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Comparative Study on High Rise RC Flat -Slab Building Performance for Lateral Loads with and without Diagrid System

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ABSTRACT

The latest trend in high rise building is diagrid structures because of structural and architectural effectiveness. In the study diagrids are provided for Flat-slab Building and detailed analysis is carried out to check the behavior of flat-slab buildings with and without diagrid. ETABS 16.2.0 software is used for modeling, analysis and designing of models. G+11 and G+23 storey buildings of plan size 36m x 36m with storey height 3.5m located at zone v are modeled, analyzed and designed. Equivalent static and response spectrum analyses are carried out and comparison are drawn between conventional building, flat-slab building and flat-slab building with diagrids in terms of base shear, top storey displacement, maximum storey drift and modal period. Flat-slab diagrid buildings are more lateral resistant than flat-slab buildings as top storey displacement and maximum storey drift are decreased. Flat-slab diagrid building with corner columns is more lateral resistant than flat-slab diagrid buildings without corner columns but flat-slab diagrid buildings without corner columns are spacious than flat-slab diagrid buildings with corner columns.Performance of flat-slab diagrid buildings depend on aspect ratio. Flat- slab diagrid building without corner columns requires higher diagrid member section than that of flat-slab diagrid building with corner columns.

Key Words: *Diagrid Structures, Flat-Slab Building, Flat-Slab Diagrid Building, ETABS*

1. INTRODUCTION

Diagrid structural system is a new design trend for tall buildings. It is the evolution of braced tube structure. It is structurally and architecturally effective and hence they are adopted in Tall buildings. Diagrids are provided at the perimeter of a building and they are represented by a narrow grid of diagonal members which resist both gravity and lateral load and hence diagonals act as both columns and bracing. They also do not require core as lateral shear are carried by diagonals. Diagrid structural system uses overall dimension of a plan to counteract overturning moment and through axial action of diagonals flexural rigidity is provided. Diagrid structures provide shear resistance and rigidity through axial action of diagonals. The angle obtained from the height of the storey module to the base width of the storey module is called diagrid angle. For the maximum bending rigidity the angle is 90˚ and for the maximum shear rigidity the angle is 35˚ and so to maintain both bending rigidity and shear rigidity the diagrid angle are maintained between 35˚ and 90˚. Diagrid angle increases as height of the Storey module increases. Diagrid angle depends on height and base of diagrid module. Triangular diagrid module is defined as the single level of diagrids that extend over multiple stories.

Flat-slab structural system is the structural system where reinforced concrete slabs are directly supported by concrete columns without the use of beams. Flat-slab is defined as one sided or two sided supported system with shear load of the slab being concentrated on the supporting columns and a square slab called ‘Drop panels’. Flat-slab building structures are beneficial over conventional slab-beam-column structures because of the free design of space, shorter construction time, and architectural – functional aspects. Flat-slab structural system is undoubtedly flexible for lateral loads than conventional RC frame system because of the absence of deep beams and shear walls and this makes the system more vulnerable under seismic events. Hence to improve seismic behavior of flat-slab, modification with additional construction elements is required.

Since high rise Flat-slab structures are flexible to lateral loads than gravity loads here the comparative study is carried out to check the behavior of flat-slab building and flat-slab building provided with diagrids at the periphery of the building for both gravity loads and seismic loads. The latest trend in high rise building is diagrid structures. Hence in this study diagrids are provided for Flat-slab Building and detailed analysis is carried out.

1.1 OBJECTIVES

1. Comparative study of behaviour of Flat-slab RC building with and without diagrid at the periphery of the structure in terms of base shear, top storey displacement, storey drift and time period.
2. To check the resistance of Flat-slab Diagrid Building against lateral loads.

