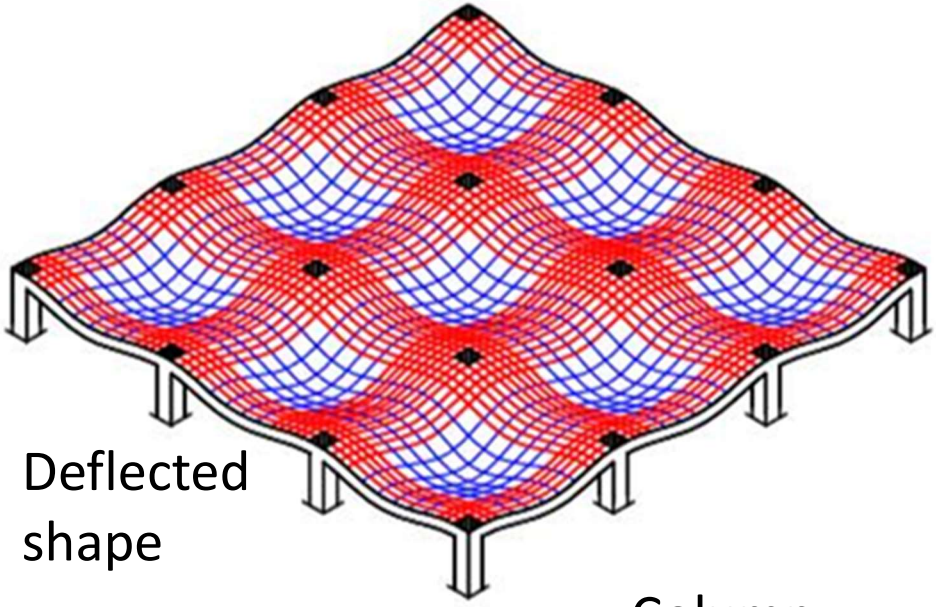
- A flat-plate floor system is a two-way concrete slab supported directly on columns.
- A flat-slab floor system is similar to a flat-plate, with the exception that the slab is thickened around the columns as shown in the figure.

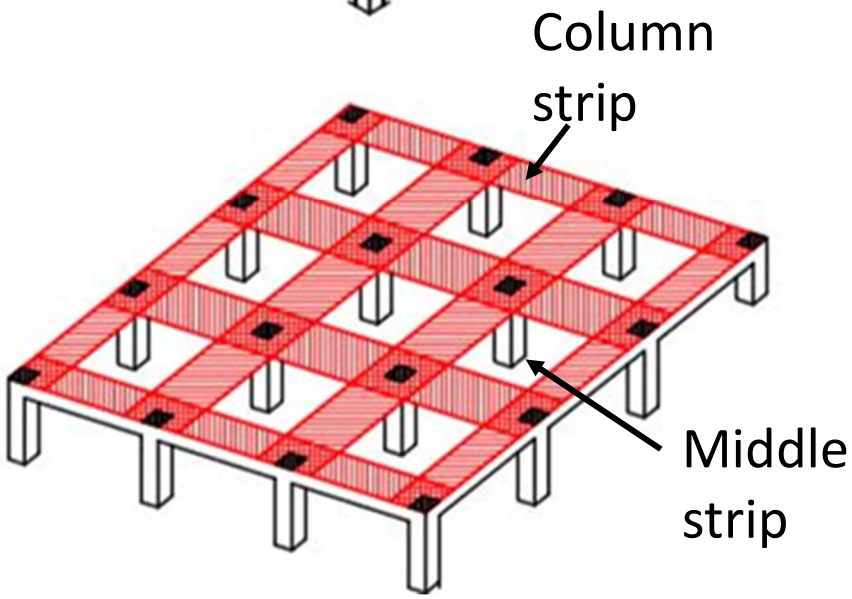




Flat Plate and Flat Slap System

- Structural behavior under loads





- The panels are divided into ‘column strips’ and ‘middle strips’ in both directions as shown in the figure.
- Using the analogy of the slabs on beams, the column strips act as beams while the middle strips acts as slabs to transfer loads to the columns or the vertical elements.

Flat Plate and Flat Slap System

- **System Characteristics**

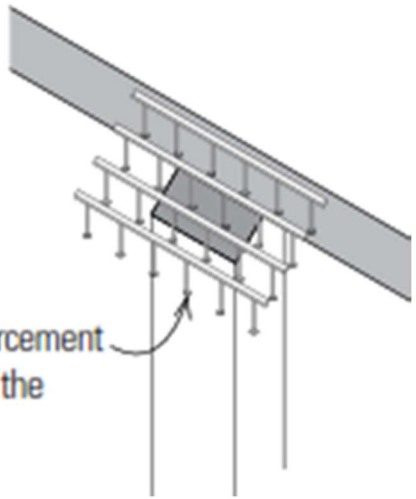
- Flat plates are typically economical for span lengths between 4.5 m and 8 m when subjected to moderate live loads. In this range, the slab thickness varies from 15 – 25 cm. On the other hand, Flat slabs are typically economical for spans between 6 m and 9 m, however, they require more formwork for column capitals and drop panels.
- For relatively short spans and live loads of 2.5 KN/m^2 or less, the thickness of a flat plate will usually be controlled by the deflection requirements. In this case flexural reinforcement will be the minimum specified by the code.
- Where the spans are relatively long and/or the live load is 5 KN/m^2 or greater. Two-way or punching shear may determine the slab thickness.

Flat Plate and Flat Slap System

- **Punching shear problem**

Punching shear problem can be solved by:

- Increasing slab thickness;
- Increasing column sizes;
- Using drop panels/ column capital.
- Providing shear reinforcement.



- Specially designed shear stud reinforcement at column locations can help reduce the required thickness of flat plates.

Flat Plate and Flat Slap System

- **Advantages:**

- Simple construction and formwork.
- Provide a flat ceiling which enables flexibility in design and space utilization and may reduce the story height.

- **Limitations**

- Flat plate systems are not permitted to be the primary seismic-force-resisting system in areas of high seismicity.
- Complexity in service integration like plumbing, electrical, and HVAC systems, despite the ease of installation.
- In the context of the local market, the design and construction of flat slabs may require a higher level of expertise.

