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Orthogonal and Diagonal Grid Slabs Analysis Using E-TABS

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ABSTRACT

Grid floor is an assembly of intersecting beam at regular interval and interconnected to a slab of nominal thickness is known as grid floor .These slab covers large free area and therefore it is adopted for public hall. A waffle slab is a type of building material that has two direction reinforcement. These types of floor are used to cover a large obstruction free are and therefore a good choice for public assembly hall. The present work includes the investigative parameter in terms of flexural action such bending moment, torsion and shear force, spacing of grid are the parameter considered for analysis and the results are evaluated for various grid panels. E-Tabs software is used for the analysis of grid slabs. Objective of this study is to analysis the grid slabs for different panels of orthogonal grids & diagonal grids.

KEYWORDS: *Grid floor, orthogonal grids, diagonal grids, Bending moment, Deflection, Rankine's method, Plate analogy method, stiffness method*

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1. INTRODUCTION

Grid/waffle slab is defined as an assembly of beams that are intersecting at regular intervals & are inter-connected to a slab of uniform thickness. These waffle slabs cover large free area & are therefore adopted for public hall. These have pleasant appearance, also less maintenance cost, however the construction of a grid slab is considered to be cost prohibited. Waffle name comes in due to its grid pattern that is created by its reinforced ribs. A grid slab has reinforcement in both X & Y direction. These types of slabs cover large obstructions free are and hence these are a good choice for public assembly hall etc., and these grid structures are monolithic and are stiffer in nature. Waffle slab are designed to be more solid when used on longer span & with heavier loads. By checking the various parameters that are involved, economical solution could be initiated for grid slab. Grids are highly redundant structure system and it is indeterminate (DOF) is not measured by equilibrium equation. The matrix formulation by stiffness of structure is computed by stiffness method.

A. Types of grid slabs

1. Orthogonal grid slabs

These are regular type of grid system where the x - ordinate node and y coordinate note are mutually perpendicular to each other. The loads are transferred perpendicular from slab to column. These grid slabs considered to be stiffer compared to other types of grid

2. Diagonal grid slabs

The diagonal grids/dia grids are grid slabs that are inclined to plane, normally 45 to 60 degrees. These types of slab are less stiff inclined

3. Three way grid slabs

This type of grid include two grid running in orthogonal direction and other grid line passing diagonal in between grid between the grid junction column are placed stiffness of the joint is distributed to links surrounding the nodes.

B. Methods of analysis

Grid is highly redundant structural system and therefore statically indeterminate. Various approaches available for the analysis of grid floor frame, are as listed below.

1. Analysis of grid by Rankine – Grashoff method.
2. Analysis by plate analogy theory.
3. Stiffness method.

1. Rankine - Grashoff method
This is an approximate method. This method is based on equating the deflections at junctions of ribs at either per unit width of slab strip. The slabs are considered simply supported on edges

2. Plate analogy method
This method is based on Timoshenko analysis of orthopic plate theory considering plane stress analysis accounts shear and bending effect. This is a rigorous method of analysis. In this method also the analysis is done by considering the grid simply supported on edges. Bending & torsion moments and shears are obtained per unit width of slab strip

3. Stiffness method
This method, also called as Matrix/direct stiffness method, is used for the computer-automated complex structures study which includes statically indeterminate type structures. This method uses member stiffness relations for computing these member forces and displacements in the structures. This method is the exact application of the finite element method (FEM).

C. Objectives
The following objectives are considered in the present study

- To compare the nodal forces of a grid slab between Manual & Software analysis
- Analysis of orthogonal and diagonal grid slab for various grid panels & to obtain nodal forces for a particular Live load(10kN/m^2)
- To obtain deflection of grid slabs

2. METHODOLOGY
First a numerical data of a grid slab available will be considered for both manual as well as software calculation is done using different methods. With the obtained results from the manual calculation, software analysis is observed. Bending moments are obtained at mid span & cross beam is taken for considerations. Results are compared between manual & software analysis. Software analysis for orthogonal grids & diagonal grids of various grid sizes considering live load (10kN/m^2) only. Bending moment, shear force and deflection are obtained for different grid panels

