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Effect of Spacing of Grid Beam and its Depth on Peripheral beams in Grid Floor Frame

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Abstract: **The floor resting on the beams which are running in two directions is known as Grid Floor. These types of floors are used to cover a large obstruction free area and therefore, are a good choice for public assembly halls. The Grid structure is monolithic in nature and is stiffer. It provides pleasing appearance and also has less maintenance cost. However, construction of the grid floor is cost prohibitive. By investigating various parameters involved, a cost effective solution can be found for the grid floor. The present work includes the parametric investigation in terms of flexural actions such as bending moments, torsion and shear force. Spacing of Grid beam is one of the parameters considered for investigation. The other parameter considered for investigation is the depth of Grid beams along with the design feasibility.**

Keywords—Grid floor, Peripheral Beam, Grid Beam, Spacing of Grid beams, Size of beams

I. INTRODUCTION

An assembly of intersecting beams placed at regular interval and interconnected to a slab of nominal thickness is known as Grid floor or Waffle floor. In this type of floor, a mesh or grid of beams running in both the directions is the main structure, and the slab is of nominal thickness. These floors are used to cover a large column free area and they are generally employed for architectural reasons for large rooms such as auditoriums, vestibules, theatre halls, show rooms of shops where column free space is often the main requirement.

The advantage of grid over other types of floors is that the flat roof or floor is obtained. By using ordinary reinforced concrete construction and by increasing number of beams, the depth of beam can be shortened. Thus, greater clearance can be obtained. The structure is monolithic in nature and these types of floors have more stiffness. The maintenance cost of these floors is also negligible than that of steel-girders and pre-stressed concrete.

One of the limitations of Grid floors is the construction cost which is prohibitive. Amit A. Sathawane, and R. S. Deotale[2] have carried out the cost comparison between flat slab and grid slabs. On the basis of analysis and design carried out, they conclude that Concrete required in Grid slab is more as compared to Flat slab with Drop and Flat slab without Drop.

Ibrahim S. Vepari and Dr. H. S. Patel [3] have studied Economical aspects of long span slabs between flat slab and grid slab. In grid slab as the span range increases, the increase in the unit cost is not significant. Flat slab with smaller spans are proved to be economical but as the span range increases the grid slab becomes economical. Thus, Grid slab is proved to be more economical for long span slab in comparison to Flat slab.

J. Prasad, S. Chander and A.K. Ahuja[4] carried out analytical study on square waffle slab medium size floor system with a view to achieve the optimum dimensions of rib spacing, its depth and width.

Literature review shows that, the cost of construction of grid floors depends on various parameters like span, spacing of Grid beams, and size of the peripheral & grid beams, span to depth ratio etc. Various parameters need to be investigated, to obtain cost effective solution for Grid floors. In the present work some of these parameters are investigated such as ratio of hall dimensions (L/B), ratio of spacing of Grid beams, and the depth of Grid beams.

Figure 1 shows a plan of typical grid system configuration for the present study.

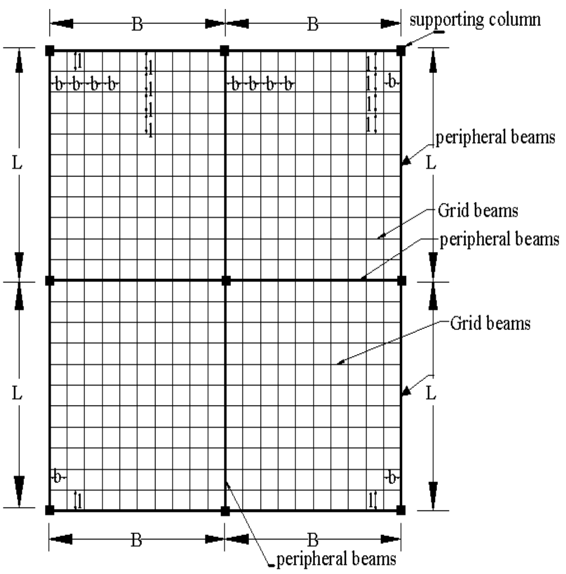


Figure 1 Plan of Grid System

A. Methods of Analysis

Grid is highly redundant structural system and therefore, it is statically indeterminate. It is found that, the Stiffness method is most effective & accurate for analysis of Grid structures [1]. Therefore, the stiffness method is used for investigation. This method is based on matrix formulation of the stiffness of the structure and gives closed form solution. By using this method the analysis can be done by considering rigid supports as well. The stiffness method treats the structure in its actual form. One of the advantages of this method is that it is conductive to computer programming. Once the analytical model of a structure is defined, no further engineering decisions are required in the stiffness method in order to carry out the analysis.