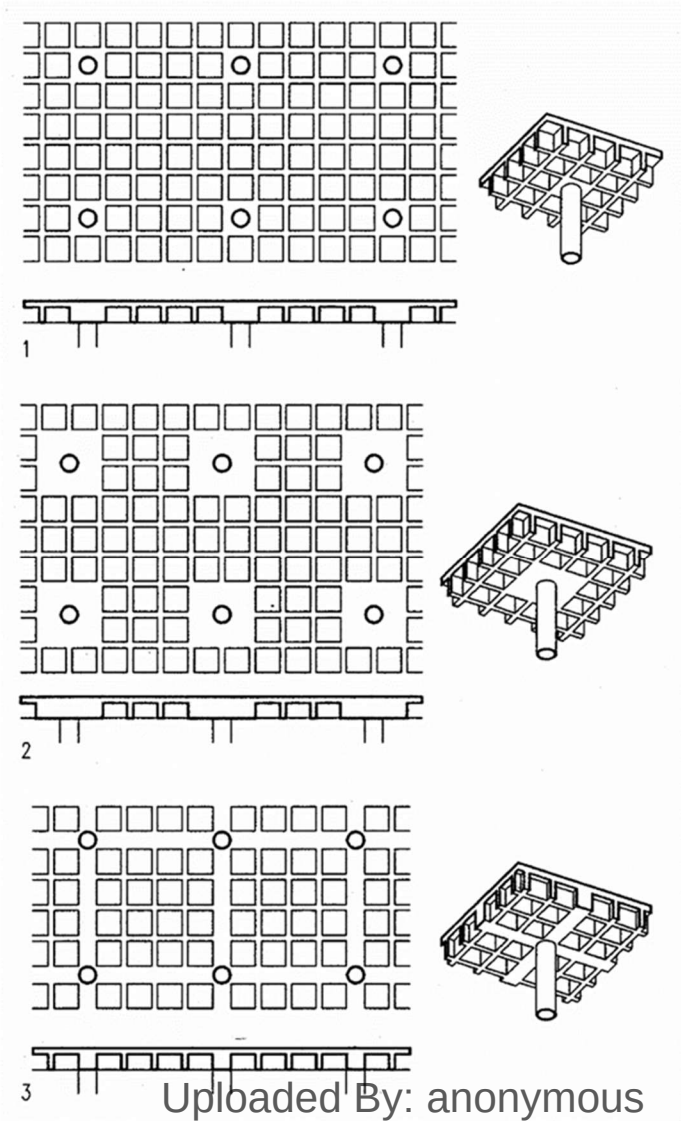
Waffle slab System

- Waffle slabs are two-way systems, suitable for medium spans where flat slabs or plates would be too deep and too heavy.
- They are composed of ribs in two directions covered by a thin plate, therefore, reducing the dead weight of the slab by eliminating the ineffective concrete between the ribs.
- Formed by placing reusable prefabricated pans of plastic or steel over a grid of wood boards.

Waffle slab System

- **Structural behavior under loads**. Similar to the behavior of the flat plate system.
- **System Characteristics**

- Waffle slabs are able to carry heavier loads and span longer distances than flat slabs. Ribbed construction produces a relatively light concrete system for spans of 8 m to 13 m. Longer spans, up to 20 m, are possible.
- Need either solid panels on top of columns to resist shear stress or require intermediate beams.
- Since negative bending reverses the stress, waffle slabs are not efficient as cantilevers with negative bending.

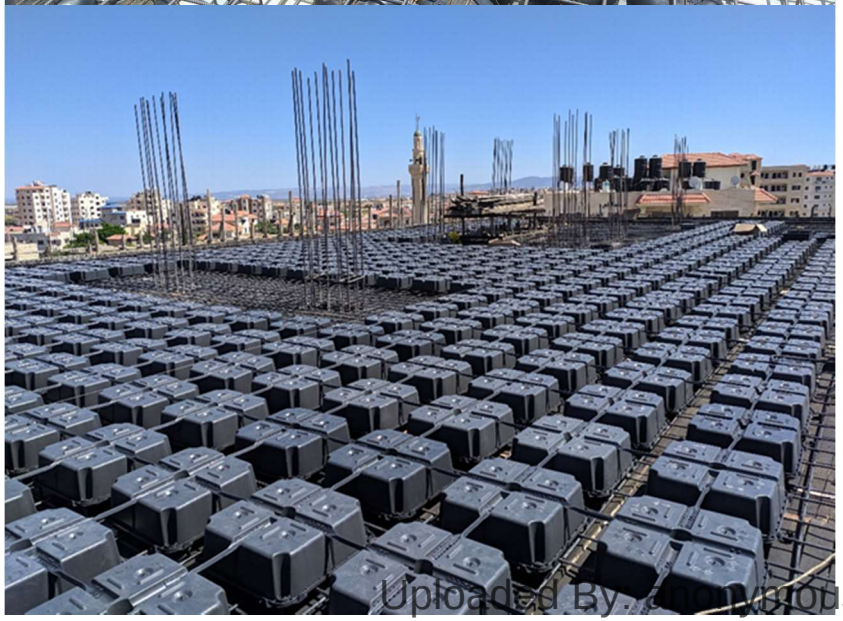


Waffle slab System

- **Advantages**
- Material Efficiency: removal of the ineffective concrete. The reduced material usage results in a lighter slab.
- Longer Spans: Ribbed slabs can span greater distances compared to solid slabs. This allows for more open and flexible interior spaces.
- Aesthetic Flexibility: Ribbed slabs can be left exposed as an architectural feature, providing an interesting ceiling pattern.
- **Limitations**
- Complex formwork.
- Higher initial costs.
- Difficulties in service integration.
- Not permitted to be the primary seismic-force-resisting system in areas of high seismicity.

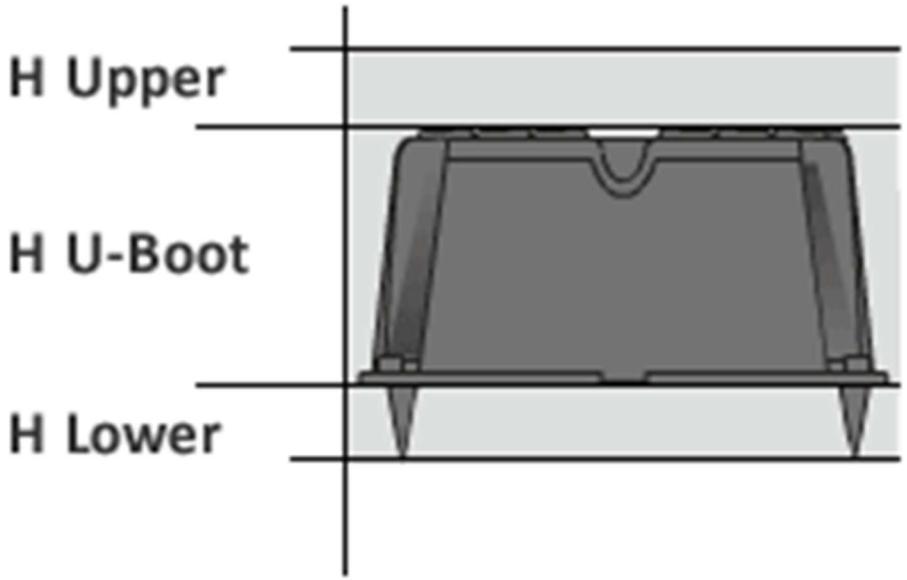
Voided Slabs System

- Voided slab incorporates an array of rigid void formers that contain air. The arrangement creates an array of hollow boxes in the slab that support the flat surface.
- The concept centers on removing concrete mass from the areas of the slab where it is not structurally efficient; thus reducing the dead load by as much as 35%.
- The system provides support in both directions and is economically viable for medium to long spans and for moderate live loads (7-12 m).

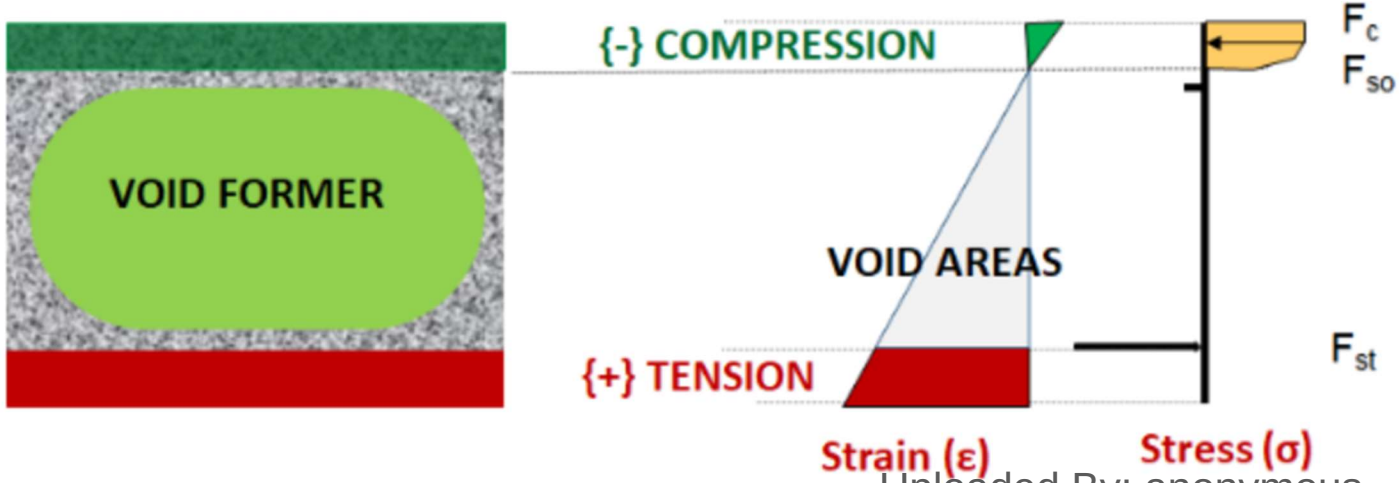


Void Slabs System

- ***Advantages***
- Larger spans without beams
- Larger open floor areas
- Lower floor-to-floor heights
- Improved Earthquake Performance
- Resource efficiency