3. MODELLING AND ANALYSIS

Type of analysis	Manual analysis	E- TABS software
Size of grid	12m by 16m	12m by 16m
Spacing of ribs	2 m c/c	2 m c/c
Concrete (f_{ck})	*20 N/mm^2*	*20 N/mm^2*
Steel (f_y)	***415 N/mm^2***	***415 N/mm^2***
Slab thickness	100 mm	100 mm
Beam size	200 mm*600 mm	200 mm*600 mm
Live load	-	1.5 kN/m^2
Floor finish	-	0.6kN/m^2

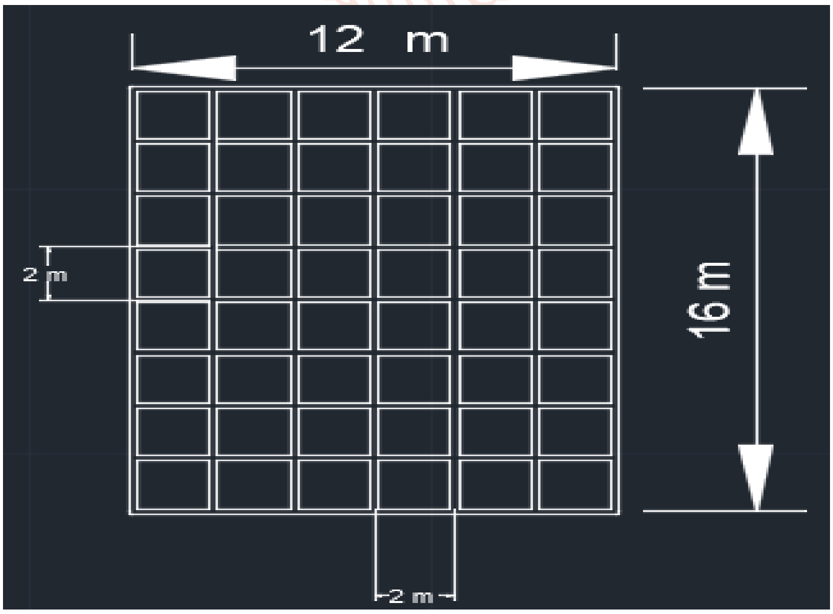


Fig 1: AutoCAD diagram of grid slab

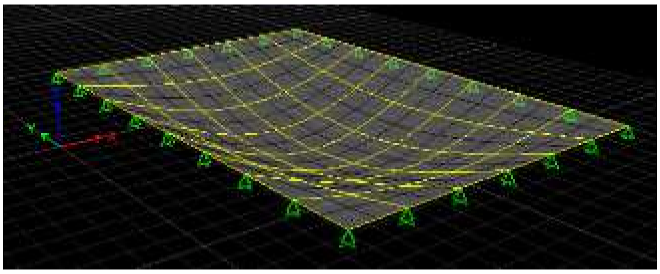


Fig 2: Deformation of grid slab

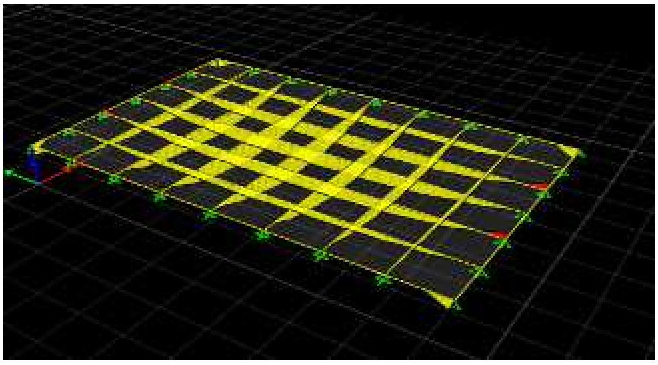


Fig 3: Bending moments

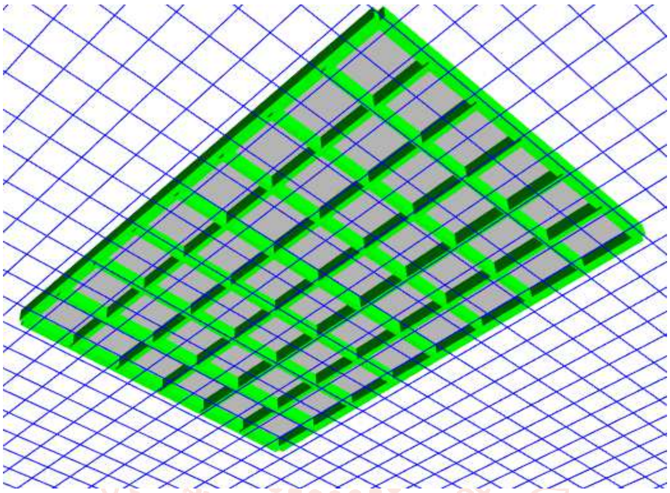
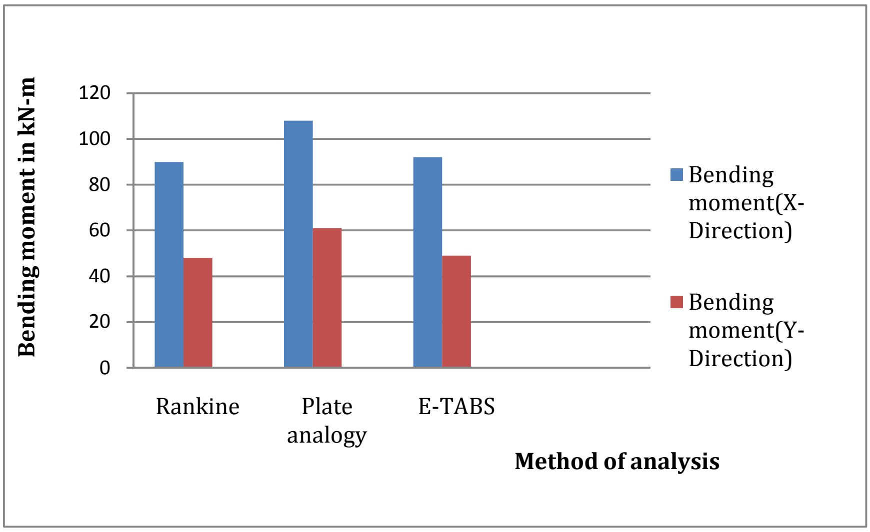


Fig 4: 3-D view of Grid slab

Table 1:- Comparision of Maximum moments in grid (per metre)

Method of analysis	Rankine Grashoff Theory	Timoshenko's Plate theory	E-Tabs 2017 Stiffness method
Bending Moment M_x (kN-m)	90	108	92
Bending Moment M_y (kN-m)	48	61	49

COMPARISION CHART



4. RESULTS

