Analytical Study on Economic Effect of Grid Floor Geometric Parameters

Markandeya Raju Ponnada

Professor, Department of Civil Engineering,
Maharaj Vijayram Gajapathi Raj College of Engineering,
Chintalavalasa, VIZIANAGARAM, 535005, Andhra Pradesh, INDIA.
+91 9440528403, markandeyaraju@gmail.com

ABSTRACT

Timoshenko's theory of plates is used to evaluate design moments and shears occurring in ribs of a Grid floor accurately. However, it involves assuming magnitudes of parameters like spacing of ribs, thickness of slab and width of rib which have considerable influence on the overall economy of the Grid floor. The aim of this study is to analytically find the effect of these assumed parameters on the overall economy of the structure. Grid floors of sizes 12 m X 16 m, 14 m X 16 m and 16 m X 16 m were designed for various dimensions of slab, rib and different spacing. The cost of each slab is estimated and interaction curves are developed. From this study, it can be concluded that the cost of the grid floor would be minimum if minimum thickness of slab, minimum width of ribs and maximum spacing of ribs is adopted. Further, for the typical case considered, the approximate method of Rankine - Grashoff theory underestimates the moments by around 20 %.

Keywords: grid floor, economic design, width of ribs, spacing of ribs, thickness of slab, computer aided analysis and design.

INTRODUCTION

Slabs may be viewed as moderately thick plates that transmit loads to the supporting walls or beams and sometimes directly to the columns by flexure, shear and torsion. It is because of this complex behavior that it is difficult to decide whether the slab is a structural element, component or a system in itself. Purushothaman (1984) visualises Slabs as intersecting, closely spaced grid-beams and hence they are highly indeterminate. This is indirectly helpful to designers, since multiple load-flow paths are available. However, rigorous elastic solutions are not available for many practically important boundary conditions. Iyengar (2004) opines that Finite difference and finite element methods and more methods have been developed to find the collapse loads of various types of slabs through the yield-line theory and strip-methods. The study and detailing of slabs is a challenge as precise technical information is not readily available. An intuitive feel is still the basis for the design of slab as many parameters that affect its performance are assumed. As the greatest volume of concrete that goes into a structure is in the form of slabs, even a slightest change in these parameters will affect the economy. The basic idea behind intuitive or indirect design in engineering is the memory of past experiences, subconscious motives, incomplete logical processes, random selections or sometimes mere superstition. This will not lead to the best design. The shortcomings of the indirect design can be overcome by adopting a direct or optimal design procedure. The feature of the optimal design is that it consists of only logical decisions by setting out the constraints and then minimizing or maximizing the objective function (which could be either cost, weight or merit function).

Most civil engineering structures are even to-day designed on the basis of permissible stress criterion. However, some of the recent methods use a specified factor of safety against ultimate failure of the structure. Presently, the approach is based on the design constraints expressing the maximum probability of various types of events such as local or ultimate failure.
During the early fifties there have been considerable advances in `art` and economy of the structural design through the use of better structural materials and refined knowledge of structural design processes. Thus, the aim was to put structural design on a scientific basis. The need for innovation and optimization arose in the challenging problems faced by the aerospace industry, which gave a Philip to research activities in this area.

GRID FLOORS

General

The cast-in-situ reinforced concrete roof and floor slab is the simplest form of slab construction, but it is rather wasteful in materials, particularly cement. Substantial savings can be affected by modifying the composition of the slab so that its weight is reduced without impairing its strength or behavior. Ribbed and waffle slabs are examples. Amit A. Sathawane and R.S. Deotale (2011) compared Flat Slab and Ribbed floor and found that the former is more economical. The formwork for such a system is complex and the extra initial cast may not be justified where a small-sized domestic construction is involved. Some weight reduction can be effected by the use of hollow clay blocks which eliminates the need for special form-work by acting as a part of the formwork in the construction of the in-situ ribbed slabs. Ribbed, hollow block or voided slab construction has been covered in the IS:456 (1978) code for the first time. Ibrahim. S. Vepari and H.S.Patel (2011), observed that Grid or coffered floor systems consisting of beams spaced at regular intervals in perpendicular directions, monolithic with a slab 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 rectangular or square voids formed in the ceiling are advantageously utilized for concealed architectural lighting. The size of the beams running in perpendicular directions is generally kept the same. Instead of rectangular beam grid, a diagonal gird can also be used with the beams inclined at 45° to the sides.

