

Investigation of Diagrid Structural System for High Rise Buildings Subjected to Mass and Torsional Irregularities

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ABSTRACT: The rise in urban population, economic prosperity and unavailability of land leads to the construction of high rise structures. Increasing the height of the building increases the importance of lateral load resisting system than structural system that resists gravitational loads. The diagrid structural systems are preferred nowadays due to its structural efficiency and its aesthetic potential provided by the unique configuration. The diagrid or diagonal grid structural system can be defined as a diagonal member which is formed as a framework provided by the intersection of different materials like metals, concrete or wooden beams, used in the construction of roofs and buildings. This paper mainly deals with the performance of diagrid steel structures with mass irregularity and torsional irregularity. A 36 storey steel diagrid structure with a regular floor plan of 36 m X 36 m is considered. ETABS software is used for modelling and analysis. Comparison of analysis results in terms of time period, storey drift, storey shear and storey displacement is studied.

KEYWORDS: Diagrid, Mass irregular buildings, Time period, Storey displacement, Storey drift, storey shear.

I. INTRODUCTION

The fast growth of urban population and limited availability of land considerably influenced the development of city. The high cost of land, the wish to avoid a continuous conurbation and the need to maintain important agricultural production have all contributed to force residential building upwards. The increasing height of the building increases the importance of lateral load resisting system than structural system that resists gravitational loads. Widely used lateral load resisting systems are rigid frame, shear wall, wall-frame, braced tube system, outrigger system and tubular system. Diagrid (or diagonal grid) structural system are widely used for its structural efficiency and aesthetic potential provided by the unique geometric configuration in tall buildings. The common examples of diagrid structure all around the world are Hearst Tower in New York, Swiss Re in London, Capital Gate Tower in Abu Dhabi and Jinling Tower in China. Recently, diagrid structures gained increasing attention among both designers and researchers of high rise buildings for creating one of a kind signature structures. Diagrid is in the form of a space truss. It includes perimeter grid made up of a series of triangulated truss system. Diagrid is formed by the intersection of diagonal and horizontal components. Due to their triangulated configuration, diagonal members in diagrid structural system can carry gravity and lateral loads. According to IS 1893 Part I: 2002, Mass irregularity in building is considered when the seismic weight of any storey is more than 200% of that of its adjacent stories. Torsional irregularity can be interpreted as the ratio of maximum drift to the average drift of the individual story. When maximum story drift at one side of the structure transverse to an axis is more than 1.2 times the mean of the story drift at the two closures of the structure, torsional irregularity is considered. $\Delta 1$ and $\Delta 2$ are the story drift (or inter-story drifts) at the two ends of the structure. Relative eccentricity is generally considered the main factor influencing the torsional effects.

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II. OBJECTIVES

- To examine the response of high rise buildings with diagrid system.
- To conduct static analysis on diagrid structures.
- To study the response of structure under seismic loadings.
- To study the performance of structures with varying mass distribution for different heights (ie., at 36th, 30th, 25th, 20th, 15th, 10th, 5th storey).
- To examine torsional irregularities with different mass eccentricities (5%, 10%, 15%, 20% and 25%).
- To analyse the structure on the basis of base shear, storey drift, displacement and time period.

III. BUILDING DESCRIPTION

The building details and sectional properties of all the models used in the analysis are given in Table 1 and Table 2.

Table 1 Building Details

No. of storey	36
Plan area	36 m x 36 m
Floor height	3.6 m
Type of slab	shell element
Inclined column spacing	6 m
No. of bays in x and y direction	6
Type of frame	steel
Steel sections	Fe 250
Dead load	3.75 KN/m ²
Wind speed	30 m/sec
Terrain category	III
Zone factor	0.16
Soil type	Medium
Importance factor	1

Table 2 Girder Section Properties of the Model

Diagonal columns	<ol style="list-style-type: none"> 1. Pipe section - 450 mm x 25 mm (From 1st to 18th storey). 2. Pipe section - 375 mm x 12 mm (From 19th to 36th storey).
Interior columns	1000 mm x 1000 mm
Beams	Beam 1 : ISMB 550 Beam 2 : ISWB 600 Top and bottom cover plate : 220 x 50mm
Slab	120 mm

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Vol. 8, Issue 8, August 2019

In order to mass irregularity models from each other, various abbreviations are used. Table 3 shows mass distributions done at different levels.

