Structural System in Architecture
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Lecture – 19
Structural Grid and Framing

Welcome to the NPTEL online certification course in the Structural Systems in Architecture. Today, we are in the module 4, the fourth lecture of the module 4 and in continuation this is the lecture number 19. The topic of today's lecture is Structural Grid and Framing.

Concepts Covered

- Structural Grid
- Load Path
- Structural Configuration
- Tributary Area
- Load Distribution

Learning Objective

- Configuring the structural grid.
- Outlining the load path in building structure.
- Evaluating the beam and column loading through tributary area concept.

Structural Grid

The concept of structural grid is extremely important from the point of view of both structural engineering and architecture. Figure 1 shows the components of a typical structural grid.

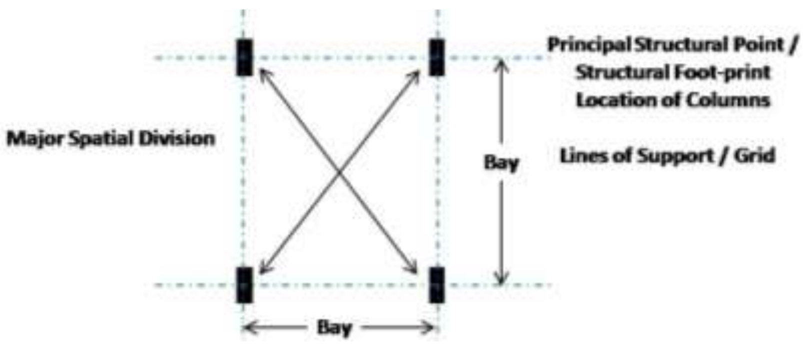


Figure 1 Structural grid

A grid is defined as the principal points or the lines of support for any structural system. At the points of intersection of these lines there might be either a vertical member such as a column, a shear wall or a plate member or a linear member.

While designing a building the architect is needed to have an idea about the structural grid as it is the footprint of the basic structural system. The series of lines in the grid represent the position of beams or maybe trusses. The structural grid also represents the position of columns in the plan. Though the beams will not cause any hindrance in the circulation as those would be present either above or below but the columns might come in the way of circulation. Hence it is very essential to position them wisely.

The series of lines of supports create the bay. In between the bays in both directions creates the major spatial division. In general the length of the bays maybe around 16’-24’. Hence it is highly essential that in case of parking like spaces there is enough space for the cars to circulate freely throughout the parking. Also, if there’s a staircase or a lift well kind of a space, you’ve to see whether the bay dimensions are sufficient. If not, you may have to shift the position of the columns. And when you do that, sometimes you may not get the requisite permissions as it will increase the span which will further lead to an increased bending stress. So the structural engineer may not allow that. Hence you need to have an idea about the tentative grid size and how will it impact the activities of your building.

As a matter of fact, the arrangement of the bays provides four basic classification of structural grid which are as follows:

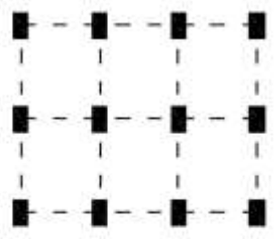


Figure 2 Rectangular Grid

Rectangular Grid

Bay distances are almost equal in both the x and y directions.

Figure 3 Curvilinear Grid

Curvilinear Grid

The major bay lines are curvilinear while the other side of the bay lines forms a radial line.

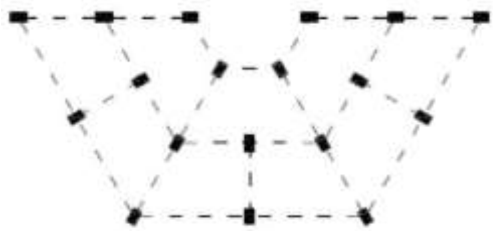


Figure 4 Oblique Grid

Oblique Grid

The inter bay distances are irregular, but forms a certain symmetric arrangement amongst the point of support.

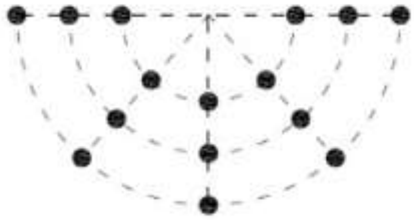


Figure 5 Circular Grid

Circular Grid

This is a typical type of curvilinear grid, where the major bay lines are circular. The radial lines are also connected with lines of structural supports.

All these are the regular grid patterns. However, sometimes it may so happen that none of these regular patterns are being completely suitable for your building. For instance, somewhere near the entrance you may notice that the oblique grid is being suitable. But then you notice that it is no longer appropriate for the other parts of the building and you go for a rectangular grid there. Then you might notice that the rectangular grid is obstucting your circulation in the hallway. So you might opt for a curvilinear grid there.