Methods of analysis

According to the Indian Standard Code of practice for Plain and Reinforced Concrete i.e. IS: 456 (2000), the ribbed slab system can be analysed as a solid slab if the spacing of the ribs is not be greater than 1.5 m and 12 times the flange thickness. In situ ribs should not be less than 65 mm wide. The ribs should be formed along each edge parallel to the span, having a width equal to that of the bearing. The moments and shears per unit width of grid are determined from Table 22 of IS: 456 (2000) code and the reinforcements are designed in the ribs. ln slabs, reinforcement generally consists of a mesh or fabric.

A second approximate method which is applicable to the grid floor system is the Rankine Grashoff (1857) Theory of equating deflections at the junctions of ribs. However this method does not yield the twisting moments in the beams. For small span grids with spacing of ribs not exceeding 1.5 m, it can be used. But for grids of larger spans with spacing of ribs exceeding 1.5 m, a rigorous analysis based on orthotropic plate theory is generally used. A reinforced concrete grid floor with ribs at close intervals in two mutually perpendicular directions connected by slab in between in the ribs can be considered as an orthotropic plate freely supported on four sides. Timoshenko and S. Woinowsky-Krieger (1963) evaluated the moments and shears in the grid which depend upon the deflection surface. Maximum Bending moments develop at center of span while maximum torsional moments are generated at the corners ot the grid and maximum shear forces develop at mid points of longer side supports. Al-Ansari (2006) adopted MATHCAD for two way ribbed slab analysis and design.

Minimum cost design of grid floor

The most common form of reinforced concrete construction of private and public buildings is T-beam and grid floor. The design of these structures is generally based on either stress design or strength design. It has been well established that the strength design is more logical and also economical. For the design slabs of various shapes and edge conditions limit design procedures have also been well established. These methods result in considerable economy in the design of reinforced concrete structures. However, one can further improve the design if one chooses the dimensions optimally.

The cost of the structure is often a nonlinear function of the dimensions of the structure. It is necessary that the structure in addition to being low cost must meet the safety and functional requirements. These are also generally nonlinear. Adidam (1978) investigated the optimal design of T-beam and grid floors using Nonlinear Mathematical Programming Technique in which the objective function represents the cost of one beam and slab assembly per unit length along the beam span per unit spacing. This is also expressed as a ratio of cost per unit area of floor to the cost of one unit of concrete. An existing square grid of 18.83 meter span was optimized. He found that the optimal design turns out to be 1.2 meter square grid instead of existing one meter square. This indirectly results in saving of form work and material.

From study of literature, it can be understood that the economy of a Grid slab is not only affected by the Geometry, but also the Design parameters. The following are some of the parameters that affect the overall cost of a grid floor.

1. Size of Grid Floor and Spacing of Ribs (in X and Y directions)
2. Grade of Concrete and Grade of Steel
3. Live load on the slab
4. Thickness of slab, Width of Rib and Depth of Rib
5. However, the structural design engineer has control over Thickness of slab, Width of Rib and Depth of Rib only and hence the study of their effect on the cost of the Grid floor is important.

OBJECTIVES AND SCOPE OF PRESENT STUDY

Objective of present study

The present project work is an attempt to study the effect of Thickness of slab (CASE 1), Width of ribs (CASE 2) and Spacing of ribs (CASE 3) on economy of a Grid floor. An Excel Work sheet has been developed for analysis of Grid floor by Timoshenko's orthographic plate theory and design by Limit state Method. It was executed for different thicknesses of slab, width of ribs, spacing of ribs and grid sizes.

Assumptions and Limitations

In addition to the assumptions of Orthographic Plate theory and Limit State Design Method for Reinforced Concrete Structures, the Excel work sheet developed is limited to the scope detailed below for all the three CASES under consideration.

1. The sizes of Grids for which study is made are 16 m X 16 m, 16 m X 14 m and 16 m x 12 m.
2. Poisson's ratio was considered as 0.15 and Creep Coefficient was considered as 2.
3. Effective cover was considered as 50 mm.
4. Density of Concrete was taken as 25 kN / m^3 and the Density of steel was taken as 7850 kg/m^3 for all calculation purposes.
5. The self weight of floor finish was considered as 0.6 kN / m^2 and the slabs were designed for a live load of 1.5 kN / m^2.
6. M 20 Grade of Concrete and Fe 415 grade steel was considered for calculation purposes.
7. For all calculations, the cost of concrete was considered as Rs.5000/m^3 and that of steel was considered as Rs.65/kg.
8. For calculations, the materials are considered as M 20 Grade concrete and Ribbed Fe 415 grade HYSD steel bars.

Scope of study

Three CASES are considered for study. Scope of study for each case is detailed in **Table 1** below.