There are various applications software's available, which can be used to carry out analysis by this method. The analysis of the grids for different parameters has been carried out by using STAAD-PRO software and the effect on the various flexural actions due to variations in the parameters are collected in excel.

II. SPACING OF GRID BEAMS

After analyzing sample Grids, it is observed that, the spacing of Grid beams considerably affects the bending moments in Peripheral Beams. Therefore, study on variation of spacing of Grid beams is carried out for halls with different L/B ratios.

For this purpose, for given length to breadth ratio (L/B) of hall size; the ratio of spacing of Grid beams (l/b) is varied and the analysis is carried out.

In the present study, the width (B) of the hall is kept constant as 10m, and length is increased accordingly so as to increase (L/B) ratio at an interval of 0.05m. To arrive at appropriate ratios of spacing of Grid beams (l/b); the spacing of Grid beams along the width of hall is kept constant as 1.00m and spacing along the length of hall is varied by dividing the length of the hall in equal parts. Thus, various ratios of spacing of Grid beams are obtained.

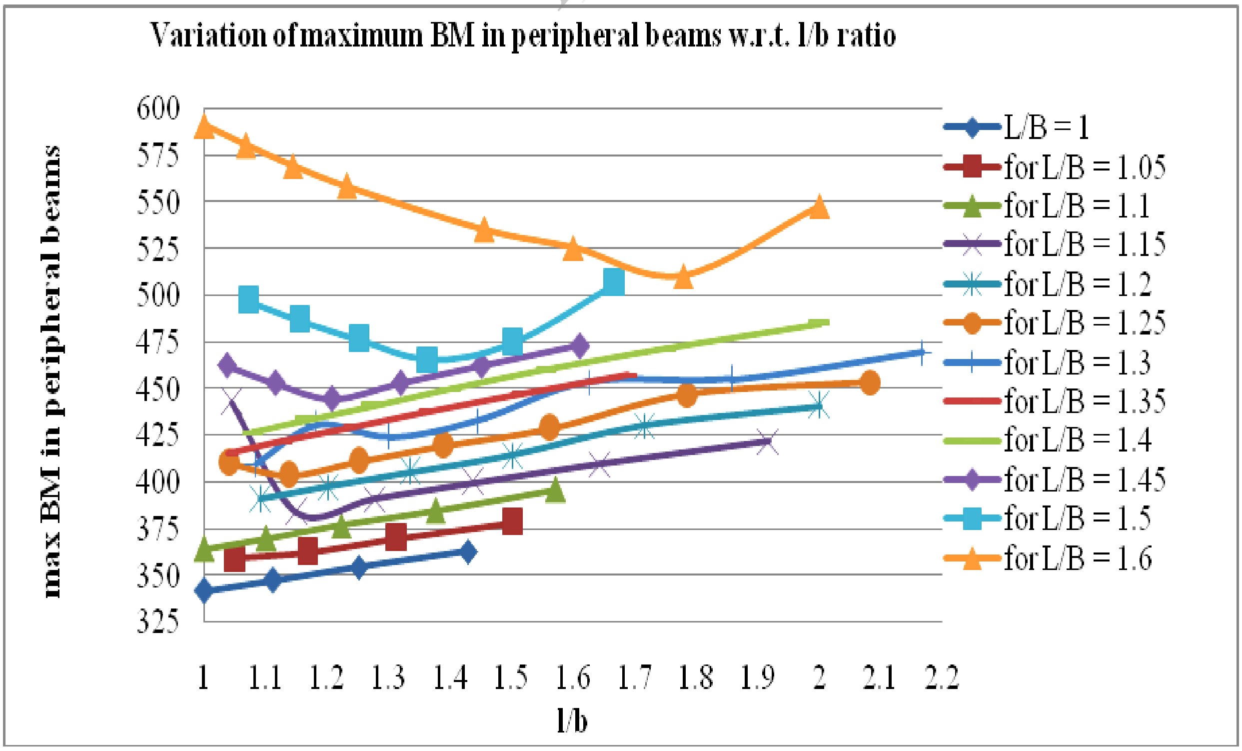
The analysis is carried out for such different Grids having various l/b ratios, with the same size of peripheral beam & grid beam i.e. 0.23 m x 0.55 m. The variation of maximum bending moments in peripheral beams is studied for various cases. The results are presented in Graph No. 1.

