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 | 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          |               |                                        |                                        |
| 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          |               |                                        |                                        |
| 2 Storey Module                     | 41.18°        | M14                                    |                                        |
| 3 Storey Module                     | 52.69°        |                                        | M15                                    |
2.3 LOADS AND LOAD COMBINATION
The live load and the flooring load considered are 3kN/m² and 1.05kN/m² respectively.

| 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-EQY)             |
| 9                | 1.5(DL-EQY)             |
| 10               | 1.5(DL-EQX)             |
| 11               | 0.9DL+1.5EQX            |
| 12               | 0.9DL+1.5EQY            |
| 13               | 0.9DL+1.5EQX            |
| 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

| Structural Element | Material |
|--------------------|----------|
| Column             | M30      |
| Beam               | M30      |
| Slab               | M30      |
| Drop Panel         | M30      |
| Diagrid            | Fe250    |
| Type of building | Structural Elements | Sectional Properties (mm) |
|------------------|---------------------|--------------------------|
| **Convention al Building** | | |
| 12 Storeys | Beams | B450x600 |
| | Columns | 900x900, 850x850, 800x800, 700x700, 600x600 |
| | Slab | 200 |
| 24 Storeys | Beams | 450x600 |
| | Columns | 1150x1150, 1100x1100, 1050x900, 900x850, 800x800, 700x700, 600x600 |
| | Slab | 200 |
| **Flat Slab Building** | | |
| 12 Storeys | Columns | 800x800, 700x700, 650x650, 600x600 |
| | Slab | 250 |
| | Drop Panel | 500 |
| 24 Storeys | Columns | 1150x1150, 1000x1000, 950x950, 900x900, 850x800, 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) |
| 24 Storeys | Columns | 1100x1100, 1050x1050, 950x950, 900x900, 850x800, 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, 800x800, 700x700, 600x600 |
| | Slab | 250 |
| | Drop Panel | 500 |
| | Diagrid | 300 x 300 x 30 (tubular section) |
| 24 Storey | Columns | 1050x1050, 950x950, 900x900, 850x850, 800x800, 750x750, 700x700, 600x600 |
| | Slab | 250 |
| | Drop Panel | 500 |
| | Diagrid | 350 x 350 x 35 (tubular section) |
Figure 2.1 a and b: Plan of conventional building and flat-slab building respectively.

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

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

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
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,
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. 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. 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.

REFERENCES

1. Ema coelho, Paulo candeias, Giorgios anamateros, Raul zaharia, Fabio taucer, Artur v. Pinto, “Assessment of the seismic behaviour of RC flat slab Building structures”, 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada, Paper No. 2630, 2004.
2. Giovanni Maria Montuori , Elena Mele, Giuseppe Brandonisio, Antonello De Luca, “Geometrical patterns for diagrid buildings: Exploring alternative design strategies from the structural point of view”, Engineering Structures,vol.71, pp.112-127, 2014.
3. Harshita Tripathi, Dr,Sarita Singla, “Diagrid Structural system for R.C. Framed multi storeyed Buildings”, International Journal of Scientific and Engineering Research,vol.7, 2016.
4. Khushbu jania, Paresh V. Patel. “Analysis and Design of Diagrid Structural System for high Rise Steel Buildings”, Procedia Engineering, vol.51, pp. 92 -100, 2013.
5. Kiran Kamath, Sachin Hirannaiah, Jose Camilo Karl Barbosa Noronha, “ An analytical study on performance of a diagrid structure using non-linear static pushover analysis”, Perspectives in Science,vol.8, pp.90-92, 2016.
6. Kyoung-sun moon, Jerome j. Connor and john E. Fernandez, “Diagrid Structural Systems for tall buildings: Characteristics and Methodology for preliminary design”, The structural design of tall and special buildings, vol.16, pp.205-230, 2007.
7. Mir M. Ali & Kyoung Sun Moon (2007), “Structural Developments in Tall Buildings: Current Trends and Future Prospects”, Architectural Science Review, vol. 50:3, pp. 205-223, 2007.
8. Rohit Kumar singh, Dr.Vivek garg, Dr. Abhay sharma, “ Analysis and design of concrete diagrid building and its comparison with conventional frame building”, international journal of science, engineering and technology, vol.2, 2014.
9. R.P. Apostolska, G.S. Nceevska-Cvetanovska, J.P.Cvtanovska and N.Miric, “Seismic performance of flat-slab building structural systems”, The 14th world Conference on Earthquake Engineering, Beijing, China, 2008.
10. Saket Yadav, Dr.Vivek Garg, “Advantage of steel Diagrid Building Over Conventional Building”, International Journal of Civil and Structural Engineering Research, vol.7, 2015.
11. IS:456:2000, “Plain and Reinforced concrete code of practice”
12. IS:875 (Part 1) - 1987, “Code of practice for design loads (other than earthquake) for buildings and structures”
13. IS:875 (Part 2) - 1987, “Code of practice for Design loads (other than earthquake) for buildings and structures”
14. IS:1893 (Part 1) - 2002, “Criteria for earthquake resistant design of structures”
15. IS:800 - 2007, “General construction in steel - code of practice”