Table 1 Scope of study for each case of study

CASE	Thickness of Slab (mm)	Width of Rib (mm)	Spacing of Ribs (m)
1	90, 100 and 110	200	2
2	110	200, 300 and 400	2
3	110	200	1.5, 2 and 2.5

Significance of present study

The interaction curves generated from the study are useful for selecting suitable parameters for arriving at an economical Design. With the advent of Laptops and Tablets, the worksheet is expected to be very helpful to field engineer to design a grid floor in the field itself if required.

COMPUTERISED ANALYSIS AND DESIGN OF GRID FLOOR – NECESSITY

Grid Slabs, being highly indeterminate, are difficult to analyse by elastic theories. Since slabs are sensitive to support restraints and fixities, rigorous elastic solutions are not available for many practically important boundary conditions. Since large volumes of reinforced concrete go into slabs, the slightest change in different parameters will lead to considerable economy in the final analysis. Economy is the basis of all good designs, the slab being no exception to this golden rule. Repeated analysis and design leads to economical design but is tedious. Hence it is necessary that the analysis and design of Grid Floors be computerized to arrive at a more rationale design. So, an Excel worksheet is developed for analysis and Design of Grid floor using Rigorous plate method **APPENDIX A.** The Advantage of Excel work sheet is that input of Data is highly user friendly. Further Microsoft Excel package is a very commonly available package on any Desktop or Laptop. As the worksheet is adopted for further study of effect of various dimensional parameters on cost of the slab, it has to be calibrated. For verifying this worksheet, the Grid floor shown in **Fig. 1** for dimensions shown in **Fig. 2** is analyzed and designed using the worksheet and manually analysed and designed by Approximate and exact methods. The moments per meter width are computed by the rigorous and approximate methods and the comparison of maximum moments is shown in **Table 2.** In **APPENDIX B,** the moments from rigorous analysis at all salient points are shown. The approximate method underestimates the bending moments developed in X and Y directions, to the extent of 17 % and 21 % respectively. The moments are very much under estimated in the long span direction.

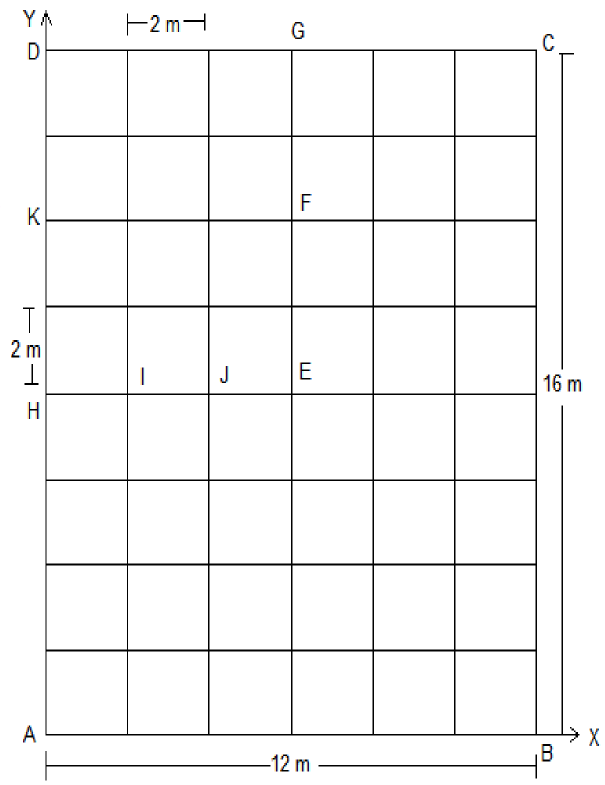

Fig. 1 Reinforced Concrete Grid Floor – Dimensions in Plan

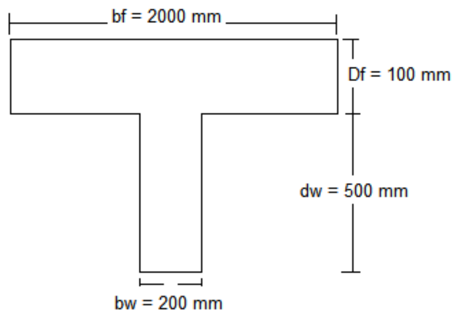

Fig. 2 Reinforced Concrete Grid Floor – Section of Ribs in X and Y Directions

Table 2 Comparison of maximum moments in Grid floor

Method	**Moment Mx kN_m / m width**	**Moment My kN_m / m width**
Rankine Grashoff Theory (Approx.)	90	48
Timoshenko's Plate Theory (Rigorous)	108	61
From Excel work sheet developed	112. 95	63.53

RESULTS AND DISCUSSION

Using the Excel worksheet, the quantity of steel and concrete and the total cost are determined for different Grid floor sizes, thicknesses of slab (Table 3), width of Ribs (Table 4) and spacing of Ribs (Table 5) and the results are tabulated for the three Cases defined in the scope.