Table 2:- Results of orthogonal grids for Live load of 10kN/m^2

Grid details	Beam direction	Beam mark	M_x, M_y kN-m	Qx, Qy kN	□ mm
Grid panel size = 5 m x 5 m Beam size = 200mm x 250mm Beam spacing = 1 m c/c	X & Y direction	B1 B2	6.3 3.6	3.42 1.6	2 1.2
Grid panel size = 6 m x 8 m Beam size = 200mm x 300mm Beam spacing = 2 m c/c	X-direction	B2 B1	27.5 20	17.6 10.5	9 6.3
	Y-direction	B1	13	8.3	7.7
Grid panel size = 6 m x 10 m Beam size = 200mm x 300mm Beam spacing = 2 m c/c	X-direction	B1 B2	34 21.5	20 10.5	117
	Y-direction	B1	11	8.3	10
Grid panel size = 8 m x 8 m Beam size = 200mm x 400mm Beam spacing =2 m c/c	X & Y direction	B1 B2	46 31.1	24.5 15.1	12 8.5
Grid panel size = 8 m x 10 m Beam size = 200mm x 400mm Beam spacing =2 m c/c	X-direction	B1 B2	65 38	32 17.2	17 10
	Y-direction	B1 B2	42.5 30.2	24 15	18 12
Grid panel size = 8 m x 12 m Beam size = 200mm x 400mm Beam spacing =2 m c/c	X-direction	B1 B2 B3	87.2 75.3 41	40 34.6 17.5	22 20 11
	Y-direction	B1 B2	35.5 25.5	23.3 14.6	22 16