All in all, it is important to note that there is no fixed pattern in this last type of grid. It is developed as per the design requirements where you've to mainly see how the columns are binding with the other structural elements of the building; and hence it is termed as the Hybrid Grid. Figure 6 shows the image of a hybrid grid.

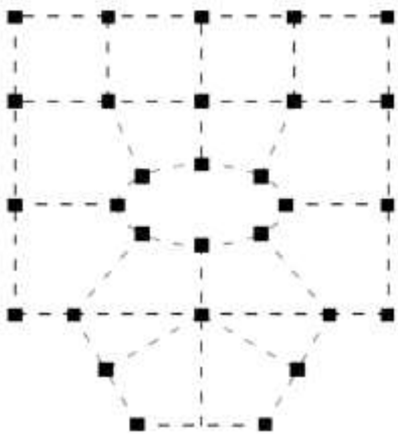


Figure 6 Hybrid Grid

Structural Grid Defines

➢ **Basic Function Area for Any Specific Activity**

Suppose we have a given space whose structural grid is shown in the Figure 7. Suppose this is an art gallery or a museum. Then I've a defined area in which I've to provide spaces for different activities such as exhibition space, cafeteria, souvenir shop, entry, circulation space etc. So based on the activities I can assign spaces in this grid.

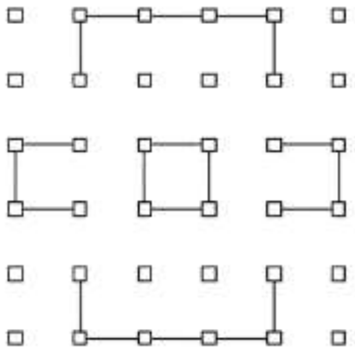


Figure 7 Grid-1

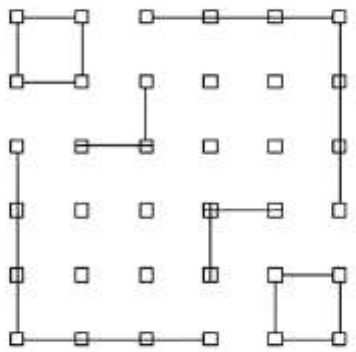


Figure 8 Grid-2

➢ **Modular Relation of Any Space**

In the places like hostels, apartments and hotels, you can create one module such as one hostel room, one apartment and one hotel room respectively and then replicate them to complete the design.

➢ **Structural Loading Intensity**

Sometimes you may want to change the grid size as per the structural loading intensity. For instance, if you have a library in the upper floor where the dead load is huge, then here the grid size will be different as compared to a conference room or any other space which requires comparatively less furniture and also there is minimum dead load.

➢ **Pattern of Spaces**

Suppose you have the same grid layout given to you where the ground floor was assigned for some different purpose. Then you cannot obviously change the grid in the upper floors but construct the internal walls in such a way that you reach a middle ground with the already existing column layout and as well as your purpose. In other words, you can construct the internal walls such that it not only aligns with your grid but also serves your purpose.

Load Path

Multiple Structural elements are used to transmit and resist external loads. These elements define the mechanism of load transfer in a building known as the load path. The load path extends from the super structure roof through each structural element to the substructure foundation.

Depending on the type of load to be transferred, there are two basic load paths viz., the gravity load path and the lateral load path.

Gravity Load Path

Gravity load is the vertical load acting downward on a building. It includes dead load and live load due to occupancy or snow. Gravity load on the floor and roof slabs is transferred to the columns or walls, down to the foundations, and then to the supporting soil beneath.

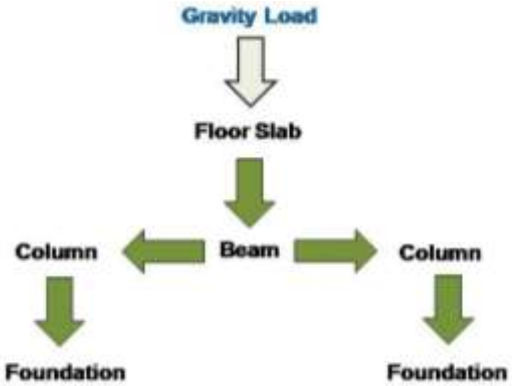


Figure 9 Gravity load path flow chart

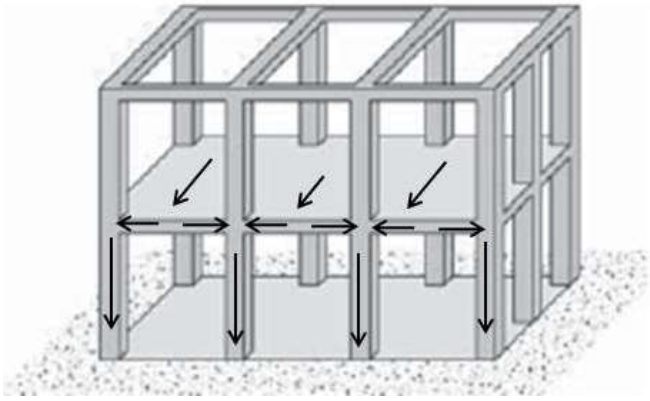


Figure 10 Gravity load path in a multi-storeyed structure

The gravity load path travels from the floor slab to the beams and from here they're transferred to the columns and from the columns finally to the foundations. Figures 9 and 10 show the path taken by the gravity loads in a building.