2 METHODOLOGY

2.1 METHODOLOGY FALLOWED

1. Modeling of 12 storey conventional building, flat-slab building and flat-slab diagrid building with different diagrid angles.
2. Modeling of 24 storey conventional building, flat-slab building and flat-slab diagrid building with different diagrid angles.
3. Equivalent static and response spectrum analysis are carried out using ETABS 16.2.0 software.
4. Comparisons of the Results obtained from different models are done.
5. Conclusions are drawn.

2.2 STRUCTURAL MODELS

Table 2.1: Types of models considered for the study

Types of structures	Diagrid angle	No. of storey	
		Type 1 12 Storey (h/b=1.75) Model Name	Type 2 24 Storey (h/b=3.5) Model Name
Conventional frame building		M1	M7
Flat-slab building		M2	M8
Flat-slab diagrid building with corner columns			
2 Storey Module	41.18°	M3	M9
3 Storey Module	52.69°	M4	M10
4 Storey Module	60.25°	M5	M11
6 Storey Module	69.14°	M6	M12
8 Storey Module	74.05°		M13
Flat-slab Diagrid building without corner columns			
2 Storey Module	41.18°	M14	
3 Storey Module	52.69°		M15

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2.3 LOADS AND LOAD COMBINATION

The live load and the flooring load considered are 3kN/m2 and 1.05kN/m2 respectively.

Table 2.2: Parameters considered for earthquake load

Parameters	Consideration
Zone factor	0.36
Response reduction factor	3
Importance factor	1
Soil type	Hard soil
Damping	5%

Table 2.3: Load combinations considered for design and analysis

Load Combination	Load Combination Details
1	1.5(DL)
2	1.5(DL+LL)
3	1.2(DL+LL+EQX)
4	1.2(DL+LL-EQX)
5	1.2(DL+LL+EQY)
6	1.2(DL+LL-EQY)
7	1.5(DL+EQX)
8	1.5(DL-EQX)
9	1.5(DL+EQY)
10	1.5(DL-EQY)
11	0.9DL+1.5EQX
12	0.9DL-1.5RSX
13	0.9DL+1.5EQY
14	0.9DL-1.5EQY
15	1.2(DL+RSX)
16	1.2(DL+RSY)
17	1.5(DL+RSX)
18	1.5(DL+RSY)
19	0.9DL+1.5RSX
20	0.9DL+1.5RSY

2.4 MATERIALS AND SECTION PROPERTIES OF STRUCTURAL ELEMENTS

Table 2.4: Structural elements and their materials

Structural Element	Material		
	Concrete	Rebar	Steel
Column	M30	HYSD500	
Beam	M30	HYSD500	
Slab	M30	HYSD500	
Drop Panel	M30	HYSD500	
Diagrid			Fe250

Table 2.5: Section Properties of Structural Elements used in models

Type of building	Structural Elements	Sectional Properties (mm)
Conventional Building 12 Storeys	Beams	B450x600
	Columns	900x900,850x850,800x800,700x700,600x600
	Slab	200
Conventional Building 24 Stories	Beams	450x600
	Columns	1150x1150,1100x1100,1050,1050,900x900,850x850,800x800,700x700,600x600
	Slab	200
Flat Slab Building 12 Storeys	Columns	800x800,700x700,650x650,600x600
	Slab	250
	Drop Panel	500
Flat Slab Building 24 Storeys	Columns	1150x1150,1000x1000,950x950,900x900,850x850,800x800,750x750,700x700, 600x600
	Slab	250
	Drop Panel	500
Flat Slab Diagrid Building 12 Storeys	Columns	850x850, 800x800, 750x750, 700x700, 600x600
	Slab	250
	Drop Panel	500
	Diagrid	250 x 250 x 25 (tubular section)
Flat Slab Diagrid Building 24 Storeys	Columns	1100x1100,1050x1050,950x950,900x900,850x850,800x800,750x750,700x700, 600x600
	Slab	250
	Drop Panel	500
	Diagrid	300 x 300 X 30 (tubular section)
Flat slab Diagrid building Without Corner Columns 12 Storey	Columns	900x900, 850x850,800 x 800,700x700,600x600
	Slab	250
	Drop Panel	500
	Diagrid	300 x 300 x 30 (tubular section)
Flat Slab Diagrid Building without Corner Columns 24 Storey	Columns	1050x1050, 950x950, 900x900, 850x850, 800x800, 750x750, 700x700, 600x600
	Slab	250
	Drop Panel	500
	Diagrid	350 x 350 x 35 (tubular section)