Table 3 Mass Distributions at Different Levels

Cases	Mass Variation
MI – 36S	at 36 th storey
MI – 30S	at 30 th storey
MI – 25S	at 25 th storey
MI – 20S	at 20 th storey
MI – 15S	at 15 th storey
MI – 10S	at 10 th storey
MI – 5S	at 5 th storey
MI – 0S	With no variation

For example, MI1 – 36S denotes Model 1, MI2 – 36S for the Model 2 and MI3 – 36S for Model 3 with mass variation done at 36th storey. MI-0S shows model with no mass variation.

IV. MODELLING OF STRUCTURE

Description of Models

3 models with varying distribution of mass for different heights (i.e. at 36th, 30th, 25th, 20th, 15th, 10th, 5th storeys) in plan which is compared with the same model without varying mass and 3 models with varying mass eccentricities of 5%, 10%, 15%, 20% and 25% are considered. For varying masses a live load of 25 KN/m² is given at different heights (i.e. at 36th, 30th, 25th, 20th, 15th, 10th, 5th storey). Floor-to-floor height for every storey is 3.6 m. ETABS software is used for modelling of the structures. Elevations and 3D view of the models 1, 2 and 3 are given in Fig 1 and Fig 2 respectively. The regular floor plan is shown in Fig 3.