Grid details	Beam direction	Beam mark	M_x, M_y kN-m	Qx, Qy kN	□ mm
Grid panel size = 9 m x 9 m Beam size = 200mm x 450mm Beam spacing = 1.5 m c/c	X & Y direction	B1 B2 B3	53.2 45.4 26	29 25.1 13.2	13 11.2 6.4
Grid panel size = 9 m x 10 m Beam size = 200mm x 450mm Beam spacing = 1.5 m c/c along shorter span & 2 m c/c along longer span	X -direction	B1 B2	70.5 42.5	35 21	17 10.4
	Y-direction	B1 B2 B3	60 52 29	28 23.6 11.6	18 15.4 8.7
Grid panel size = 9 m x 12 m Beam size = 200mm x 450mm Beam spacing = 1.5 m c/c along shorter span & 2 m c/c along longer span	X-direction	B1 B2 B3	101.6 87.6 49.2	45 40 22.3	24 21 12
	Y-direction	B1 B2 B3	54.1 47 26.4	27.4 23.2 11.4	24 21 12
Grid panel size = 9 m x 15 m Beam size = 200mm x 450mm Beam spacing = 1.5 m c/c	X -direction	B1 B2 B3 B4 B5	110 105 90.4 66 34.3	46 44.2 40 29.4 14.1	26.3 25.2 22 16.2 8.6
	Y-direction	B1 B2 B3	36 31 18	27 23.4 12.5	26.3 23 13.1
Grid panel size = 10 m x 10 m Beam size = 200mm x 500mm Beam spacing = 2 m c/c	X & Y direction	B1 B2	88.5 55	37 20.6	19.3 12

Grid panel size = 10 m x 12 m Beam size = 200mm x 500mm Beam spacing = 2 m c/c	X -direction	B1	129	50.4	28
		B2	111.7	44	24.3
		B3	65	23	14.1
	Y-direction	B1	81.6	36	26.6
		B2	51	20	16.3
Grid panel size = 10 m x 14 m Beam size = 200mm x 500mm Beam spacing = 2 m c/c	X -direction	B1	154.1	57.1	33.5
		B2	124.6	46.4	27.3
		B3	70	23.5	15
	Y-direction	B1	72.2	34.2	32.7
		B2	45.1	19	20.1
Grid panel size = 10 m x 15 m Beam size = 200mm x 500mm Beam spacing = 2 m c/c along shorter span & 1.5 m c/c along longer span	X -direction	B1	140.4	50	31
		B2	134.4	47.7	29.4
		B3	116	41.4	25.5
		B4	85.6	30	19
		B5	45	15.2	10
	Y-direction	B1	54.1	32	29.2
		B2	33.6	19.4	18
Grid panel size = 10 m x 16 m Beam size = 200mm x 500mm Beam spacing = 2 m c/c	X -direction	B1	180	64	39
		B2	168	60	37
		B3	131	47	29
	Y-direction	B4	72.2	23.4	16
		B1	61.3	33	37
		B2	39	18.5	23