Graph No. 1 shows variation of maximum bending moment in peripheral beams with respect to increasing l/b ratio of spacing of grid beams, for given ratio of the hall dimensions L/B.

From the graph it is observed that, for a given L/B ratio the maximum bending moment in the peripheral beam increases with increasing l/b ratio of the spacing of grid beams.

Initially for lower values of L/B ratio up to1.1, rate of increase in maximum bending moment in peripheral beams is nearly alike. The linearity of the variation of maximum Bending moment in peripheral beams changes with further increase in L/B ratio beyond 1.1.

For L/B>1.2, variation in maximum bending moment in peripheral beams is observed to be non linear with further increase in L/B ratio. For L/B>1.45, it is observed that initially the maximum bending moment in beams decreases up to a certain point; then afterwards it increases with increase in l/b ratio of the spacing of grid beams. It means for L/B>1.45, the bending moments can be optimized. However, these optimum bending moments are higher than those for smaller L/B ratio.



Graph No. 1 Maximum Bending Moments in Peripheral beams v/s l/b

It is also observed that with increasing L/B ratio, the maximum bending moment is increasing for a given ratio of spacing of grid beams (l/b). The percentage increase in the maximum bending moment for given l/b ratio, is @ 2.5% up to L/B <1.45. It is also found that for L/B>1.45, the percentage of increase in maximum bending moment increases from 2.5% to 5.62%.

III. DEPTH OF BEAMS

The other parameter considered is the depth of beams. It has been observed that there is considerable difference in bending moments of peripheral beams and grid beams. The maximum bending moment in Grid Beams is quite less as compared to maximum bending moment in Peripheral Beams. Therefore, the depth of grid beams need not to be same as that of peripheral beams.

To study the possibility of reducing the depth of Grid Beams as compared to peripheral beams, different depths of Grid Beams have been tried for the given constant size of Peripheral Beam. This is done for Halls having various L/B ratios. (See Table No. 1)

For this purpose the size of the Peripheral beams is kept constant as 0.30 m x 0.75 m, and the width of the Grid Beams is 0.23 m for all cases.

TABLE I

Case No.	Hall sizes (in m)	L/B ratio	Various Depths of Grid beam considered (in m)
I	10.00x10.00	1.00	0.55, 0.60, 0.65, 0.70, 0.75
II	10.00x10.50	1.05	0.55, 0.60, 0.65, 0.70, 0.75
III	10.00x11.00	1.10	0.55, 0.60, 0.65, 0.70, 0.75
IV	10.00x11.50	1.15	0.55, 0.60, 0.65, 0.70, 0.75
V	10.00x12.00	1.20	0.55, 0.60, 0.65, 0.70, 0.75
VI	10.00x12.50	1.25	0.55, 0.60, 0.65, 0.70, 0.75
VII	10.00x13.00	1.30	0.55, 0.60, 0.65, 0.70, 0.75