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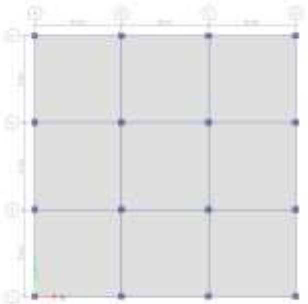
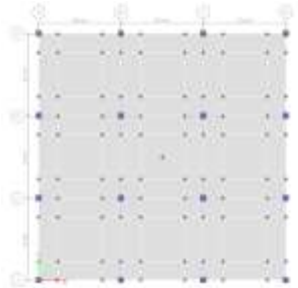
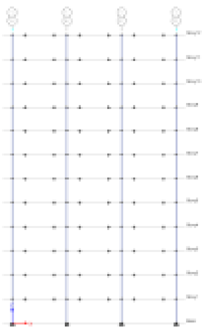




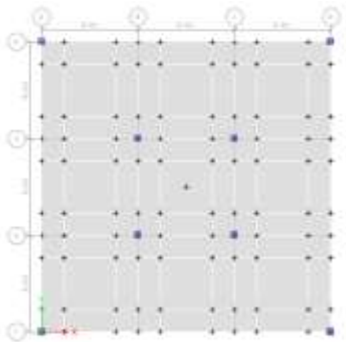
(a) (b)

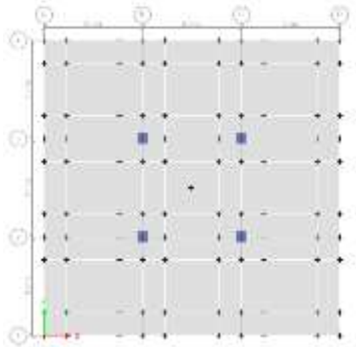
Figure 2.1 a and b: Plan of conventional building and flat-slab building respectively



(a) (b)

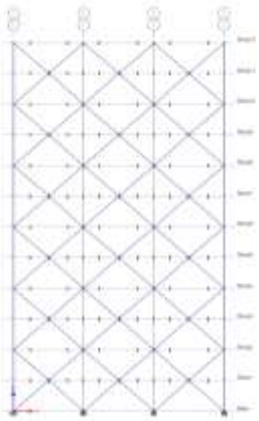
Figure 2.2 a and b: Elevation of 12 storey conventional and flat-slab building respectively

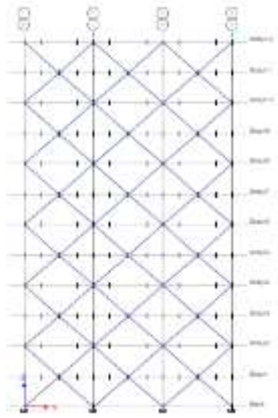




(a) (b)

Figure 2.3 a and b: Plan of flat-slab diagrid building with corner columns and without corner columns respectively.





(a) (b)

Figure 2.4 a and b: Elevation of 12 storey flat-slab diagrid building with diagrid angle 41.18° with corner columns and without corner columns respectively.

3 RESULTS AND DISCUSSIONS

The objective of this study is to compare the behavior of flat-slab building and flat-slab diagrid building to find the resistance of flat-slab diagrid building for lateral loads. Here all the models are designed for the gravity load, lateral loads and the combination of loads considered. Equivalent static analysis and Response spectrum analysis is carried out and the results are drawn. The results drawn are in terms of model period, base shear, story drift and story displacement.