Grid details	Beam direction	Beam mark	M_x,M_y kN-m	Qx, Qy kN	δ mm
Grid panel size = 10 m x 18 m Beam size = 200mm x 500mm Beam spacing = 2 m c/c	X -direction	B1	194	66	42.4
		B2	174.3	60	38
		B3	134	47	29.5
		B4	73.1	23.1	16.1
	Y-direction	B1	55.3	32	41
		B2	35	18	25
Grid panel size = 10 m x 20 m Beam size = 200mm x 500mm Beam spacing = 2 m c/c	X -direction	B1	207.5	68.5	45.6
		B2	200.4	66.5	44
		B3	177	60	39
		B4	134.6	46.2	30
		B5	73.3	24	16.2
	Y-direction	B1	53	31.6	43.3
		B2	32.7	18	27
Grid panel size = 12 m x 12 m Beam size = 200mm x 600mm Beam spacing = 2 m c/c	X & Y direction	B1	156.2	53.7	29.2
		B2	134.2	46.6	25.4
		B3	77.5	25	15
Grid panel size = 12 m x 14 m Beam size = 200mm x 600mm Beam spacing = 2 m c/c	X -direction	B1	203.5	65.1	37.5
		B2	162	53	30.3
		B3	89.3	27.5	17
	Y-direction	B1	149.5	51.4	38.4
		B2	129.2	45	33.3
		B3	75.1	24.1	19.2
Grid panel size = 12 m x 15 m Beam size = 200mm x 600mm Beam spacing = 2 m c/c along shorter span & 1.5 m c/c along longer span	X -direction	B1	194	59.1	35.7
		B2	184.5	56.6	34.1
		B3	157	49	29.3
		B4	113	35.6	21.5
		B5	59.2	19.2	11.4

	Y-direction	B1	116	46.1	35.6
		B2	100.1	41	31
		B3	58.3	24	18
Grid panel size = 12 m x 16 m Beam size = 200mm x 600mm Beam spacing = 2 m c/c Grid panel size = 9 m x 12 m Beam size = 200mm x 450mm Beam spacing = 1.5 m c/c along shorter span & 2 m c/c along longer span	X-direction	B1	252	76.4	46.1
		B2	233.1	71.3	43
		B3	178	56	33.3
		B4	96	28.5	18.2
	Y-direction	B1	132.6	48.7	46
		B2	115	42.4	40
		B3	67	22.7	23
Grid panel size = 12 m x 18 m Beam size = 200mm x 600mm Beam spacing = 2 m c/c	X -direction	B1	281	82.3	51.4
		B2	249.1	74.1	45.8
		B3	185.7	56.8	34.8
		B4	98.7	29.4	18.8
	Y-direction	B1	115	46.2	52.1
		B2	99.1	40.3	45.1
		B3	58.2	21.6	26.1
Grid panel size = 12 m x 20 m Beam size = 200mm x 600mm Beam spacing = 2 m c/c	X -direction	B1	309.4	88	56.5
		B2	296.3	84.6	54.2
		B3	256.3	74.7	47.3
		B4	188.7	56.7	35.4
		B5	100	30.6	19
	Y-direction	B1	100	44.5	56.5
		B2	87.4	38.8	49
		B3	51.8	20.8	28.3
Grid panel size = 14 m x 14 m Beam size = 230mm x 700mm Beam spacing = 2 m c/c	X & Y direction	B1	230.6	67	32.5
		B2	185	54.7	26.2
		B3	104	30	15

Grid details	Beam direction	Beam mark	M_x, M_y kN-m	Qx, Qy kN	δ mm
Grid panel size = 14 m x 15 m Beam size = 230mm x 700mm Beam spacing = 2 m c/c along shorter span & 1.5 m c/c along longer span	X -direction	B1	232.6	63.2	32.5
		B2	221.5	60.5	31
		B3	189.1	52.3	26.5
		B4	138.1	38.3	19.5
		B5	73	23	10.3
	Y-direction	B1	190.6	62	31.7
		B2	152.3	51.7	25.5
		B3	85.1	29.7	14.3
Grid panel size = 14 m x 16 m Beam size = 230mm x 700mm Beam spacing = 2 m c/c	X -direction	B1	302.7	83	42.2
		B2	280.2	77	39
		B3	215	61	30
		B4	118	34	16.6
	Y-direction	B1	218.5	64.3	41.2
		B2	175.3	52.5	33.3
		B3	98.3	27.6	18.5
Grid panel size = 14 m x 18 m Beam size = 230mm x 700mm Beam spacing = 2 m c/c	X-direction	B1	353	93	49.1
		B2	312.1	83.3	43.6
		B3	233.7	64	33
		B4	126	36.3	17.7
	Y-direction	B1	200.3	60.7	48.6
		B2	161	50	39.2
		B3	90.2	26.1	21.8