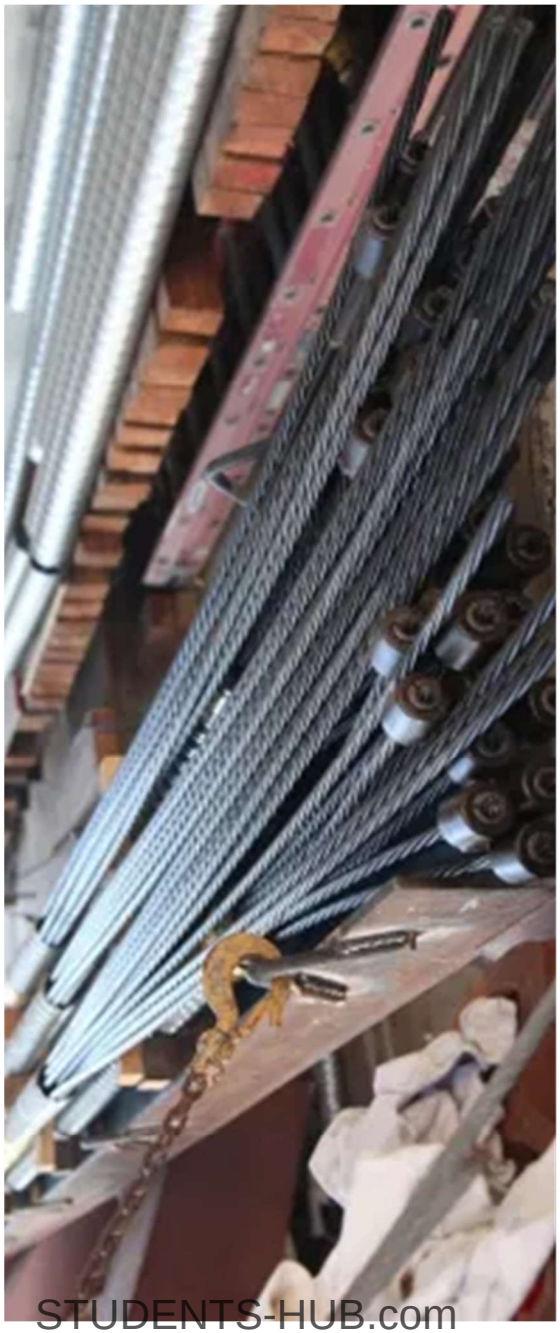
Cross-section of voided slab

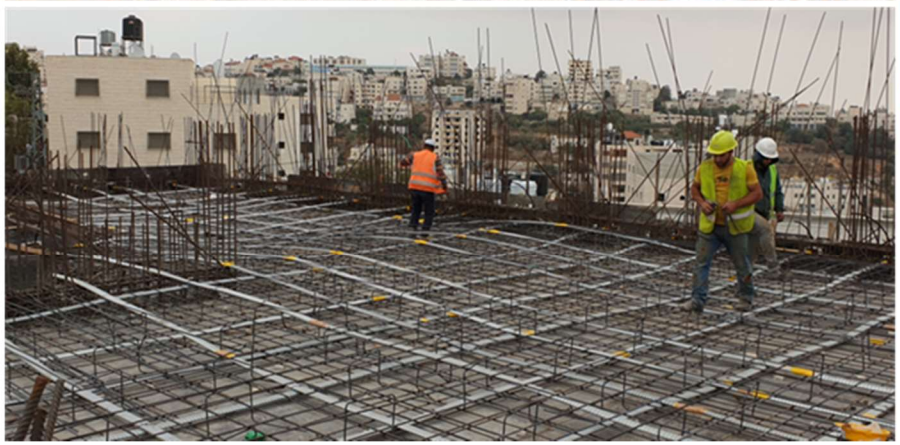


Post-Tensioned Slab System

- Post tension slab is a combination of conventional slab reinforcement and additional protruding high-strength steel tendons, which are consequently subjected to tension after the concrete has been set. This hybridization helps achieve the formation of a much thinner slab with a longer span devoid of any column-free spaces.
- Require experience, special equipment, strict supervision, and skilled labor and can not be modified after casting. Additionally, the prestressing tendons are costly compared with normal reinforcement steel.

Post-Tensioned Slab System





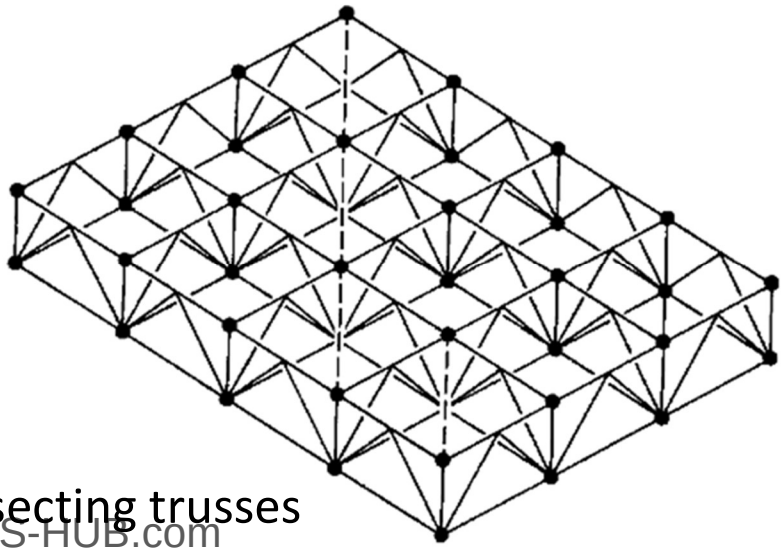
Other Flooring systems

Several other types of structures have a general structural behavior that is analogous to that of a plate, such as:

- Space frames
- Folded plates

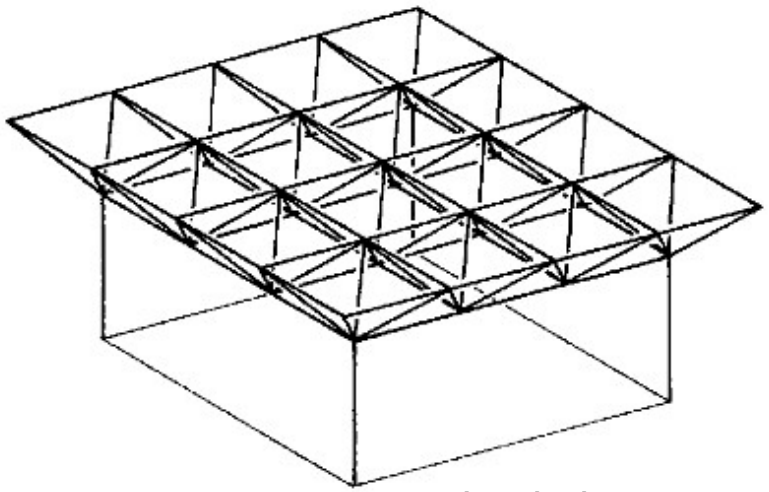
Space Frames

- Space-frame structures are typically made of rigid linear members normally arranged in repeating geometric or modular units to form a thin, horizontally spanning structure.
- The structure can take the form of intersecting sets of single-plane elements such as triangulated trusses or of a fully three-dimensional triangulated space framework. They can utilize a standard module to generate flat grids, barrel vaults, domes, and free-form shapes.