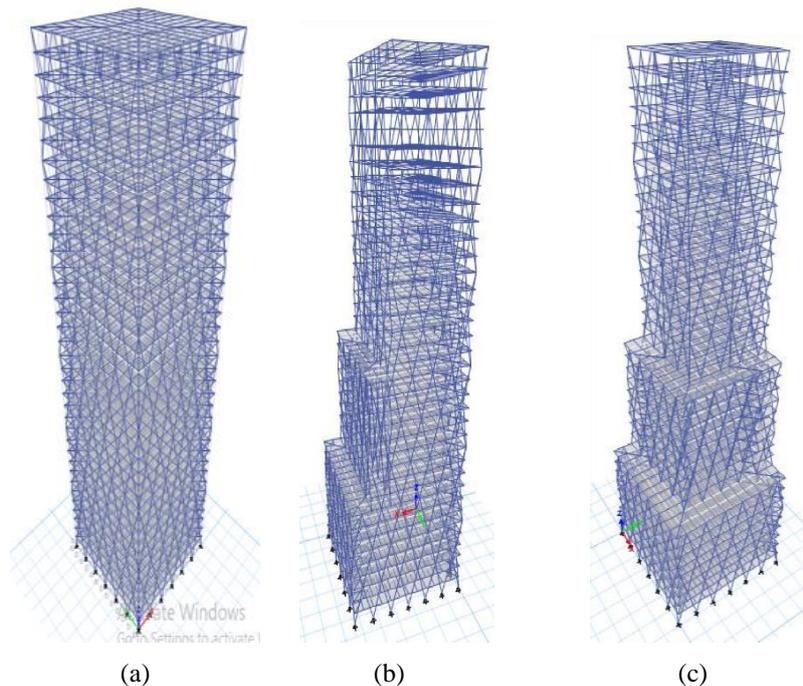


Fig. 1. 3D view (a) Model 1 (b) Model 2 (c) Model 3

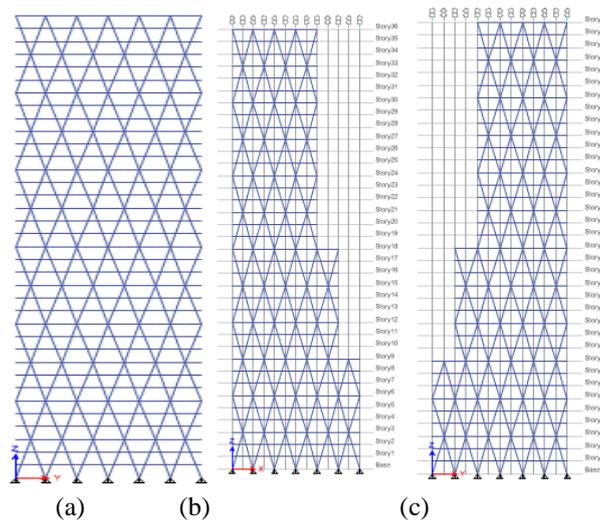


Fig. 2. Elevation (a) Model 1 (b) Model 2 (c) Model 3

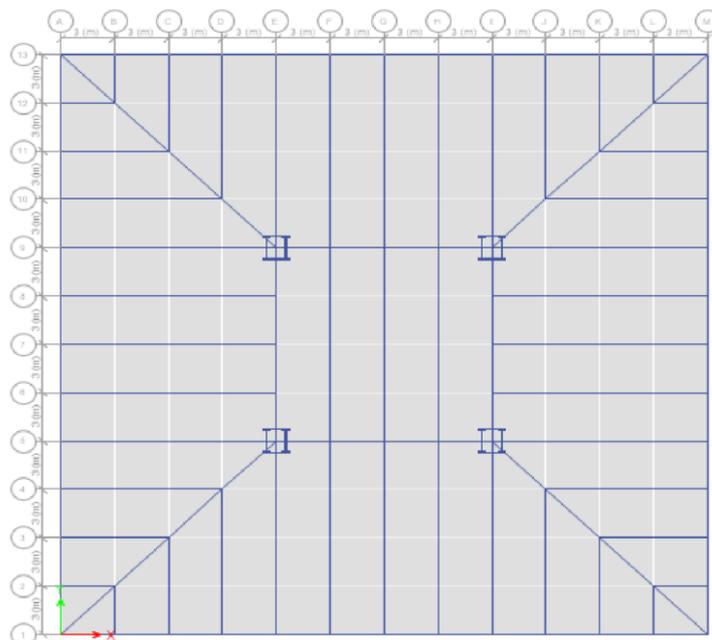


Fig. 3. Plan of Model

V. RESULTS AND DISCUSSIONS

Mass Irregularity

After analysing the specimens, the time period, storey shear, maximum storey displacement, and maximum storey drift were obtained. Figures and tables of the results are given below. For all the 3 models, maximum storey drift is less for MIR-20S and Store shear is less for MIR-36S. The structures with mass irregularity is compared with results of MI – 0S which is the model with no mass variation. The time period, maximum storey displacement, storey drift and storey shear obtained are within the limit specified by IS 1893 (Part 1): 2002. Table 4 to 6 shows results obtained from analysis. The Storey vs. Displacement graph of the 3 Models are shown from Fig 4 to Fig 6.

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Vol. 8, Issue 8, August 2019

Table 5 Results of Model 1

Models	Time Period in sec	Max Storey Displacement in mm	Max storey Drift	Storey Shear kN
MI1 – 36S	3.496	42.402	0.000477	1856
MI1 – 30S	3.471	41.31	0.000476	2007
MI – 25S	3.296	40.696	0.000478	1969
MI – 20S	3.21	40.176	0.000463	2022
MI – 15S	3.161	41.554	0.000477	2053
MI – 10S	3.136	42.381	0.00049	2070
MI – 5S	3.123	42.984	0.000498	2078
MI – 0S	3.117	39.854	0.000469	1922

Table 6 Results of Model 2

Models	Time Period in sec	Max Storey Displacement in mm	Max storey Drift	Storey Shear kN
MI1 – 36S	3.499	50.66	0.000628	1484
MI1 – 30S	3.366	48.259	0.000619	1542
MI – 25S	3.256	47.864	0.000615	1595
MI – 20S	3.165	48.477	0.000598	1639
MI – 15S	3.129	49.795	0.00062	1683
MI – 10S	3.105	50.94	0.000639	1696
MI – 5S	3.097	52.461	0.000659	1726
MI – 0S	3.095	48.109	0.000605	1574

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Vol. 8, Issue 8, August 2019