3.1 Base shear of type 1 and type 2 models for the load combination 7

Table 3.1: Base shear of type 1 models

Model	Base Shear in kN
M1	2734.94
M2	2863.95
M3	10526.76
M4	9270.88
M5	8921.62
M6	7190.55
M14	8042.44

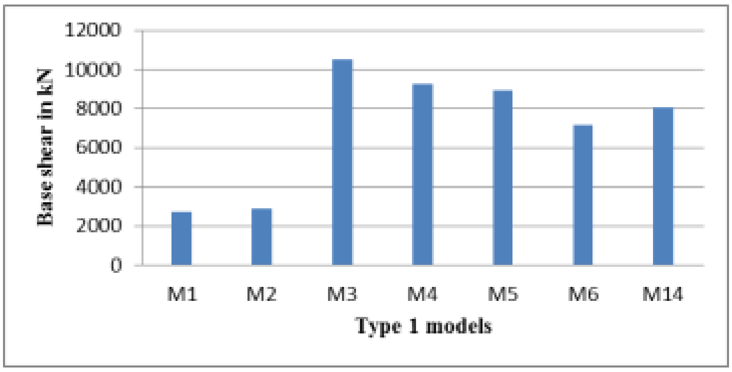


Figure 3.1: Base shear of type 1 models

Table 3.2: Base shear of type 2 models

Model	Base Shear in kN
M7	3117.96
M8	3163.04
M9	8865.03
M10	8557.22
M11	7484.21
M12	6513.49
M13	5870.09
M15	6913.98

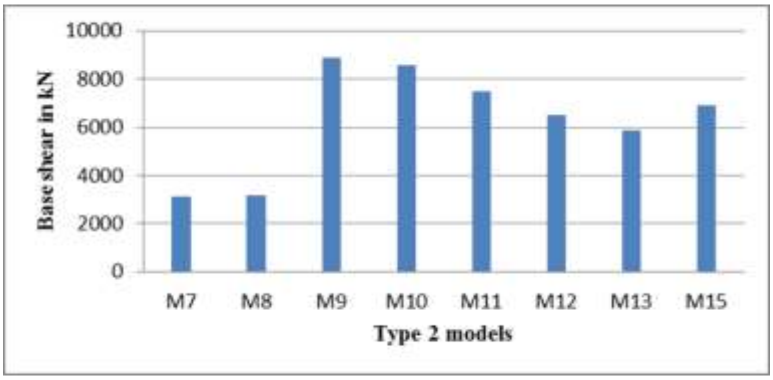


Figure 3.2: Base shear of type 2 models

3.2 Modal time period of type 1 and type 2 models

Table 3.5: Modal time period of type 1 Models

Model	Modal Period
M1	1.94
M2	2.01
M3	0.59
M4	0.59
M5	0.69
M6	0.86
M14	0.47

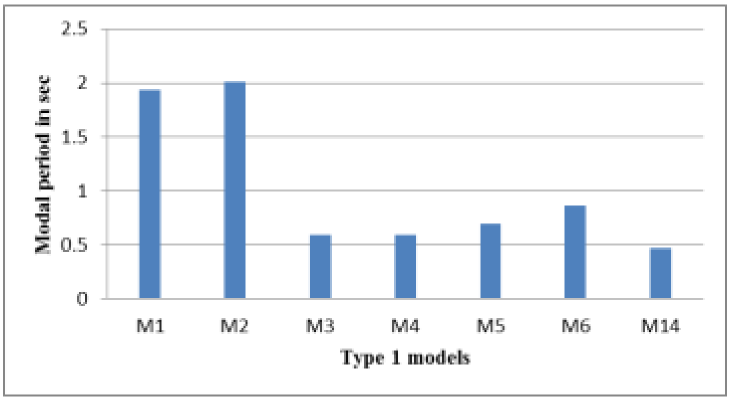


Figure 3.5: Modal time period of type 1 models

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Table 3.6: Modal time period of type 2 models