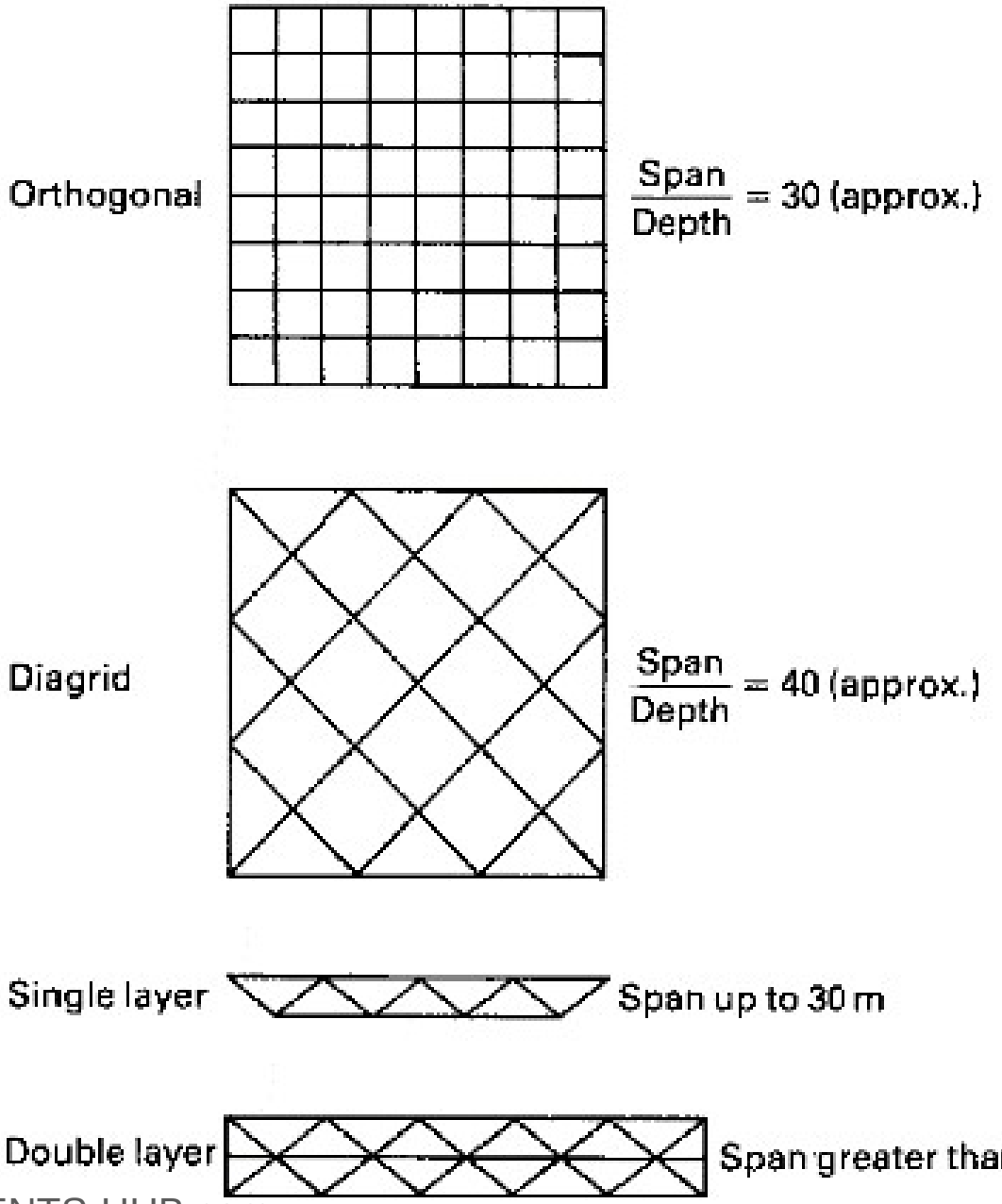


Intersecting trusses

fully triangulated



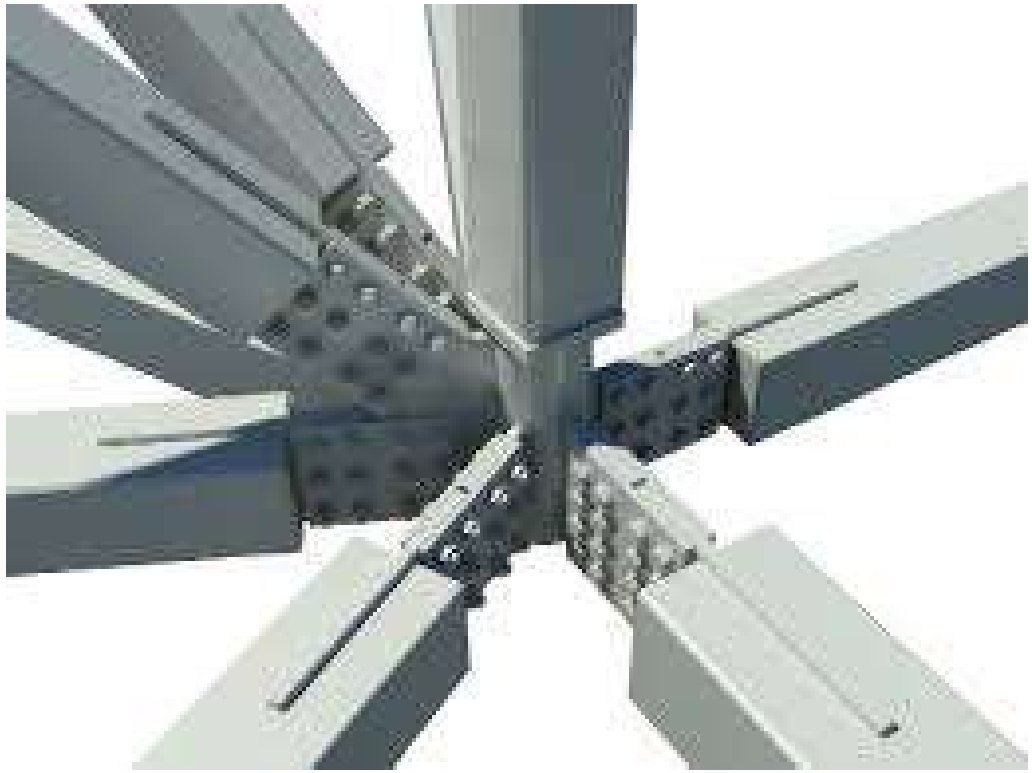
Space Frames – Basic Arrangements

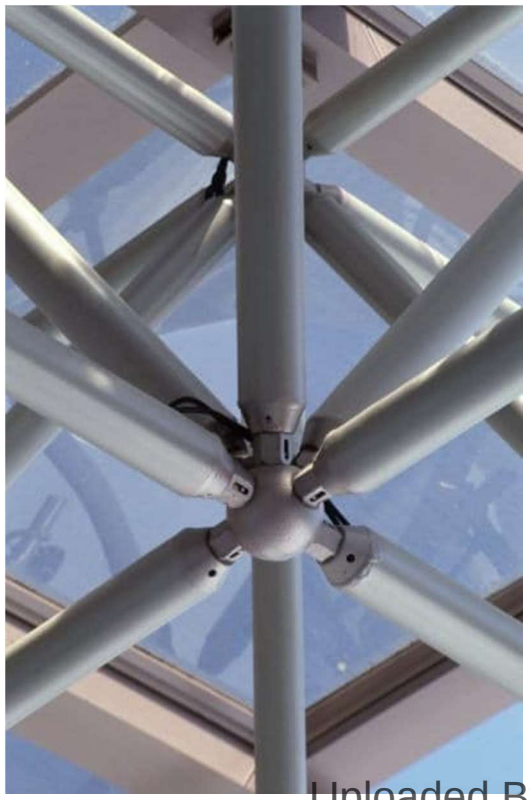


The basic arrangement of space frames and the approximate spanning range

Space Frames – Joints

The joints in space frames are crucial because they connect the various elements of the structure, allowing it to distribute loads efficiently across the entire frame. Designing nodal connections to accommodate the complexities of how members meet at a point is problematic, however, several interesting approaches have been developed.