Table 7 Results of Model 3

Models	Time Period in sec	Max Storey Displacement in mm	Max storey Drift	Storey Shear kN
MI1 – 36S	2.968	49.359	0.000588	1436
MI1 – 30S	2.873	47.001	0.000575	1484
MI – 25S	2.793	46.455	0.000569	1526
MI – 20S	2.724	46.893	0.00055	1565
MI – 15S	2.701	48.197	0.00057	1622
MI – 10S	2.67	49.548	0.000591	1641
MI – 5S	2.662	51.973	0.000622	1701

For all the 3 models used in the analysis of mass irregularity i.e. MI1, MI2 and MI3, time period obtained is less for MI-5S (i.e. mass variation done at 5th storey). Maximum storey displacement is less for MI2-25S and MI3 - 25S and for model 1, mass irregularity done at 20th storey (i.e. MI1 - 20S) shows less maximum storey displacement.

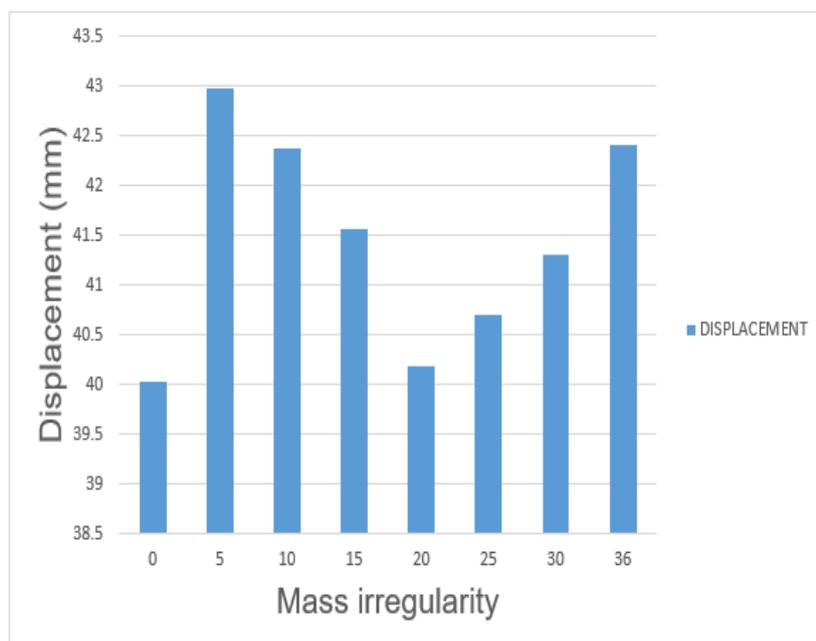


Fig. 4. Storey vs. Displacement graph of Model 1

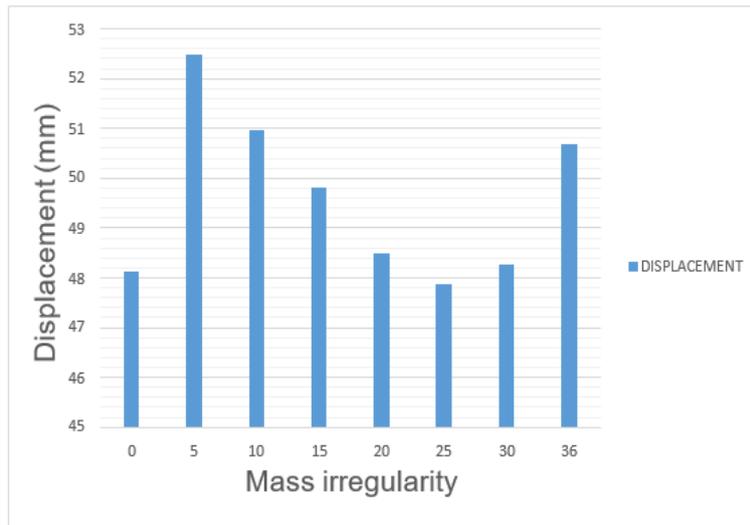


Fig. 5. Storey vs. Displacement graph of Model 2

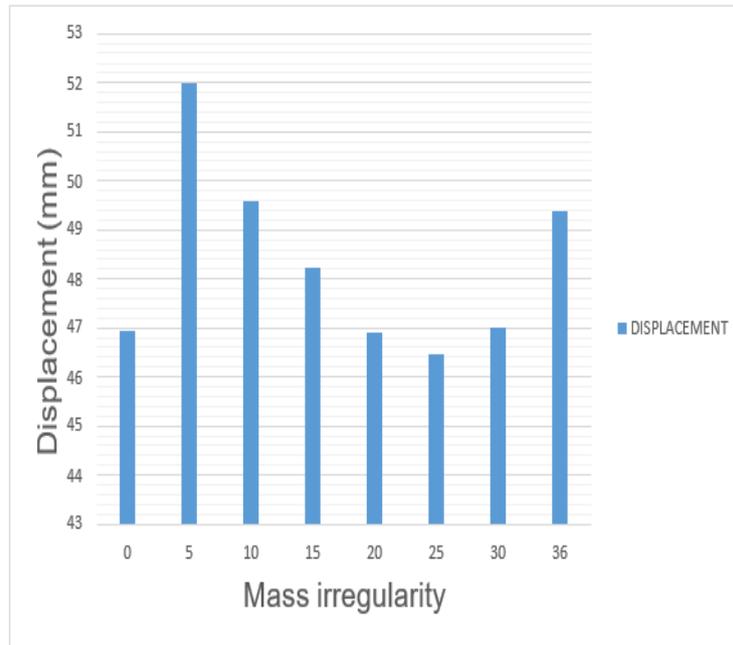


Fig. 6. Storey vs. Displacement graph of Model 3

Torsional Irregularity

After analyzing the models, the storey drifts (or inter-storey drift) at the two ends of the structure was found. The ratio of maximum storey drift to average storey drift was calculated. Table 7 to Table 9 shows inter-storey drift obtained corresponding to the given eccentricities for the models. The parameter criterion θ for torsion were also calculated. If θ obtained is 1.2 or more, torsional irregularity was considered. From the results, the parameter criterion of torsion, θ obtained is less than 1.2, so all the models checked for torsional irregularity is safe from torsional irregularity. Where Δ_{max} is the maximum storey drift and Δ_{avg} is the average storeydrift.

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Vol. 8, Issue 8, August 2019

Table 7 Results from the Analysis of Model 1