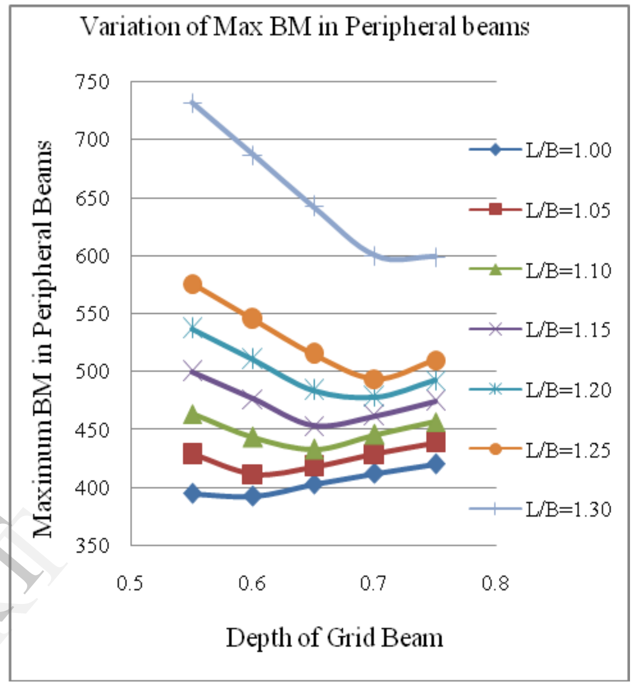
The analysis is carried out for the above mentioned different cases and variations in flexural actions are studied. The results are presented as below:

A. *Variation of Maximum Bending Moment in Peripheral Beams*

Graph No. 2 shows the variation of Maximum Bending Moment in Peripheral beams with respect to increasing depth of Grid beams for various Ratios of Hall dimensions (L/B).

From the graph, it is observed that, for given depth of Peripheral beam the maximum bending moment in Peripheral beam goes on decreasing with increasing depth of Grid beams. After attaining a minimum value, it further increases with increasing depth of Grid beam. Similar variation is observed for halls having various L/B ratios.

From the graph, it is also observed that the optimum bending moment increases with increasing ratio of hall dimension (L/B).



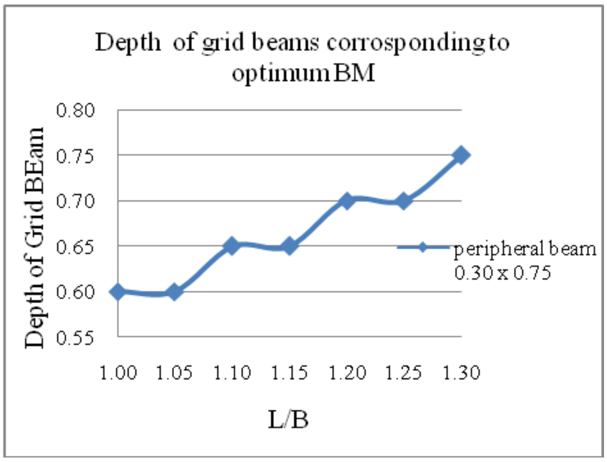
Graph No. 2 Variation in Maximum Bending Moment in Peripheral beam v/s Depth of Grid Beam

B. *Variation of Depth of Grid Beam Corresponding To Optimum Bending Moment*

Graph No. 3 shows the variations in the depth of Grid beams for optimum values of maximum bending moment in Peripheral beams, with increasing L/B ratios of hall dimensions for Peripheral beam of size 0.30 m x 0.75m.

From the graph, it is observed that, the depth of Grid beams at optimum values of maximum bending moment increases only when L/B ratio increases with an interval of 0.1. The optimum values of maximum bending moment remain nearly the same for increasing interval of L/B =0.05. Therefore, it is recommended that the interval of increasing L/B ratio should be kept 0.1 instead of 0.05.

It is also observed that as L/B increases, the difference between the depth of Peripheral beam and depth of Grid beams at optimum value of maximum bending moment goes on reducing. Therefore, the maximum bending moment in Peripheral beams can be optimized by reducing the depths of Grid beams than that of Peripheral beams for smaller L/B ratios.