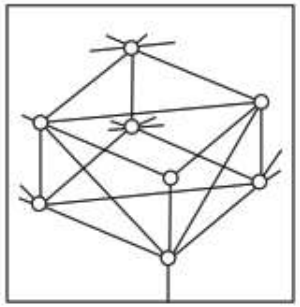




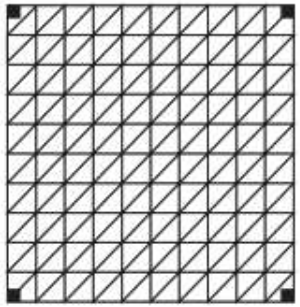
Space Frames - Structural Behavior

- Space frames are suitable for use with uniformly distributed loads and do not handle large, concentrated loads well.
- Members' forces generally depend on the loading magnitudes, spans, depth of the structure, and the size of the modules. Member forces in shallow structures with coarse grids are normally higher than those in deeper structures with finer-grained grids.
- When modular units are fully triangulated, these structures are better characterized as space trusses rather than space frames, although the latter name is commonly used. Members in triangulated units normally experience only axial tension or compression forces and are thus often made with symmetric cross-sections (e.g., pipes). Fully triangulated frames allow a more efficient use to be made of material than in the case of the intersecting plane-frame.

Space Frames - Structural Behavior

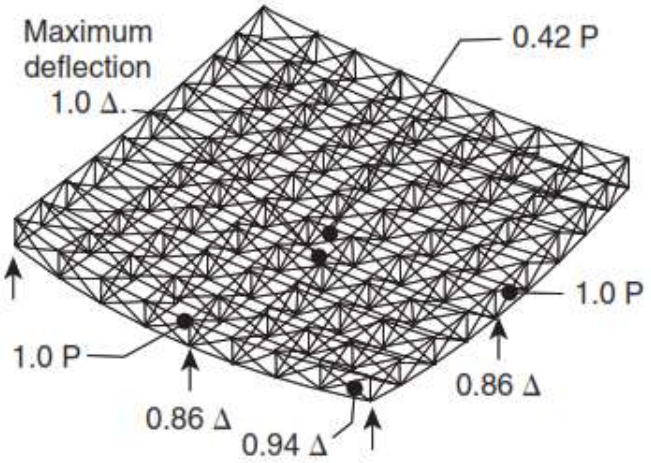


Basic triangulated module

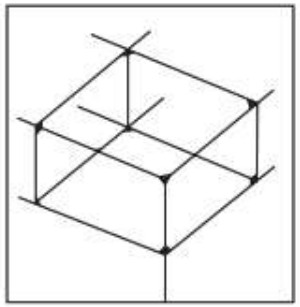


Plan—Support conditions

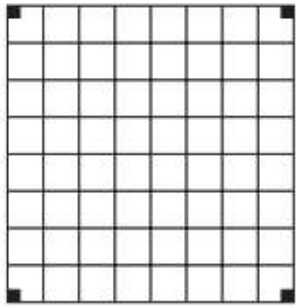
(a-1) Reference Case: Space frame with full triangulation and simply supported on corners.



(a-2) The maximum deflection in the structure is defined as 1.0 Δ. The maximum compressive force is defined as 1.0P.

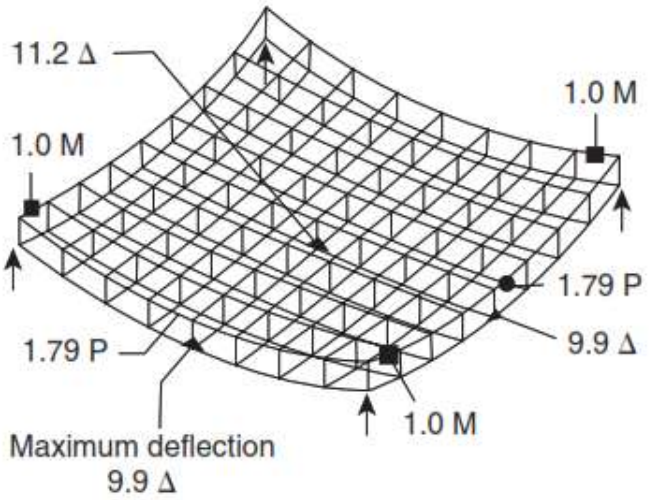


Basic triangulated module



Plan—Support conditions

(b-1) Vierendeel space frame with no triangulation and simply supported on corners. Bending moments are developed as well as axial forces. Stability is increased.

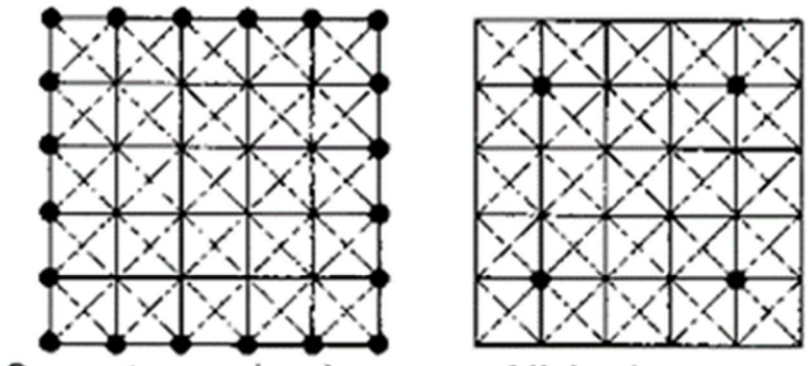


(b-2) Values are relative to (a). Maximum bending moments occur at comers and reduce toward the center. Members must be designed for combined axial and bending stresses.

Relative forces, moments, and deflections in fully triangulated versus framed structures. Member sizes and loadings are comparable. Values are calculated using a computer-based structural analysis program.

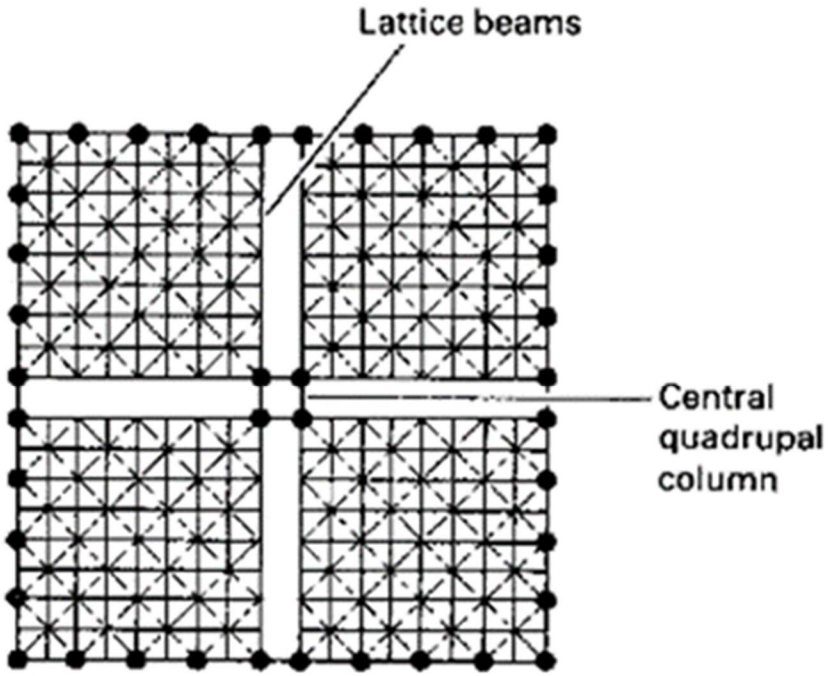
Space Frames - Supports

- Space frames may be supported in a variety of ways—along their edges, at corners, or with inset supports that allow the structure to cantilever outward.
- Forces vary throughout a structure in a way that is dependent on the support conditions present.