Model	Modal Period
M7	0.42
M8	0.48
M9	0.09
M10	0.13
M11	0.14
M12	0.22
M13	0.28
M15	0.12

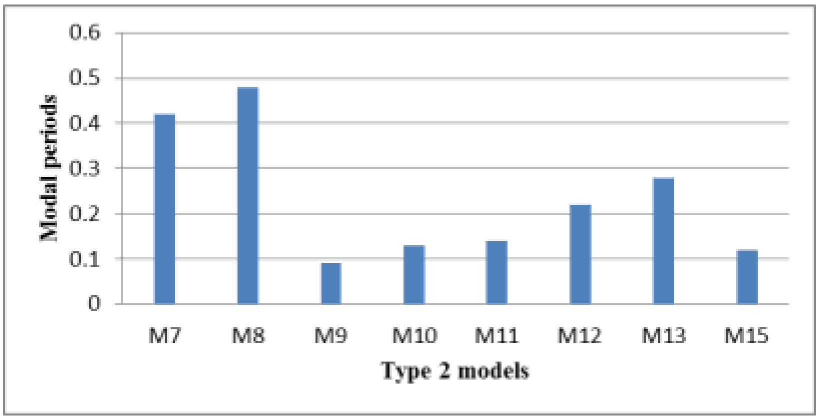

Figure 3.6: Modal time period of type 2 models

3.3 Top storey displacement of type 1 and type 2 models for the load combination 7

Table 3.6: Top storey displacement of type 1 models

Models	Top Storey Displacement
M1	83.15
M2	86.03
M3	27.09
M4	26.3
M5	30.06
M6	35.85
M14	37.72

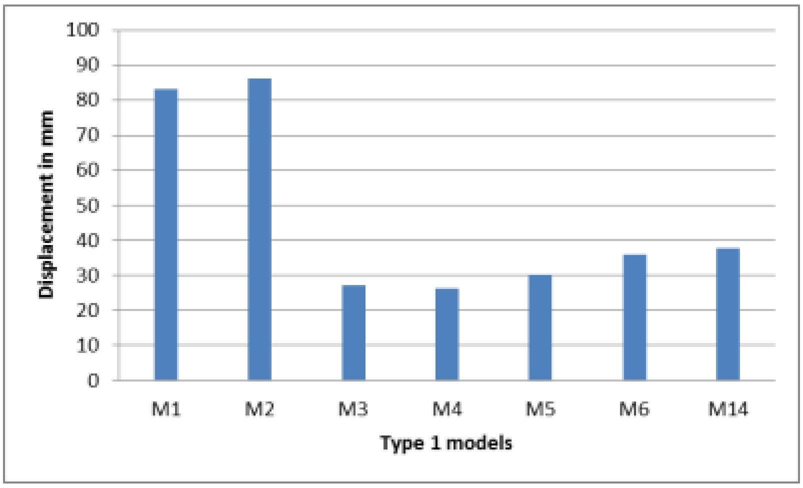

Figure 3.7: Top storey Displacement of type 1 models

Table 3.7: Top storey displacement of type 2 models

Models	Model Period
M7	170.86
M8	177.95
M9	80.24
M10	75.89
M11	75.72
M12	81.17
M13	89.41
M15	95.12