CASE 1

Table 3 Grid floor Material cost for different Grid size's for varying thicknesses of slab

Size of Grid Floor (m^2)	Thickness of slab (mm)	Quantity of steel (m^3)	Quantity of Steel (kg)	Quantity of concrete (m^3)	Total Cost (Rs.)
12 x 16	90	0.210	1648.50	34.01	277,192.50
	100	0.226	1774.10	35.60	293,316.50
	110	0.242	1899.70	37.19	309,440.50
14 x 16	90	0.262	2056.70	43.83	352,825.50
	100	0.282	2213.70	45.68	372,290.50
	110	0.302	2370.70	47.53	391,755.50
16 x 16	90	0.293	2300.05	54.85	423,743.25
	100	0.298	2339.30	56.96	436,854.50
	110	0.366	2873.10	59.07	482,111.50

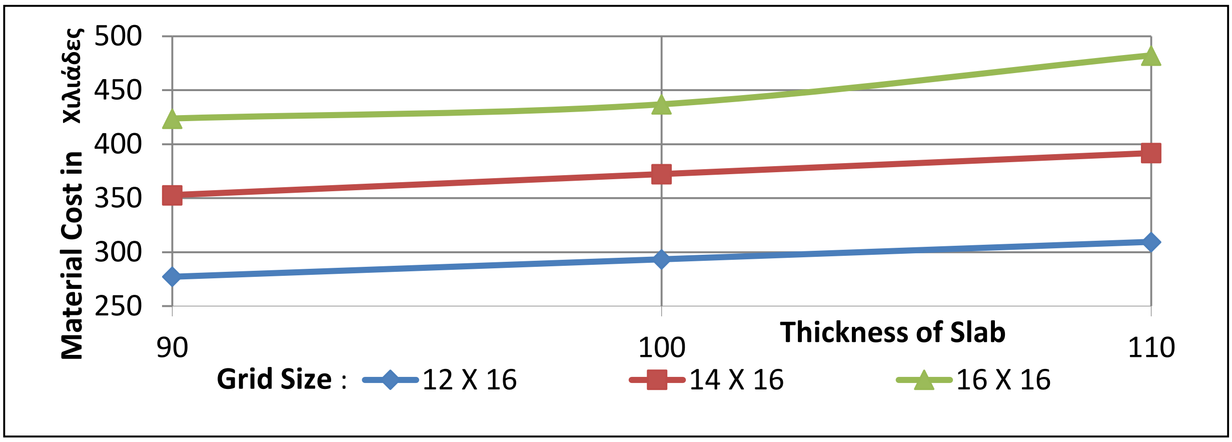

Fig. 3 Variation of thickness of slab with total material cost for different sizes of Grid floor

From Fig. 3, it can be observed that
1. The cost of material requirement of slab increases with increase in thickness of slab.
2. For an increase in thickness of slab by 10 mm, the increase in cost of steel and concrete requirement for a given grid size is in the range of 3 to 10 %.
3. The % increase in cost for increase in thickness of slab decreases with increase in grid size.
4. The graphs plotted for thickness of slab against cost of material requirement appear to diverge which means that at a greater thickness of slab, the cost of the material requirement of the slab is going to vary considerably with the size of grid.
5. The slope of these graphs decreases with increase in thickness of slab which means that the cost of the slab is not going to increase considerably beyond certain thickness of slab.

CASE 2

Table 4 Grid floor Material cost for different Grid size's for varying width of Ribs

Size of Grid Floor (m^2)	Width of Rib (mm)	Quantity of steel (m^3)	Quantity of Steel (kg)	Quantity of concrete (m^3)	Total Cost (Rs.)
12 x 16	200	0.24	1899.70	37.19	309,440.50
	300	0.23	1766.25	45.23	340,946.25
	400	0.21	1632.80	53.26	372,452.00
14 x 16	200	0.30	2370.70	47.53	391,755.50
	300	0.28	2221.55	58.98	439,290.75
	400	0.26	2048.85	70.42	485,295.25
16 x 16	200	0.34	2653.30	59.07	467,824.50
	300	0.32	2504.15	74.53	535,409.75
	400	0.30	2323.60	89.98	600,954.00