Lateral Load Path

Lateral loads are imposed in the building structure due to wind and earthquake. The lateral load path is the way lateral loads are transferred through a building.

The primary elements of a lateral load path are shown in the Figures 11 and 12.

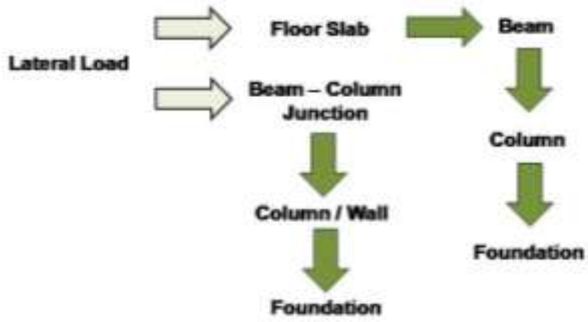


Figure 11 Flow chart of lateral load path

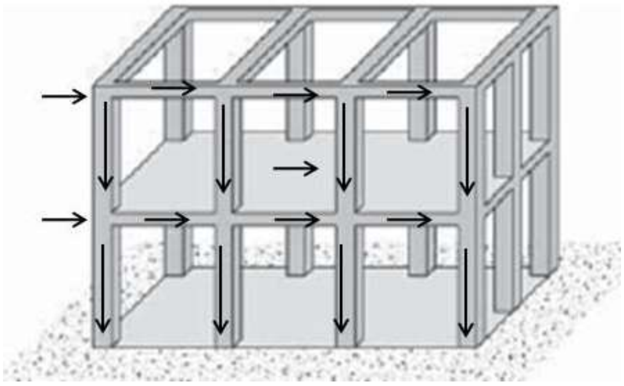


Figure 12 Lateral load path in a multi-storeyed structure

As evident from the Figure 11, the lateral load first comes in either the floor slab or the beam-column junction. In case of the latter, the load is then transferred from the beam-column junction to the columns or the walls and then to the foundations. But in case of the former, i.e. if the lateral load first comes to the floor slabs a diaphragmic action will take place wherein the load from the floor slab moves to the peripheral beams and from there to the columns and from the columns to the foundations.

Structural Configuration

Moment Resisting Frames

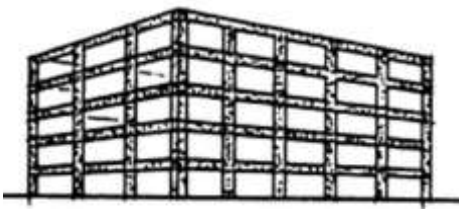


Figure 13 Moment resisting frames

The moment resisting frames or the portal frames are the most commonly used structural configuration nowadays.

As discussed in the previous lecture, a simple portal frames consist of a beam supported over two columns.

Then if you just keep repeating the bays both in the horizontal and the vertical directions the whole beam-column system is ready for a particular building. This is known as the moment resisting frame.

However, these are not completely suitable for the places where there is a high wind velocity or earthquake prone i.e., where lateral load could be more; or maybe the building has a varying load distribution due to varying heights and also in case of the tall buildings. In such cases some bracing is required to hold the structure tight. So you can go for the braced frame structures.

Braced Frame Structures

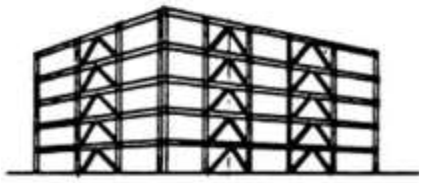


Figure 14 Braced frame structures

This structure is same as the moment resisting frames except there are some added bracing in some of the bays at strategic locations to provide an inherent strength to the building. Thus this structure is capable of providing more stiffness or rigidity against the increased lateral loading.

Shear Wall

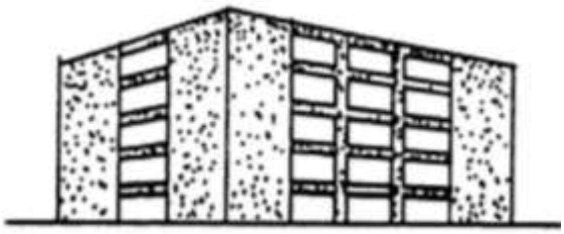


Figure 15 Shear walls

It is a wall which can carry a huge amount of shear force. It is mostly required in case of tall buildings.