Eccentricity	Δ_{\max}	Δ_{avg}	$\theta = \Delta_{\max}/\Delta_{\text{avg}}$
5%	0.000288	0.000288	1
10%	0.000317	0.000317	1
15%	0.000468	0.000468	1
20%	0.000529	0.000529	1
25%	0.000586	0.000586	1

Table 8 Results from the Analysis of Model 2

Eccentricity	Δ_{\max}	Δ_{avg}	$\theta = \Delta_{\max}/\Delta_{\text{avg}}$
5%	0.000331	0.000333.5	1.007
10%	0.000427	0.000419	1.01
15%	0.000514	0.000497	1.03
20%	0.000580	0.000519	1.11
25%	0.000613	0.000528	1.16

Table 9 Results from the Analysis of Model 3

Eccentricity	Δ_{\max}	Δ_{avg}	$\theta = \Delta_{\max}/\Delta_{\text{avg}}$
5%	0.000326	0.000319	1.02
10%	0.000386	0.000364	1.06
15%	0.000428	0.000392	1.09
20%	0.000518	0.000470	1.1
25%	0.000583	0.000489	1.17

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Vol. 8, Issue 8, August 2019

VI.CONCLUSION

In the above structural models, linear static and dynamic analysis is done to investigate the performance of models with mass irregularity done at different levels. From the above study following conclusions are made.

- For Model 1, Model 2 and Model 3, time period obtained is better in mass irregularity done at 5th storey.
- For Model 1, Model 2 and Model 3, storey shear is less in mass irregularity done at 36th storey
- For Model 1, maximum storey displacement and storey drift is less in mass irregularity done at 20th storey.
- For Model 2 and Model 3, maximum storey displacement obtained is less for mass irregularity done at 25th storey and storey drift is less in mass irregularity done at 20th storey due to vertical asymmetry.
- The parameter criterion torsion, θ of Model 1, Model 2 and Model 3 are under the limit of torsional irregularity, so the models are safe from torsional irregularity
- With increase in eccentricity, torsional parameter also increases.

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