Grid panel size = 14 m x 20 m Beam size = 230mm x 700mm Beam spacing = 2 m c/c	X -direction	B1	401.3	102.2	55.7
		B2	383.5	98.2	53.3
		B3	330	86.2	46.1
		B4	243.1	65.2	34.2
		B5	130	38	18.3
	Y-direction	B1	175.5	58	54.4
		B2	141	47.2	44
		B3	79.4	24.7	24.4
Grid panel size = 15 m x 15 m Beam size = 230mm x 750mm Beam spacing = 1.5 m c/c	X & Y direction	B1	214	62	28.3
		B2	203.3	59.5	27
		B3	172.5	52.1	23.1
		B4	125.3	39.3	17
		B5	66.4	21.1	9
Grid panel size = 18 m x 18 m Beam size = 250mm x 900mm Beam spacing = 2 m c/c	X & Y direction	B1	422	92	43
		B2	371	83.5	38
		B3	275.1	66	28.4
		B4	146	38	15.2
Grid panel size = 18 m x 20 m Beam size = 250mm x 900mm Beam spacing = 2 m c/c	X -direction	B1	527	113.4	53
		B2	502	109	51
		B3	428.2	95.3	43.5
		B4	312.4	73.1	32
		B5	166	45	17
	Y-direction	B1	409	92.5	52.4
		B2	360	83.2	46.3
		B3	267.5	64	34.6
		B4	144	39.4	18.5
Grid panel size = 20 m x 20 m Beam size = 250mm x 1000mm Beam spacing = 2 m c/c	X & Y direction	B1	547.7	112	50.3
		B2	520.7	107.6	48
		B3	442.3	94.2	41.1
		B4	322	74.5	30.1
		B5	170.8	45.3	16

Table 3:- Results of diagonal grids for Live load of 10kN/m^2

Grid details	Beam direction	Beam mark	M_x, M_y kN-m	Qx, Qy kN	δ mm
Grid panel size = 5 m x 5 m Beam size = 200mm x 250mm Beam spacing = 1 m c/c	X & Y direction	B1	4.7	5.2	2
		B2	4.74	4	1.5
		B3	4.1	3.5	1
		B4	5.2	5.8	0.2
Grid panel size = 8 m x 8 m Beam size = 200mm x 400mm Beam spacing =1.5 m c/c	X & Y direction	B1	27	22	7
		B2	26	16	6
		B3	25	20.2	3.5
		B4	32.3	24.6	1
Grid panel size = 10 m x 10 m Beam size = 200mm x 500mm Beam spacing = 1.8 m c/c	X & Y direction	B1	61.4	42.7	13
		B2	57.4	27	11.1
		B3	57.2	34.2	6.7
		B4	79	48.5	2
Grid panel size = 12 m x 12 m Beam size = 200 mm x 600 mm Beam spacing = 2 m c/c	X & Y direction	B1	119	69.2	20.3
		B2	106.4	40.8	17.6
		B3	109	50.8	10.6
		B4	153.1	79.1	3.1

Grid panel size = 20 m x 20 m Beam size = 250mm x 1000mm Beam spacing =1.8 m c/c	X & Y direction	B1	428	243	26.3
		B2	262.2	133	25.5
		B3	273.6	77.8	23
		B4	291	63.6	19.1
		B5	312	95.4	14.3
		B6	334.4	161	9.2
		B7	377.6	218	4.5
		B8	374.2	221	1