Support around perimeter

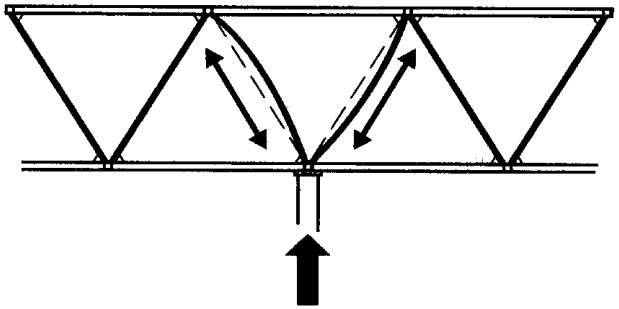
Minimal support



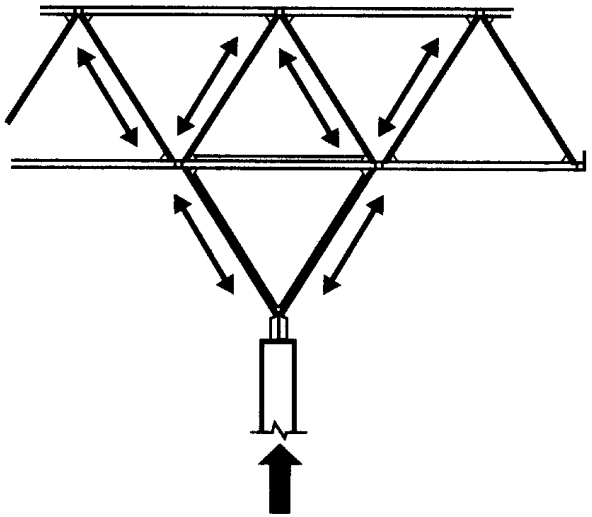
Square space frames supported around their perimeters by columns and deep lattice beams

Space Frames - Supports

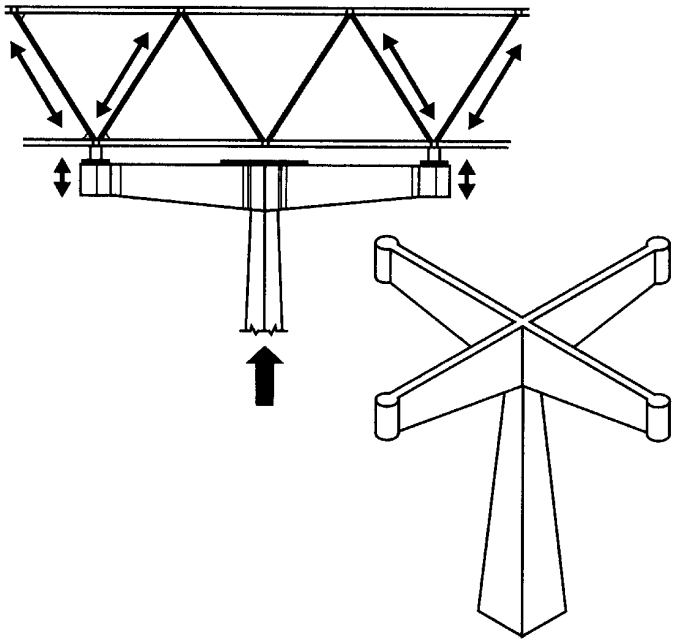
- When a point supports are used, member forces in the immediate vicinity of the point support are quite high.



(a) The large reaction force at a column must be transferred into the structure via members framing into the top of the column. Slender members may be prone to buckling.



(b) Axial forces in members may be reduced by increasing the number of members that distribute the reactive force into the structure. This is done by increasing the bearing area of the support, either by subframing or by using special rigid arms.

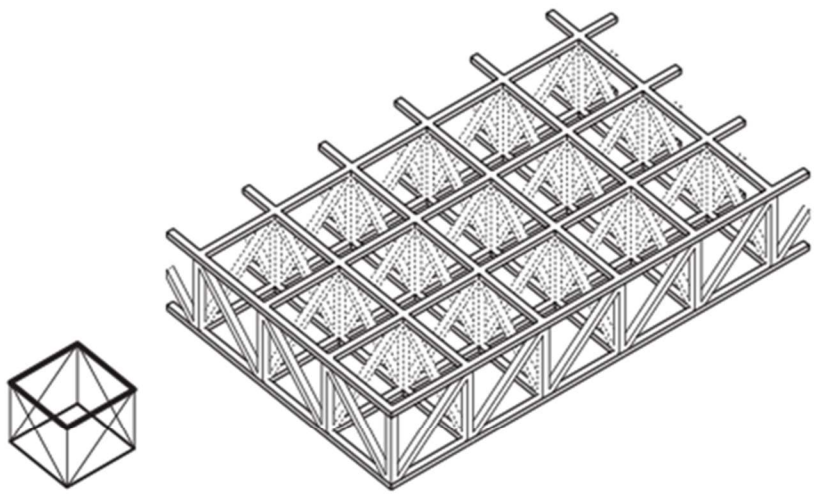


(c) Rigid arms may be used to distribute reactive forces.