The shear wall is constructed in some strategic locations just to encounter the huge shear forces encountered by the building due to the lateral load.

Therefore, different types of structural configurations can be incorporated as per the loading requirement.

Tributary Area

As we've seen that the gravity load first comes to the floor slab from where it is transferred to the beams and then to the columns. So it is important to know how much is the load share of each of these beams. The tributary area helps in finding that. It is related to the load path, and is used to determine the loads that the beams, girders, columns, and walls carry. The tributary area of slab to neighboring beam depends upon the slab aspect ratio which is a key parameter in finding the tributary area.

The aspect ratio of the slab has been categorized under three different categories viz.,$\frac{L_1}{L_2} > 2,\ 1 < \frac{L_1}{L_2} < 2$ and lastly, $\frac{L_1}{L_2} = 1$ where, L1 and L2 can be seen in the Figure 16. So let us see how to find the tributary area in each of these cases.

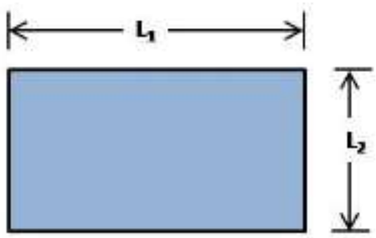


Figure 16 Nomenclature of the slab lengths

Case-1: Narrow Strip (When $\frac{L_1}{L_2} > 2$)

In this case the slab will be like a narrow strip as one side is more than double the other side. So in such a scenario the share of the load will only be on the longer beams and the amount of share will be half the length of the shorter beam.

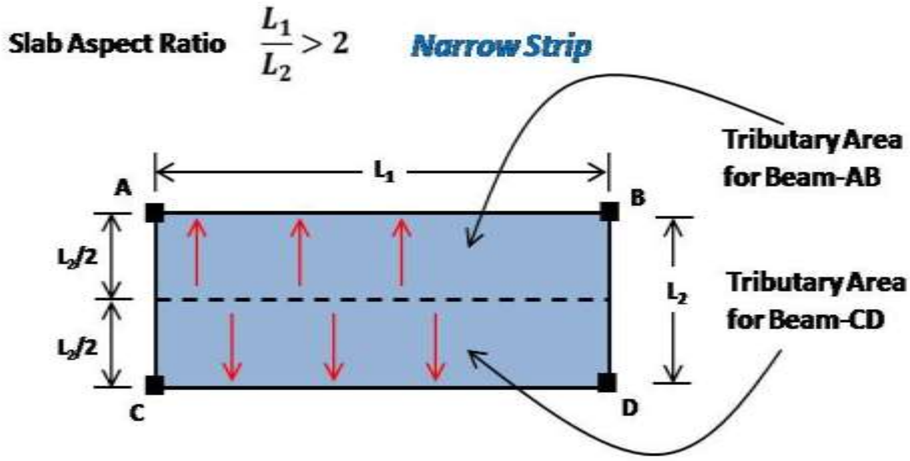
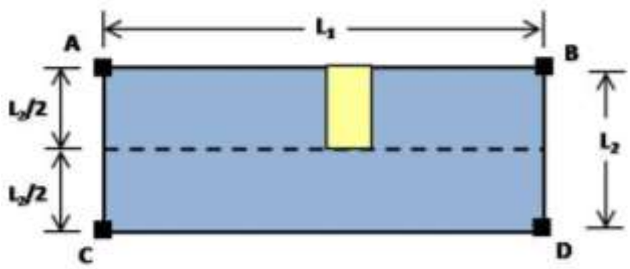


Figure 17 Slab with (L1/L2) >2

Now let us see how to find the tributary area and the magnitude of load shared by each of these beams when the aspect ratio of the slab is greater than 2 through the Example-1.

Example-1



Let The thickness of Slab is 150 mm (Density 25 KN/m^3)

The thickness of Floor Finish is 35 mm (Density 16 KN/m^3)

Let the Live Load intensity is 3 KN/m^2

L_1 = 6m, L_2 = 2.4m

To solve this let us take one-metre strip whose depth is equal to $L_2/2$ as shown in the above figure. Thus, the final dimension of the strip here would be 1m x 1.2m.