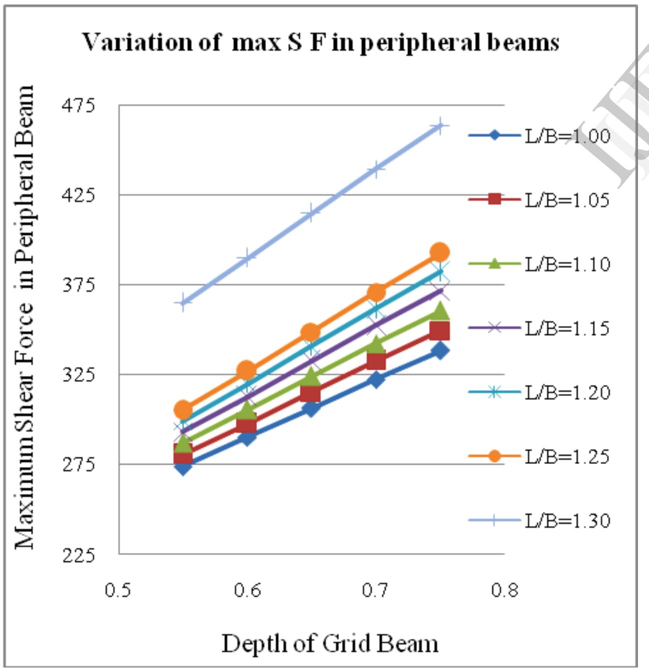


Graph No. 3 Depth of Grid beam corresponding to optimum BM v/s L/B

C. Variation of Maximum Shear Force in Peripheral Beams

Graph No. 4 shows the variation of Maximum Shear Force in Peripheral beams with respect to increasing depth of Grid beams for various Ratios of Hall dimensions (L/B).

From the graph, it is observed that for the given depth of Peripheral beam the maximum shear force in Peripheral beam goes on increasing with increasing depth of Grid beams almost linearly. Similar variation is observed for halls having various L/B ratios.

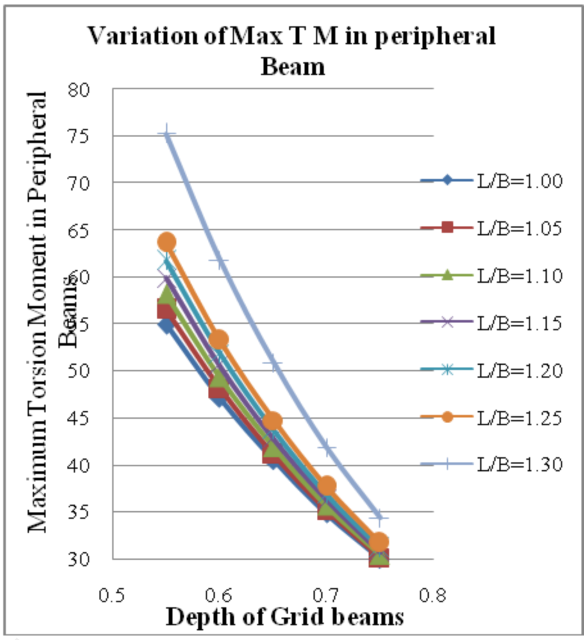


Graph No. 4 Maximum Shear Force in Peripheral beam v/s Depth of Grid Beam

D. Variation of Maximum Torsion Moment in Peripheral Beams

Graph No. 5 shows the variation of Maximum Torsion Moment in Peripheral beams with respect to increasing depth of Grid beams for various Ratios of Hall dimensions (L/B).

From the graph, it is observed that for the given depth of Peripheral beam the maximum torsion moment in Peripheral beam goes on decreasing with increasing depth of Grid beams. Similar variation is observed for halls having various L/B ratios.



Graph No. 5 Maximum Torsion Moment in Peripheral beam v/s Depth of Grid Beam

IV. DESIGN FEASIBILITY

It has been observed that the variation in flexural actions is different as compared to each other. The maximum bending moment in Peripheral beams can be optimized by reducing the depth of Grid beams than that of Peripheral beams. The torsion moment in Peripheral beams is the minimum when the depth of Grid beam is kept equal to depth of Peripheral beams. The maximum shear force in Peripheral beams increases with increasing depth of Grid beams for the given depth of Peripheral beam.

Considering the above factors, the design feasibility is checked for the combinations where the optimum value of maximum bending moment is observed.

From the clause no.41.3.1 of I.S.456:2000[7], effective nominal shear stress τ_{ve} should not be more than τ_{cmax}. With reference to design aspects, it is beneficial to keep the values of τ_{ve} (i.e. effective nominal shear stress), to a minimum.