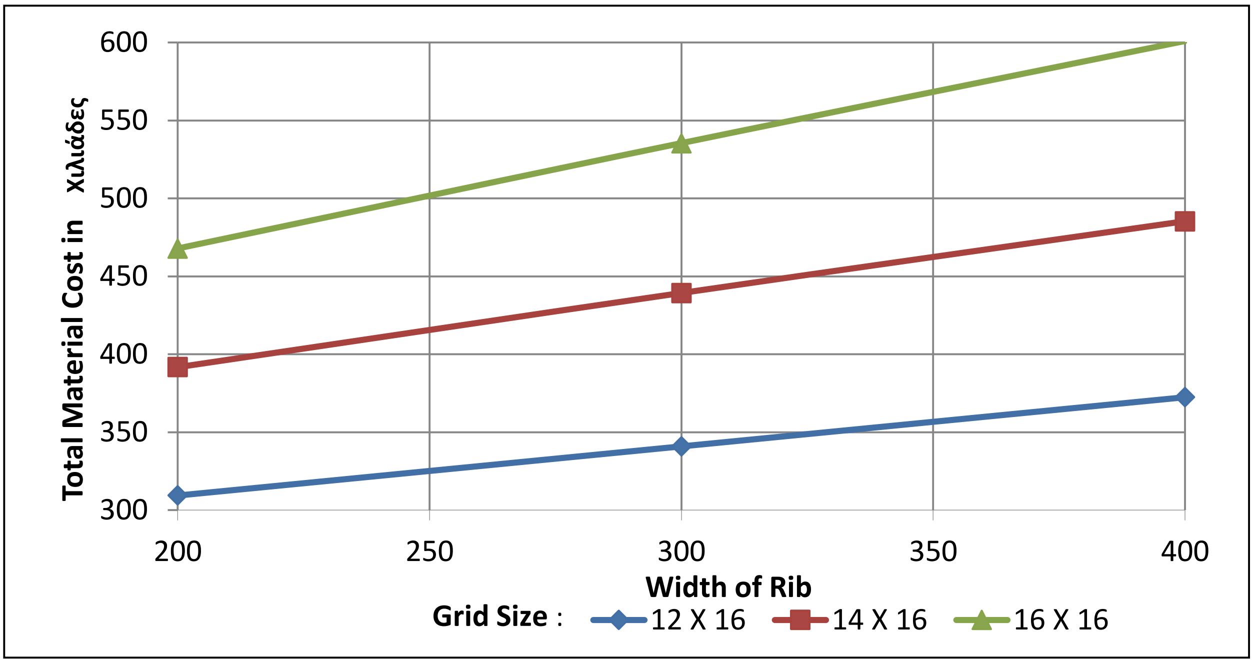

Fig. 4 Variation of width of rib with total material cost for different sizes of Grid floor

From Fig. 4, it can be observed that

1. The cost of the material requirement of the slab increases with increase in width of rib.
2. For an increase in width of rib by 50 mm, the decrease in the cost of the steel and concrete for a given grid size is in the range of 9 to 15 %.
3. The % increase in cost for increase in width of rib increases with increase in grid size.
4. The graphs plotted for width of ribs against cost of material requirement appear to diverge which means that at a greater the width of rib, the cost of the material requirement of the slab is going to vary considerably with the size of grid.
5. The slope of these graphs increases with increase in width of rib which means that the cost of the slab is going to increase considerably beyond certain width of rib.

CASE 3

Table 5 Grid floor Material cost for different Grid size's for varying spacing of Ribs

Size of Grid Floor m^2	Spacing of Ribs m	Quantity of steel m^3	Quantity of Steel Kg	Quantity of concrete m^3	Total Cost Rs
12 x 16	1.5	0.280	2198	43.464	360190.0
	2	0.242	1899.7	37.192	309440.5
	2.5	0.207	1624.95	33.428	272761.75
14 x 16	1.5	0.348	2731.8	56.342	459,277.00
	2	0.302	2370.7	47.532	391,755.50
	2.5	0.274	2150.9	42.245	351,033.50
16 x 16	1.5	0.419	3289.15	70.848	568,034.75
	2	0.366	2873.1	59.072	482,111.50
	2.5	0.325	2551.25	52.006	425,861.25