Then,

Load of Slab per meter = $(1.2 \times 1.0 \times 0.15) \times 25 = 4.5$ KN

Load of Floor Finish per meter = $(1.2 \times 1.0 \times 0.035) \times 16 = 0.672$ KN

Thus, Total Dead Load on Slab = $(4.5 + 0.672) = 5.172$ KN/m

And, Total Live Load on Slab = $1.2 \times 1.0 \times 3 = 3.6$ KN/m

Therefore, Total UDL on Beam = $(5.172 + 3.6)$ = 8.772 KN/m (Figure 18)

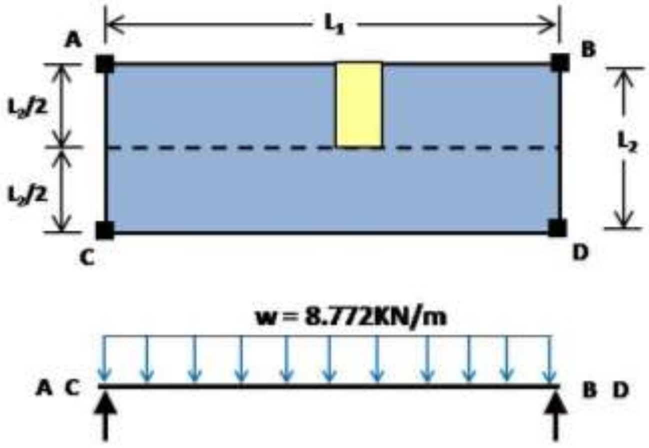


Figure 18 UDL on the slab

Hence, the beams AB and CD will carry a UDL of intensity 8.772 KN/m each.

Next, we need to find the tributary area of the column and the load carried by it.

So, Tributary Area of each Column = product of the half length of L_1 & L_2 = (3×1.2) = 3.6m^2

We have,

Load produced per Square meter of slab=(1×1×0.15×25) + (1×1×0.035×16) + 3 = 7.31KN/m^2

Thus, Load on each Column = 3.6×7.31 = 26.316 KN

Case-2: Rectangular Strip (When $1 < \frac{L_1}{L_2} < 2$)

In this case all the beams will have a contribution in carrying the load. The tributary area for each of the beams is shown in the Figure 19. Clearly, the shorter beams can be seen to have a triangular shaped tributary area while the longer beams can be seen to have a trapezoidal shaped tributary area.

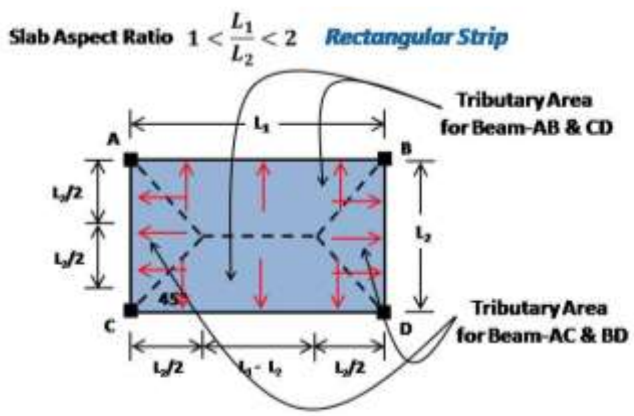
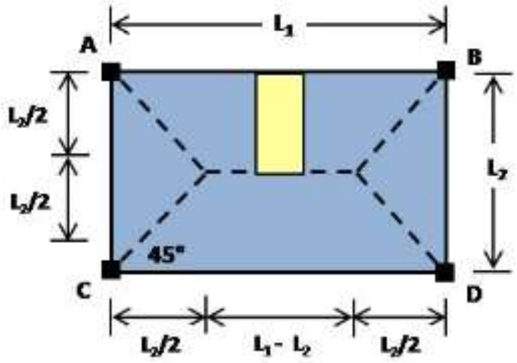


Figure 19 Tributary area when 1<(L1/L2)<2

Example-2



Let The thickness of Slab is 150 mm

(Density 25 KN/m^3)

The thickness of Floor Finish is 35 mm

(Density 16 KN/m^3)

Let the Live Load intensity is 3 KN/m^2

L_1 = 6m, L_2 = 4m

To solve this let us again take a one-metre strip whose depth is again equal to half of L_2 as shown in the above figure. Then the final dimension of the strip becomes 1m x 2m.

So,

Load of Slab per meter = (2.0×1.0×0.15) × 25 = 7.5 KN

Load of Floor Finish per meter = (2.0×1.0×0.035) ×16 = 1.12 KN

Total Dead Load on Slab = (7.5+1.12) = 8.62 KN/m

Total Live Load on Slab = 2.0×1.0×3 = 6 KN/m

Thus,

Total UDL on Beam = (8.62+6) = <u>14.62KN/m</u> (Figure 20)