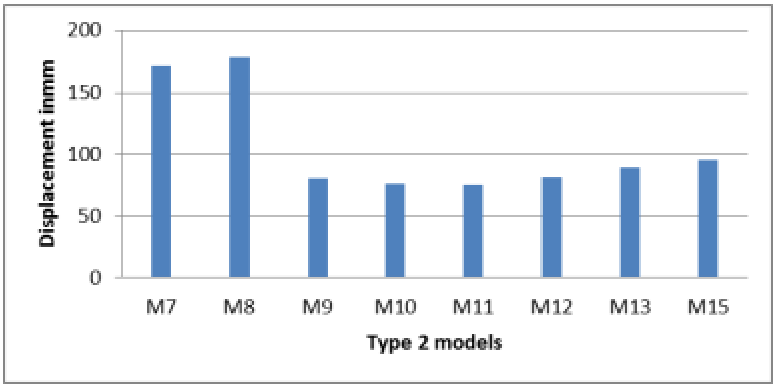

Figure 3.8: Top storey Displacement of type 2 models

3.4 Maximum Storey drifts of type 1 and type 2 models for the load combination 7

Table 3.8: Maximum Storey drifts of type 1 models

Models	Max. Drift
M1	0.0026
M2	0.0027
M3	0.0007
M4	0.0008
M5	0.0009
M6	0.0011
M14	0.0011

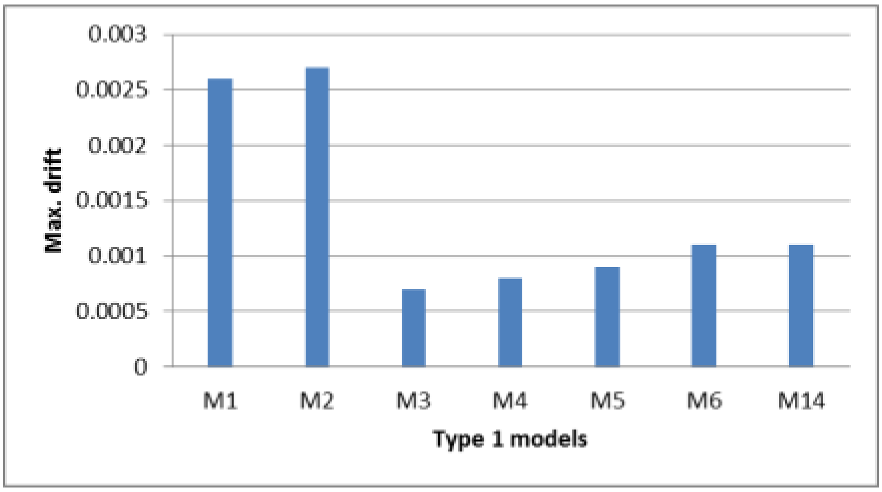

Figure 3.9: Maximum Storey drifts of type 1 models

Table 3.8: Maximum Storey drifts of type 2 models

Models	Max. Drift
M7	0.0026
M8	0.0027
M9	0.0013
M10	0.0012
M11	0.0012
M12	0.0012
M13	0.0016
M15	0.0015