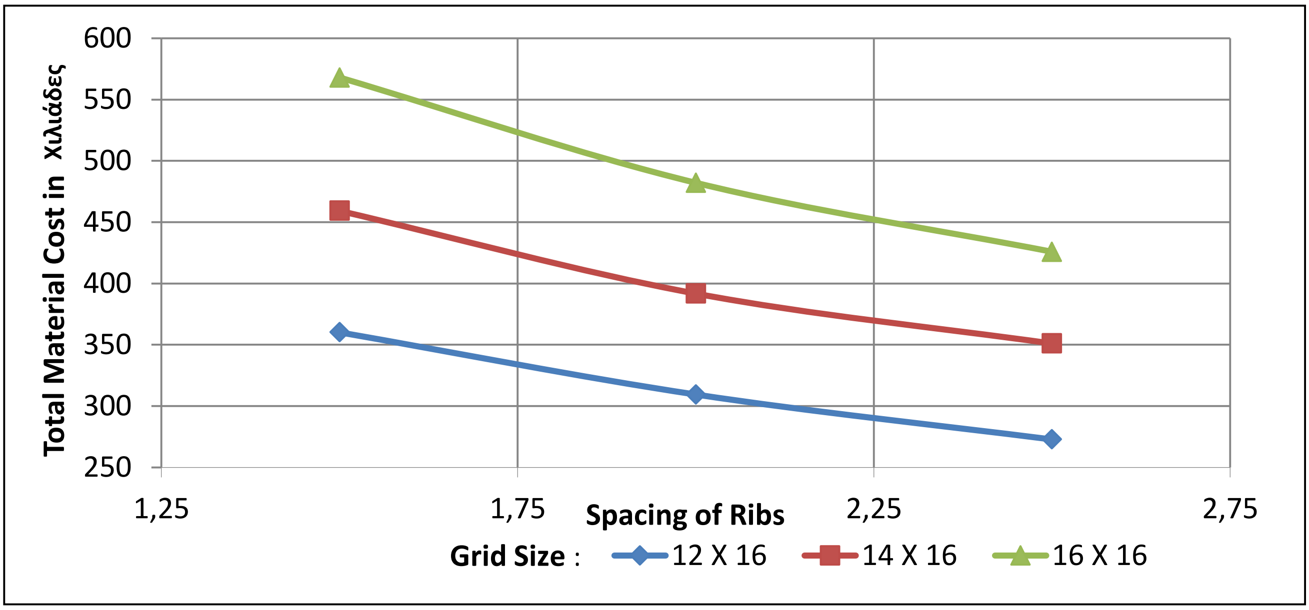

Fig. 5 Variation of spacing of ribs with total material cost for different sizes of Grid floor

From Fig. 5, it can be observed that

1. The cost of the material requirement of the slab decreases with increase in spacing of ribs.
2. For an increase in spacing of 0.5 m, the decrease in the cost of the steel and concrete for a given grid size is in the range of 10 to 16 %.
3. The % decrease in cost for increase in spacing increases with increase in grid size.
4. The graphs plotted for spacing of ribs against cost of material requirement appear to converge which means that at a greater spacing, the cost of the material requirement of the slab is not going to vary much with the size of grid.
5. The slope of these graphs decreases with increase in spacing which means that the cost of the slab is not going to reduce much beyond certain spacing.

CONCLUSIONS

From this study, it can be concluded that the increase in cost with increase in thickness of slab decreases with increase in Grid size. Further, Cost of slab increases with increase in width of Rib and size of grid while increase in spacing of ribs decreases the cost of Grid floor. For the scope defined for this study, the cost of material is minimum for minimum width of Rib (200 mm), minimum thickness (90 mm) and maximum spacing (2.5 m) for all sizes of Grid floors. As most of grid floors adopted in practice are of the sizes discussed in this study, the guidelines are expected to be of use to the design engineers before actually designing it. Also, from the results of the typical grid floor analysis, it can be concluded that the approximate method underestimates the moments. However, further study and more results are required to give a quantitative dimension to this aspect.

Even though some of the resulting conclusions are easily foreseeable, (ie., cost increases with slab thickness and decreases with rib spacing), the study provides a quantitative insight into the effect of dimensions on economy of Gird Floor.

1. For an increase in thickness of slab by 10 mm, the increase in cost of steel and concrete requirement for a given grid size is in the range of 3 to 10 %.
2. For an increase in width of rib by 50 mm, the decrease in the cost of the steel and concrete for a given grid size is in the range of 9 to 15 %.
3. For an increase in spacing of 0.5 m, the decrease in the cost of the steel and concrete for a given grid size is in the range of 10 to 16 %.

ACKNOWLEDGEMENTS

The author is thankful to the management of M.V.G.R.College of Engineering, Vizianagaram, for providing encouraging environment and computational facilities without which this work would not have been possible. I also thank Mr. S.Veera Babu, Undergraduate student of Civil Engineering, School of Continuing & Distance Education, Jawaharlal Nehru Technological University, Hyderabad for helping me in developing the Excel worksheet for Analysis and Design of Grid Floor.