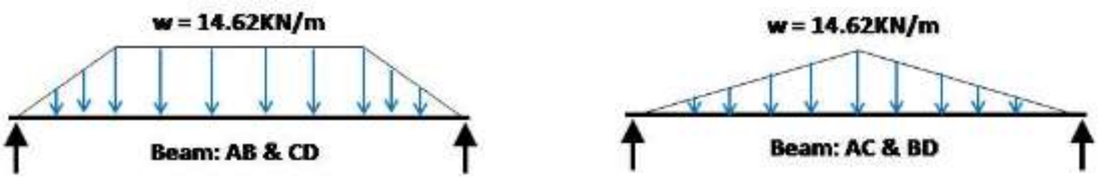


Figure 20 Load share in each of the beams

Next,
Load produced per square meter of slab = (1×1×0.15×25)+(1×1×0.035×16)+3 = 7.31KN/m^2

But,

Tributary Area of each Column = (3×2) = 6m^2

Hence,

Load on each Column = 6×7.31 = <u>43.86 KN</u>

Case-3: Square Strip (When $\frac{L_1}{L_2} = 1$)

In this case also all of the peripheral beams will have to carry a share of the gravity load coming on the floor slab but here it will be an equal share between the beams. The tributary areas of the peripheral beams are shown in the Figure 21, which are clearly triangular in shape.

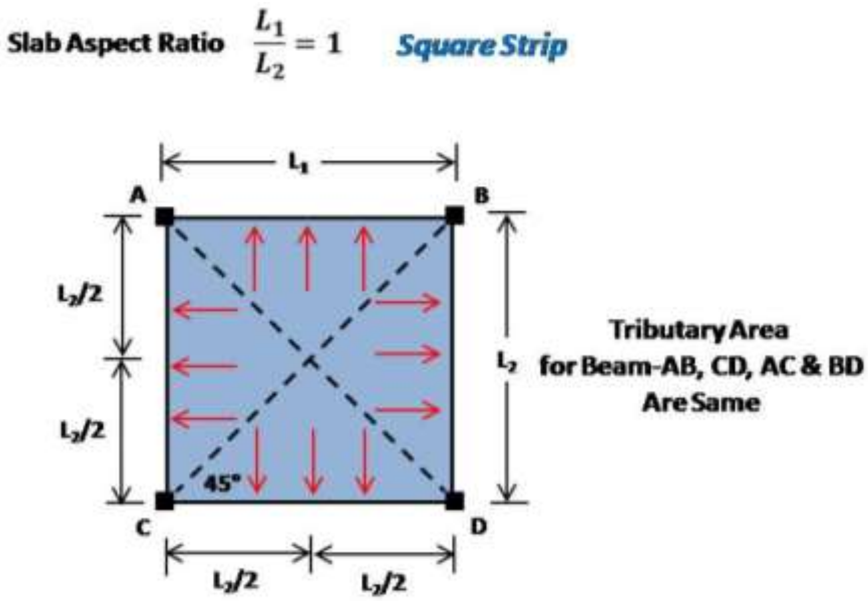
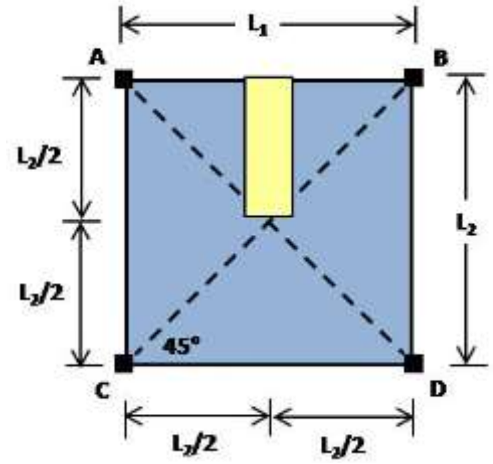


Figure 21 Tributary area of a square slab

Example-3



Let The thickness of Slab is 150 mm

(Density 25 KN/m^3)

The thickness of Floor Finish is 35 mm

(Density 16 KN/m^3)

Let the Live Load intensity is 3 KN/m^2

L_1 = 6m, L_2 = 6m

To solve this let us again take a one-metre strip whose depth is 3m (half of L_2). So the dimension of this strip becomes 1m x 3m.

Then,

Load of Slab per meter = (3.0×1.0×0.15) ×25 = 11.25 KN

Load of Floor Finish per meter = (3.0×1.0×0.035) ×16 =1.68 KN

Total Dead Load on Slab = (11.25+1.68) = 12.93 KN/m

Total Live Load on Slab = 3.0X1.0X3 = 9 KN/m

Thus,

Total UDL on Beam: (12.93+9) = 21.93KN/m (Figure 22)

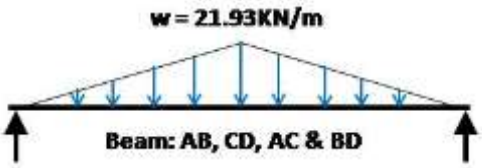


Figure 22 Load distribution of the beams

Next,

Load produces per Square meter of slab= (1×1×0.15×25)+(1×1×0.035×16)+3 = 7.31 KN/m^2