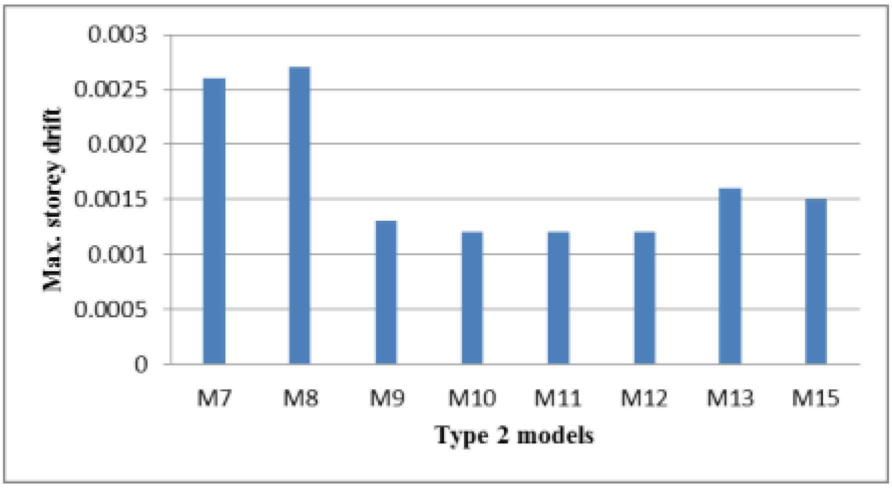

Figure 3.9: Maximum Storey drifts of type 2 models

4 CONCLUSIONS

1. In flat-slab Diagrid buildings with corner columns,
   a. Top Storey displacement Decreases by 68 % in type-1 building with diagrid angle 41.18˚ (M3) and by 57 % in type-2 building with diagrid angle 52.69˚ (M10) than type-1 (M2) and type-2 (M8) flat-slab buildings respectively.
   b. Maximum Drift ratio decreases by 72% in type-1 building with diagrid angle 41.18˚ (M3) and by 55% in Type 2 building with 52.69˚ (M10) than that of type-1 (M2) and type-2 (M8) flat-slab buildings respectively.
   c. Time period decreases by 70% in type-1 building with diagrid angle 41.18˚ and by 63% in type-2 building with diagrid angle 52.69˚ than that of type-1(M2) and type-2 (M8) flat-slab buildings respectively.
   d. Base Shear increases by 3.67 times in type-1 (12 storeys) building with diagrid angle 41.18˚ (M3) and by 2.7 times in type-2 (24 storeys) building with diagrid angle 52.69˚ (M10) than that of type-1 (M2) and type-2 (M8) flat-slab buildings respectively.

   By the above findings it is concluded that flat slab diagrid buildings are more laterally resistant than flat slab buildings as top storey displacement and maximum storey drift are decreased.

2. In flat-slab diagrid buildings without corner columns,

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a. Top Storey displacement increases by 39 % in type-1 building with diagrid angle 41.18˚ (M14) and by 25% in type-2 building with diagrid angle 52.69˚ (M15) than that of type-1(M3) and type-2 (M10) flat-slab diagrid buildings with corner columns with diagrid angle 41.18˚ and 52.69˚ respectively.
b. Maximum Drift ratio increases by 57% in type-1 building with diagrid angle 41.18˚ (M14) and by 15% in type- 2 building with 52.69˚ (M15) than that of flat-slab diagrid buildings with corner columns with diagrid angle 41.18˚ (M14) and 52.69˚ (M15) buildings respectively.

By the above findings it can be concluded that flat-slab diagrid building with corner columns is more laterally resistant than flat-slab diagrid buildings without corner columns but flat-slab diagrid buildings without corner columns are spacious than flat-slab diagrid buildings with corner columns.

3.

a. In type-1 buildings with aspect ratio 1.75, flat-slab diagrid building with diagrid angle 41.18˚ has less top storey displacement (27.09mm) and less maximum storey drift (0.0007) compared to flat-slab diagrid buildings with diagrid angle 52.69˚, 60.25˚ and 69.14˚.
b. In type-2 buildings with aspect ratio 3.5, flat-slab diagrid building with diagrid angle 52.69˚ has less top storey displacement (75.89mm) and less maximum storey drift (0.0012) compared to other flat-slab diagrid buildings with diagrid angle 41.18˚, 60.25˚, 69.14˚ and 74.05˚.

As the aspect ratio increases, range of optimum diagrid angle increases from 41.18˚ to 52.69˚, hence with these observations it can be concluded that performance of flat-slab diagrid buildings depends on aspect ratio.

4.

a. Type-1 building M14 (without corner columns) required diagrid member dimension 300mm x 300mm x 30mm(tubular section) and type-1 building M3 (with corner columns) required 250mm x 250mm x 25mm(tubular section)
b. Type-2 building M15(without corner columns) required diagrid dimension 350mm x 350mm x 35mm(tubular section) type-2 building M10(with corner columns) required diagrid dimension 300mm x 300mm x 30mm(tubular section),

Hence it is concluded that flat-slab diagrid building without corner columns requires higher diagrid member section than that of flat-slab diagrid building with corner columns.

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