As per clause no.41.3.1 of I.S.456:2000[7] the values of τ_{ve} depend upon Equivalent shear force and size of the beam. The values of τ_{ve} increase as the equivalent shear force increases; and decrease when the depth of the beam increases. From this, it is clear that the values of τ_{ve} can be kept to minimum by increasing the depth of beams and minimizing the equivalent shear force.

The equivalent Shear force also depends upon torsion moment and shear force. As it has been observed that shear force increases and the torsion moment reduces with increase in depth of Grid beams, for given depth of Peripheral beam. Therefore, actual verification is required to decide the feasibility of each case.

To find out whether design can be feasible for the depth of beam corresponding to optimum BM, as per the clause 41.3.1 of I.S.456:2000[7]; the values of τ_{ve} shall not exceed the values of τ_{cmax} as given in Table 20 of I.S.456:2000[7]. This will be the criterion for checking the design feasibility.

The abstract of the results regarding the design feasibility of Peripheral beam with the size of Grid beam corresponding to optimum bending moment in Peripheral beam, for various L/B ratios, for the particular size of Peripheral beam is shown in Table 2

Table 2 Feasible Depths of Grid Beams with L/B ratio

Size of Peripheral beams	**0.30m x 0.75m**	
L/B	**Size of Grid Beams corresponding to Optimum BM in Peripheral Beams**	**Feasible size of Grid beams**
1.00	0.23m x 0.60m	0.23m x 0.60m
1.05	0.23m x 0.60m	0.23m x 0.60m
1.10	0.23m x 0.65m	0.23m x 0.65m
1.15	0.23m x 0.65m	0.23m x 0.65m
1.20	0.23m x 0.70m	0.23m x 0.70m
1.25	0.23m x 0.70m	0.23m x 0.70m
1.30	0.23m x 0.75m	0.23m x 0.75m

From Table 2, it is observed that the size of Grid beam corresponding to optimum value of maximum bending moment in Peripheral beams is feasible from design point of view.

It also shows that, the feasible depth of Grid beams increases only when L/B ratio increases with an interval of 0.1. The feasible depths of Grid beams remain the same for increasing interval of L/B =0.05. Therefore, it is confirmed that the interval of increasing L/B ratio should be kept 0.1 instead of 0.05.

V. CONCLUSION

1 The bending moments in peripheral beams can be minimized by keeping ratio of hall dimensions less than 1.4 with minimum ratio of spacing of grid beams. The square grids are most economical. For hall sizes ratio (L/B) greater than 1.45, the spacing of grid beams (l/b) can be optimized, which produces the minimum bending moments in peripheral beams.

2 For a given depth of Peripheral beams, the maximum bending moment in peripheral beams can be optimized by reducing the depth of Grid beams. For the given depth of Peripheral beams, the optimum value of maximum bending moment in Peripheral beams increases with increasing L/B ratio.

3 By providing Grid beams of depth less than depth of peripheral beam, governing bending moment in peripheral beams can be optimized for ratio of hall dimensions (L/B) @1.25. As we go on increasing (L/B) more than 1.25, optimization is not observed. For such halls having (L/B) ratio greater than 1.25, the bending moment in peripheral beams is the minimum when the depth of peripheral beams and Grid beams is same.

4 Maximum Shear force in peripheral beam increases with increasing depth of grid beams.

5 For a given depth of peripheral beams, the torsion moments in peripheral beams goes on reducing with increasing depth of grid beam. The maximum torsion moment in peripheral beams is the minimum, when the depth of Grid beams & depth of Peripheral beams is same.

6 From design point of view, the depth of Grid beam corresponding to optimum value of maximum bending moment in Peripheral beams is feasible.

7 The difference between the depth of Peripheral beams and depth of Grid beams at optimum value of maximum bending moment goes on reducing as the L/B ratio of the hall dimensions goes on increasing.

8 The depth of Grid beam can be minimized effectively than the depth of Peripheral beam, for the hall sizes having L/B ratio less than 1.15, However, for hall sizes having larger L/B ratio (i.e. above 1.15) it is beneficial to keep the depth of grid beam equal to the depth of peripheral beam.

9 Effective Interval of increasing L/B ratio is 0.1m for such investigations.

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