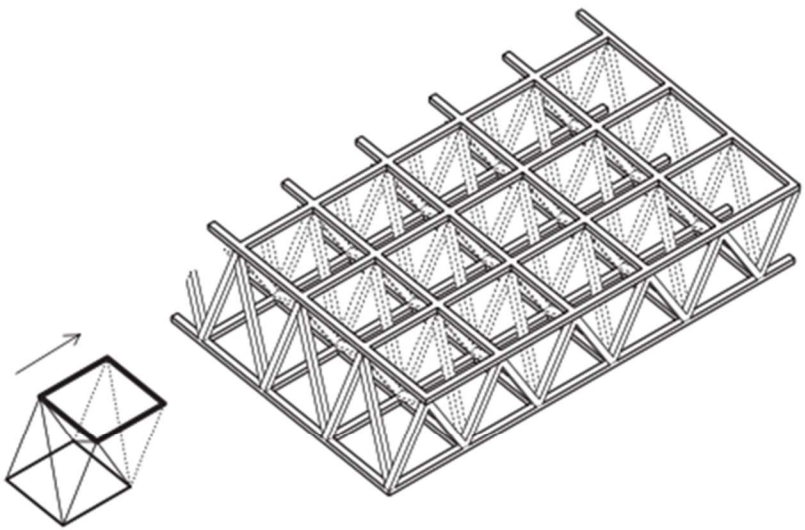
Space Frames - Supports

Space Frame
Supports

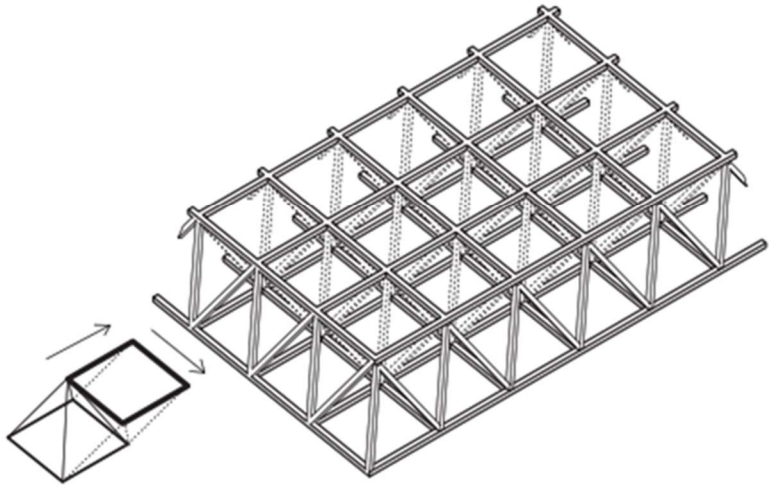
Typical Space-Frame Arrangements



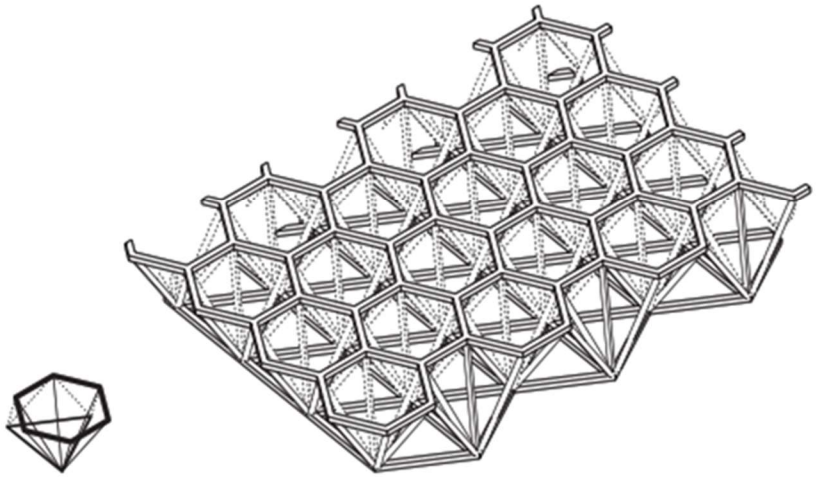
(a) The square grid of the horizontal outermost layers aligns vertically. Triangulating members connect between the outer layers.



(b) Square grids are shifted in the direction of one edge. A prismatic triangulation pattern for the diagonal infill results.



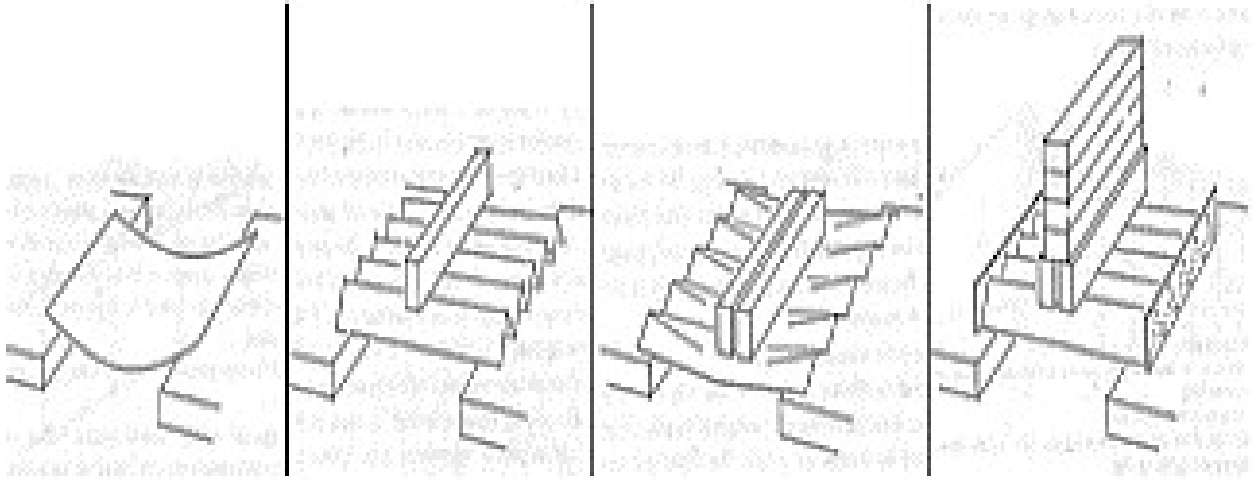
(c) The square grid of the horizontal outermost layers is diagonally offset such that a pyramid-shaped triangulation pattern results for the diagonal infill.



(d) The hexagonal upper grid connects via pyramid-shaped members with a triangulating lower grid.

Folded plate structures

- The stiffness of a plate structure can be dramatically increased by radically deforming the whole plate surface in such a way that structural depths are greatly increased.
- Folded plate is a plate with a unique cross-section that can be envisioned as a series of thin, deep elements joined together along their boundaries. A characteristic of folded-plate structures is that individual plate elements are long with respect to their width.



Folded plate structures

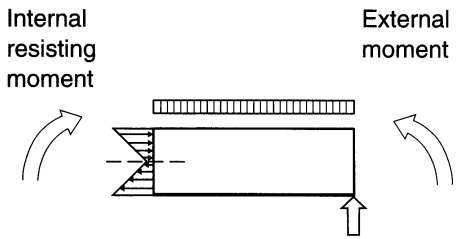
Folded plate structures

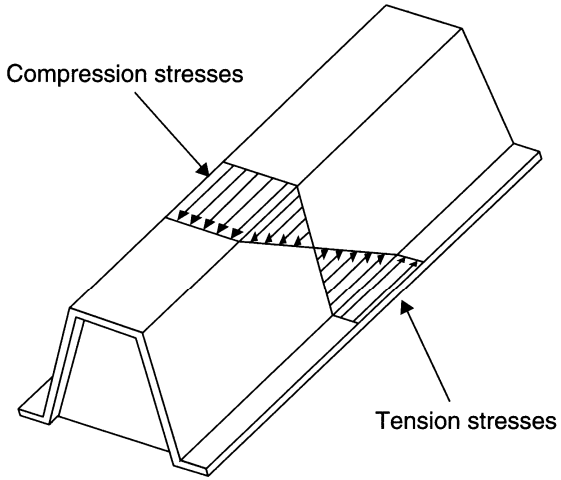
- **Benefits:** There are several benefits of folded plate construction

- They are simpler to manufacture than other shells with relatively simple formwork. However, they require more materials than curved shells since there is normally more bending involved.
- Folded plate structures have an intrinsic rigidity and high load-carrying capacity which makes them economical over long spans.

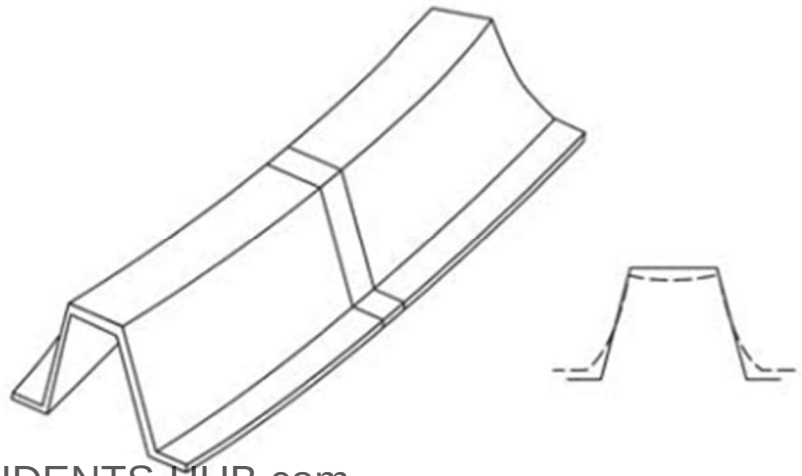
Behavior of a folded plate under loading

The way typical surface loads are carried to supports in folded-plate structures is best envisioned by considering two types of beam action: transverse and longitudinal.