Here, M_x, M_y = Bending moment

Q_x, Q_y = Shear force

δ = Deflection

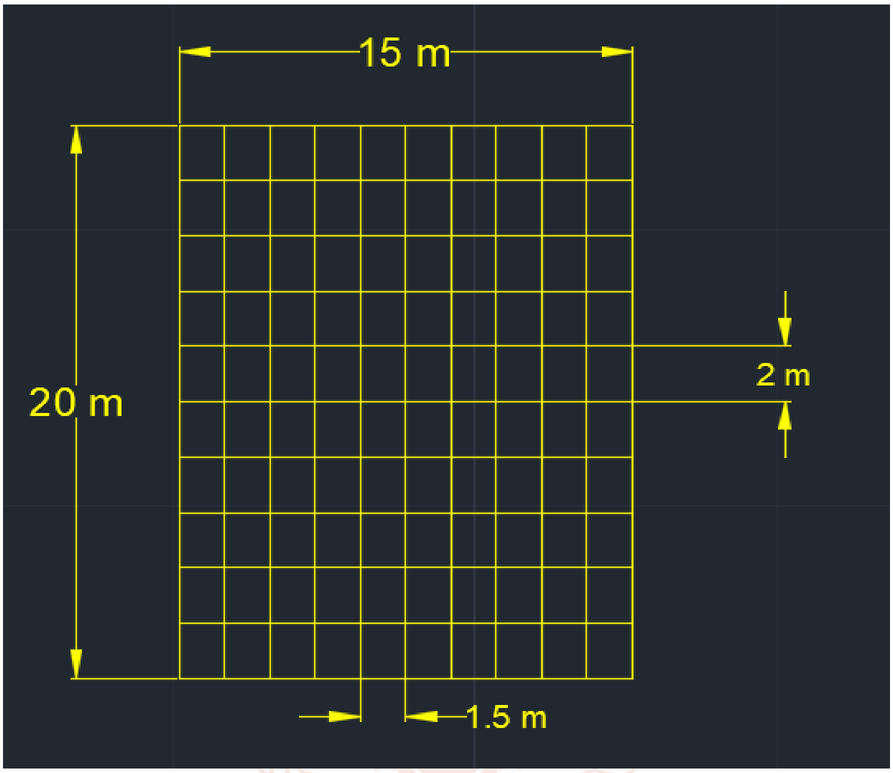


Fig 5: 15m x 20m orthogonal grid

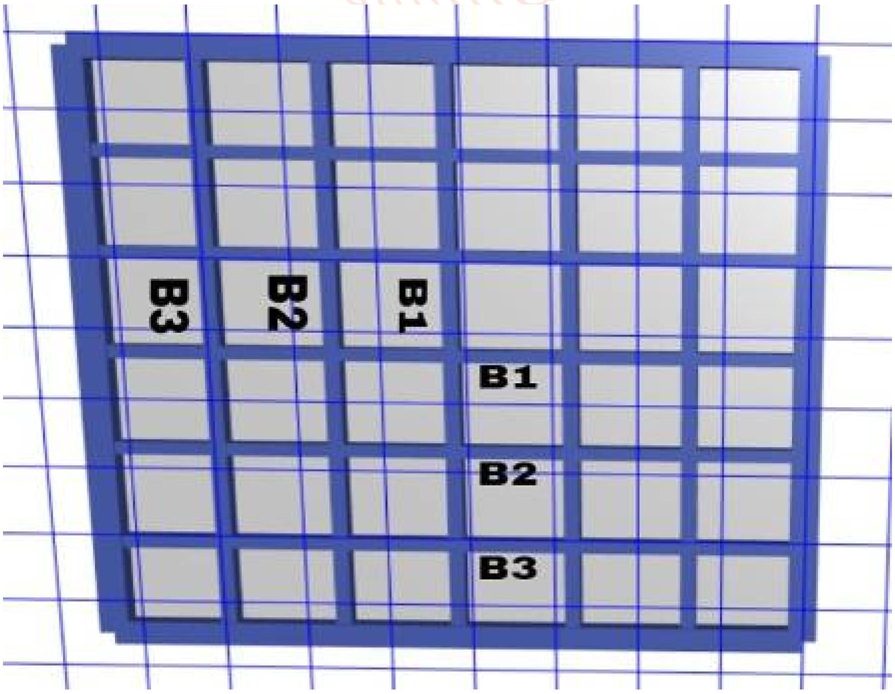


Fig 6: Orthogonal grid 3-D view with beam marking

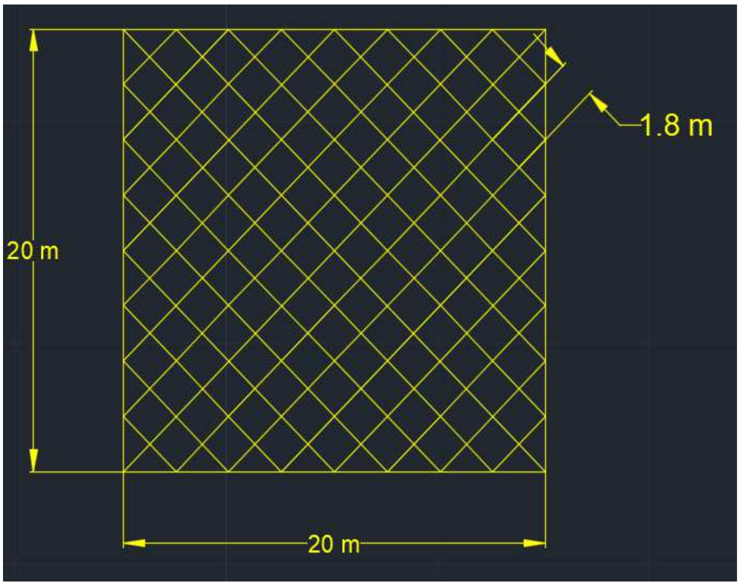


Fig 7: 20m x 20m diagonal grid

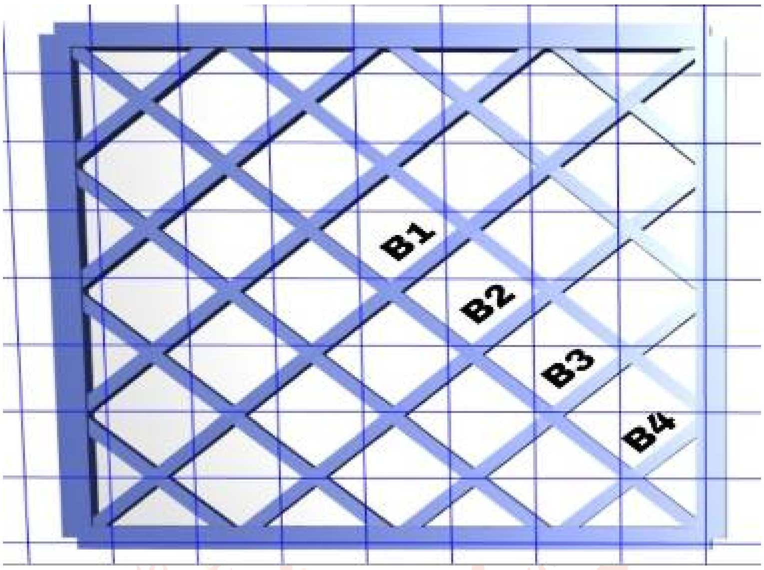


Fig 8: Diagonal grid 3-D view with beam marking

5. CONCLUSION

The present study is focused on orthogonal and diagonal grid slab analysis using E-TABS 2017 software for various grid panels with only live load acting on the slabs. Below stated are the conclusions drawn from the above analysis carried out

- Between Rankine–Grashoff, Plate analogy and Stiffness method, Rankine–Grashoff & Stiffness method results are almost same but Timoshenko's Plate analogy theory overestimates the shear force and bending moment.
- In case of orthogonal grid slabs, the bending moment of beams in grid slabs goes on decreasing towards the peripheral beams.
- In case of diagonal grid slabs, the bending moment decreases till certain beam and again starts to increases towards the peripheral beams.
- In diagonal slab the bending moment of mid span beam obtained from E-Tabs is much lesser when compared to the result obtained by using the formula **(W*2*L)/8**

Where, W = Shear force obtained from E-Tabs
L = Length of beam

This is because of its unique property of providing rigidity for bending and shear

- The bending moment of the peripheral beam is higher compared to mid span beam in diagonal grid slab.

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