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APPENDIX A

The output of the Excel output the typical Grid floor chosen for Validation of Excel worksheet developed by the author is as follows. Note that the data in bold have been entered by the user.

1. Design data

Size of Grid in X - direction = 12 m
Size of Grid in Y - direction = 16 m
Size of grid = 12 x 16 m2
Rib spacing in x-direrction = 2 m c/c
Rib spacing in y-direction = 2 m c/c
Grade of concrete = M 20
Grade of Steel = Fe 415
Floor finish = 0.60 kN/m2
Live load = 1.5 kN/m2
Modulus of elasticity = 25491.17 N/mm2
Poisson's ratio = 0.15
Creep coefficient = 2

2. Dimensions of slab and beams

over all depth of rib = 600.00 mm
depth of rib = 500 mm
Width of rib = 200 mm
No. of ribs in x-dir. = 7
No. of ribs in y-dir.= 5
Effective cover = 50 mm

3. Loads

Unit wt of concrete = 25 kN/m^3
Weight of slab = 2.50 kN/m^2
Total load of slab = 480 kN
Weight of ribs = 2.5 kN/m
Wt. of beams x-dir.= 210 kN
Wt. of beams y-dir.= 182.5 kN
Wt. of floor finish = 115.2 kN
Total live load = 288 kN
Total load on grid floor = 1275.7 kN
Load per sq.m = 6.64 kN / m2

4. Calculation of moment of inertia

Area of ribs in x-dir. = 300000 mm2
Area of ribs in y-dir. = 300000 mm2
Neutral axes from top of rib in x - direction = 150 mm
Neutral axes from top of rib in y-direction = 150 mm

Moment of Inertia about Centroidal x-x axes = 8250000000 mm4
Moment of Inertia about Centroidal y-y axes = 8250000000 mm4

5. Check for deflection

Dx = 105151096641.93 N_mm
Dy = 105151096641.93 N_mm
b/a = 3
k1 = 0.26
C = 13991330108118 mm4
Cx = 6995665054059 mm4
Cy = 6995665054059 mm4
2H = 13991330108.12 mm4
Def. @ centre = 15.64 mm
Long term Def. = 46.91 mm
Span/250 = 48

6. *Design moments and shears*

Table 6. Design moments and shears

x m	Y m	Mx N_mm /mm	My N_mm /mm	Mxy N_mm /mm	Myx N_mm /mm	Qx N/mm	Qy N/mm
0	**8**	0.00	0.00	0.00	0.00	-30.68	0.00
2	**8**	56479.97	31769.98	0.00	0.00	-26.57	0.00
4	**8**	97826.18	55027.23	0.00	0.00	-15.34	0.00
6	**8**	112959.95	63539.97	0.00	0.00	0.00	0.00
0	**10**	0.00	0.00	2156.95	2156.95	-28.34	0.00
2	**10**	52180.69	29351.64	1867.98	1867.98	-24.55	2.67
4	**10**	90379.61	50838.53	1078.48	1078.48	-14.17	4.62
6	**10**	104361.38	58703.28	0.00	0.00	0.00	5.34
0	**12**	0.00	0.00	3985.53	3985.53	-21.69	0.00
2	**12**	39937.37	22464.77	3451.57	3451.57	-18.79	4.93
4	**12**	69173.56	38910.13	1992.76	1992.76	-10.85	8.54
6	**12**	79874.74	44929.54	0.00	0.00	0.00	9.87
0	**14**	0.00	0.00	5207.34	5207.34	-11.74	0.00
2	**14**	21613.95	12157.85	4509.69	4509.69	-10.17	6.44
4	**14**	37436.46	21058.01	2603.67	2603.67	-5.87	11.16
6	**14**	43227.90	24315.69	0.00	0.00	0.00	12.89
0	**16**	0.00	0.00	5636.39	5636.39	0.00	0.00
2	**16**	0.00	0.00	4881.26	4881.26	0.00	6.98
4	**16**	0.00	0.00	2818.19	2818.19	0.00	12.08
6	**16**	0.00	0.00	0.00	0.00	0.00	13.95
Max. Values		112959.95	63539.97	5207.34	5207.34	-30.68	11.16

7 (a). Design of reinforcement in ribs in X-dir.