But,

Tributary Area of each Column = (3×3) = 9 m^2

Therefore,

Load on each Column = 9×7.31 = <u>65.79 KN</u>

Load Distribution

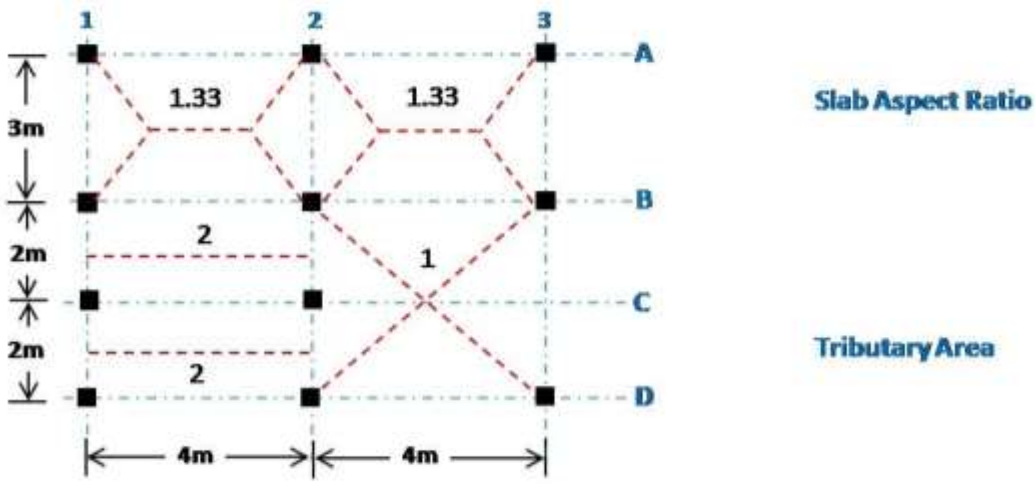


Figure 23 Grid showing the slab aspect ratios and the tributary areas

Here we have a grid whose aspect ratios for each of the slabs are calculated and their tributary areas are also marked. Also, the given data for further calculation are given below:

Let The thickness of Slab is 150 mm (Density 25 KN/m^3)

The thickness of Floor Finish is 35 mm (Density 16 KN/m^3)

Let the Live Load intensity is 3 KN/m^2

Then,

Load produced per Square meter of slab = (1×1×0.15×25)+(1×1×0.035×16)+3 = 7.31 KN/m^2

So the load shares for each of the tributary areas are:

(7.31×1.5) = 10.965 = 11 KN/m

(7.31×1.0) = 7.3 KN/m

(7.31×2.0) =14.6 KN/m

These load shares for their corresponding tributary areas are shown in the Figure 24.

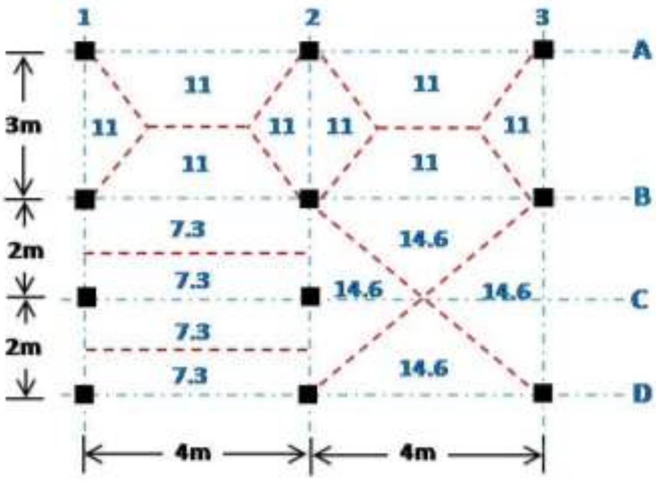


Figure 24 Load shares of the corresponding tributary areas

Then the load share for each of these beams can be drawn as follows:

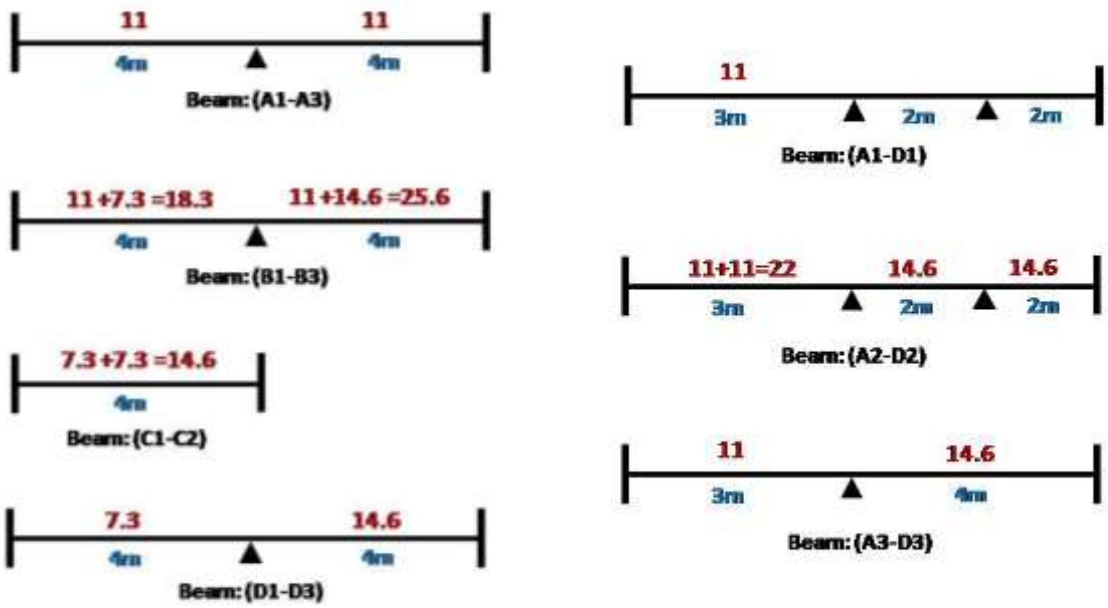


Figure 25 Beam wise load share

Finally, the column tributary areas the corresponding load shares (Column Tributary Area × 7.31 KN/m2) are given in the Figures 26 and 27 respectively.

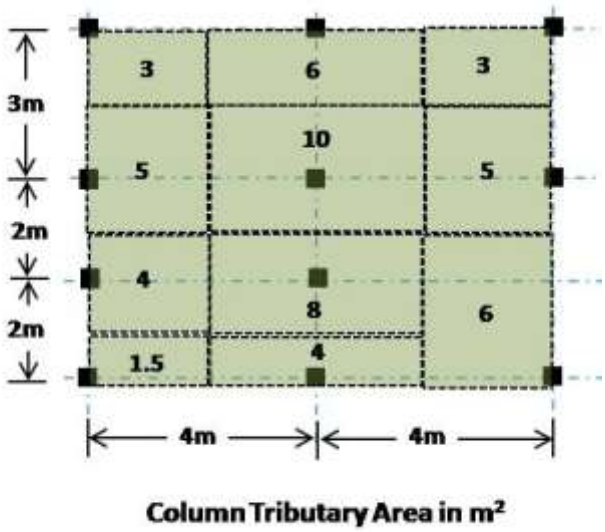


Figure 26 Column tributary area

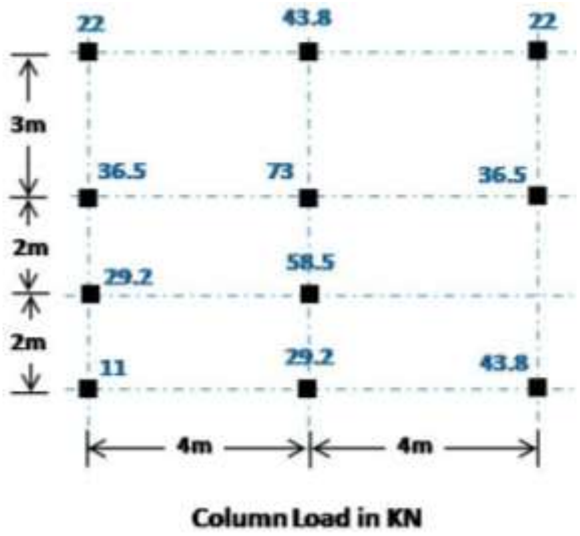


Figure 27 Column load

References

- **Engineering Mechanics** by Timishenko and Young McGraw-Hill Publication
- **Strength of Materials** By B.C. Punmia, Ashok K. Jain & Arun K. Jain Laxmi Publication
- **Basic Structures for Engineers and Architects** By Philip Garrison, Blackwell Publisher
- **Understanding Structures: *An Introduction to Structural Analysis*** By Meta A. Sozen & T. Ichinose, CRC Press

Conclusions

In short, I'd like to conclude by stating that

- The structural grid is one of the primary and important stages of erecting the building structure.
- The proportion of the load to beam and column depends upon the slab tributary area.
- The tributary area is based on the slab aspect ratio.

Homework

Q1. Estimate the load in the perimeter beams of two slabs shown in the figure. Assume:

Slab thickness 125mm (Density: 25KN/m^3)

Floor finish thickness 25mm (Density: 15KN/m^3)

Live Load: $3KN/m^2$