Transverse action of folded-plate

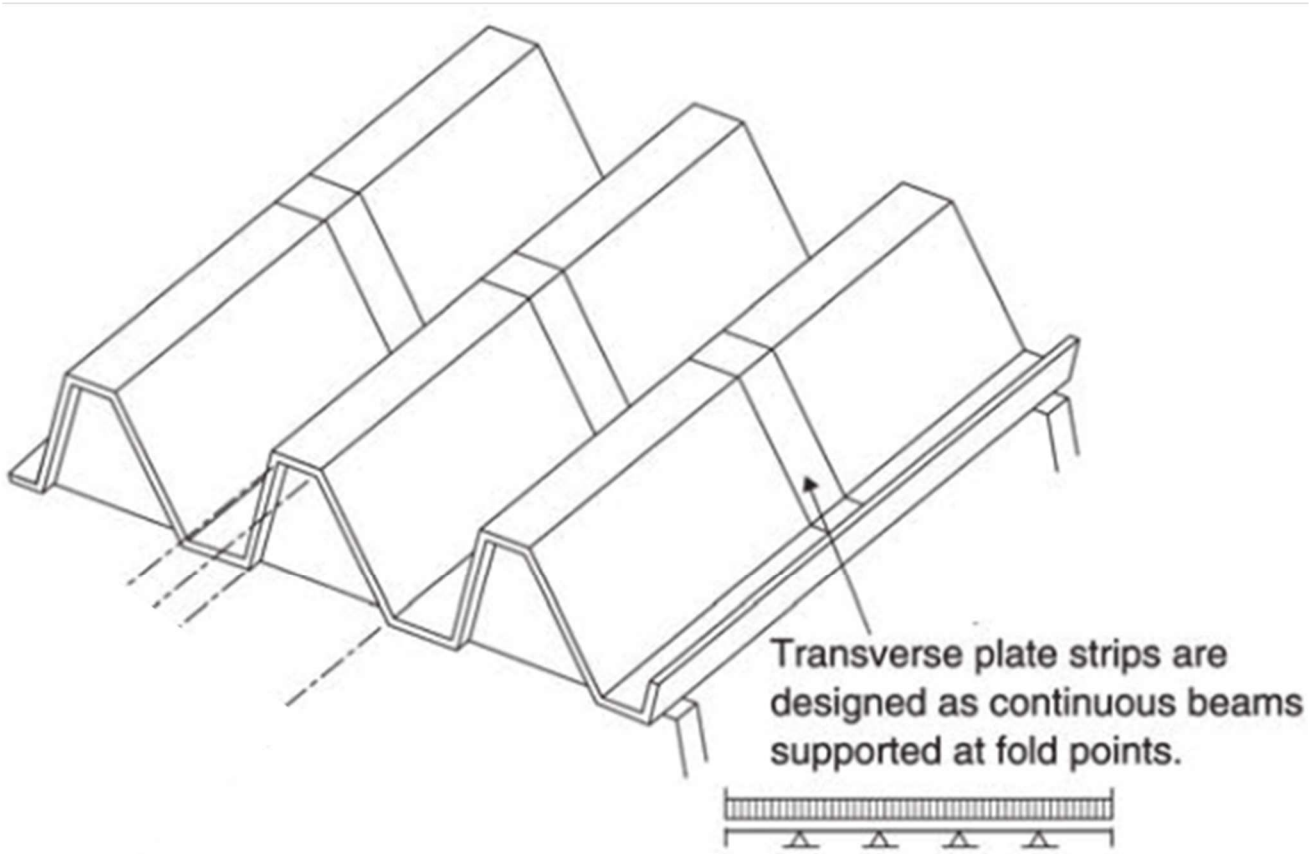


Longitudinal action of folded-plate

A typical unrestrained transverse section of a folded plate naturally tends to splay inward. The unbraced edges sag downward. Using stiffening diaphragms controls this deformation.

Behavior of a folded plate under loading

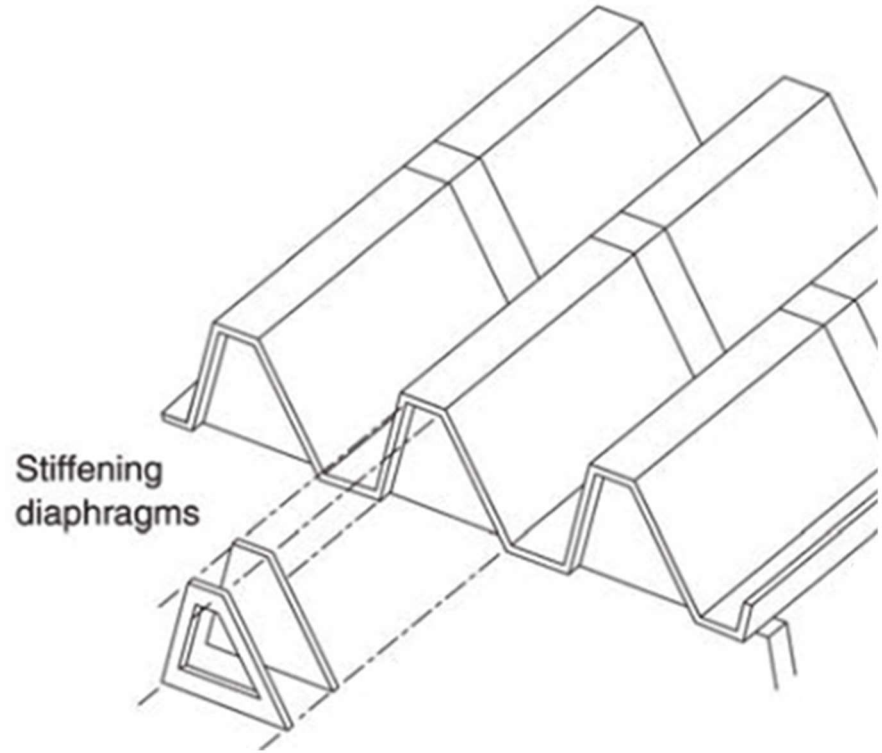
- For preliminary design purposes, the structure can thus be treated as a series of beams of unique cross section in the long direction and as one-way slabs in the transverse direction.



Design Requirements

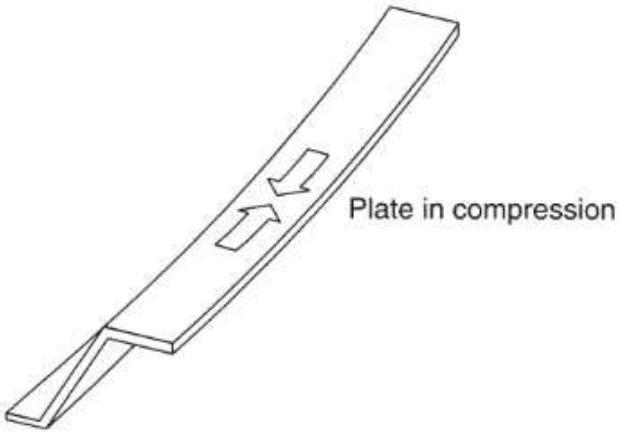
- It is crucial that the angle formed between plates be maintained constant. A transverse splaying can occur that will reduce the load-carrying capacity of the structure substantially. The phenomenon also can occur in the end plates of a continuous series of plates.

- To prevent this transverse splaying, stiffener plates are often used at the ends of folded-plate structures and at interim locations in long-span structures. These stiffeners not only prevent splaying but also provide additional lateral braces for individual plates.



Design Requirements

- End plates often deflect more than interior plates. Thus, they are frequently stiffened by the addition of boundary beams or other special end plates.
- To increase the efficiency of a folded plate structure, as much material as possible should be placed away from the neutral axis similarly to what was done in beam design.



Free edges can be stiffened by turning edges down and/or by bracing them with rigid struts to adjacent plates.

Section A

Section B

Section A is less efficient than Section B

Folded structures

- Forms of folded structures