Design for flexure

Maximum working moment Mw = 112959.95 N_mm/mm
Moment resisted by central rib in x-direction
over 2000 mm width = 225919892.98 N_mm

If Mu<Muf Neutral axis falls within the flange

a = 1

b = -53012.05

c = 90467018.58

b2-4ac = 2448409179.28

2a = 2

sqrt(b2-4ac) = 49481.4

-b/2a = 26506.02

sqrt(b2-4ac) /2a= 24740.7

Ast = 51246.73 mm2, 1765.32 mm2

Min. Ast = 225.3 mm2

Max. Ast = 4400 mm2

Area of tension steel required Ast. = 1765.32 mm2

Diametre of bars choosen = 25.00 mm

Number of bars required = 4

Area of tension steel provided Ast. prov. = 1963.5 mm2

Design for shear

Maximum ultimate shear = 33488.27 N

Nominal Shear stress Tv = 0.3 N/mm2

% Steel = 1.6, For P = 1.55

Tc = 0.75 N/mm2

Since Tv < Tc To provide nominal shear reinforcement,
using 6 mm diameter, two legged stirrups

Diameter of bar = 6 mm

Asv = 56.55 mm2

Sv = 255.21 mm

Provide 6 mm diameter 2-legged stirrups at 250 mm c/c
at supports and the spacing gradually increased to 400
mm towards the centre of span.

If Tv > Tc

Vus = -46701.73 Kn

Sv = -240.45 mm

8 (b). Design of reinforcement in ribs in Y-dir.

Design for flexure

Maximum working moment Mw = 63539.97 N_mm/mm
Moment resisted by central rib in Y-direction over 2000 mm width =
127079939.80 N_mm

ultimate moment Mu =190619909.70 N_mm

Muf = 731520000 N_mm

If Mu<Muf Neutral axis falls within the flange

a = 1
b=-53012.05
c=50887697.95
b2-4ac = 2606726461.79
2a = 2
sqrt(b2-4ac) =51056.11
-b/2a =26506.02
sqrt(b2-4ac) /2a=25528.06
Ast =52034.08 mm2, 977.97 mm2
Min. Ast = 225.3 mm2
Max. Ast = 4400 mm2
Ast. req. = 977.97
Diametre of bars choosen = 25 mm
No.of bars required = 2
Ast. prov. = 981.75
Design for shear
Maximum ultimate shear = 92038.64 N
Shear stress Tv = 0.84 N/mm2
% Steel = 0.89, P = 0.9
Tc = 0.59 N/mm2
If Tv < Tc To provide nominal shear reinforcements, using 6mm diameter, two legged stirreps
Dia of bar = 6 mm
Asv = 56.55 mm2
Sv = 255.21 mm
Provide 6 mm diameter 2-legged stirrups at 250 mm c/c at supports and the spacing gradually increased to 400 mm towards the centre of span.
If Tv > Tc
Vus = 27138.64 kN
Sv = 413.78 mm c/c
Say 660 mm c/c
Else if NA falls in web
Xu max. = 264.00 mm
Xu = 150 mm
if Xu < Xu max.
Df/d = 0.18
If Df/d < 0.2
Mu = 976935859.20 N+mm
If Df/d > 0.2
Mu = 875685859.20 N_mm
Ast = 5466.30 mm2
Estimation
Quantity of concrete (slab) =19200000000 mm3
Quantity of concrete (X-Rib) = 8400000000 mm3

Quantity of concrete (Y-Rib) = 8000000000 mm3
Total = 35.60 m3
For flexure
Quantity of Steel (X-dir.) = 148287125.07 m3
Quantity of Steel (Y-dir) = 78237491.10 m3
For shear
Asv in X-dir. = 56.55 mm2
Sv in X-dir. = 255.21 mm
Quantity of Steel (X-dir.) =18612.38 mm3
Asv in Y-dir. = 56.55 mm2
Sv in Y-dir. = 255.21 mm
Quantity of Steel (Y-dir.) = 17726.08 mm3
Total = 0.23 m3

APPENDIX B

Ref. to Fig. 1 and Fig. 2, the moments from rigorous analysis at all salient points are as follows.

Table 7 Moments and shear forces per meter width of Grid

Point	X m	Y m	Mx kN m	My kN m	Mxy kN m	Myx kN m	Qx kN	Qy kN
E	6	8	108	61	0	0	0	0
F	6	12	77	43	0	0	0	9.4
G	6	16	0	0	0	0	0	13.4
H	0	8	0	0	0	0	10.1	0
I	2	8	54	30.5	0	0	8.74	0
J	4	8	94	53	0	0	5.05	0
K	0	12	0	0	3.74	3.74	7.14	0
J	0	16	0	0	5.30	5.30	0	0