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Diagrid High Rise Steel Structure and Analysis Using E-tab

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ABSTRACT: In recent trends, the construction development has been rapidly increasing towards tall building structures. For “stiffness” and “lightness” to structural system has been evaluated based on new structural concept with newly adopted high strength materials and construction methods. Recently different structural system like braced tub structure, spaced truss, Diagrid structural system, etc. Are adopted in tall building due to its structural efficiency and flexibility in architectural planning. Diagrid structure consists of inclined columns on the exterior surface of building, compared to closely spaced vertical columns in framed tube.

Diagonalized grid structures have emerged as one of the most innovative and adaptable approaches to structuring buildings in this millennium. Variations of the diagrid system have evolved to the point of making its use nonexclusive to the tall building. Diagrid construction is also to be found in a range of innovative midrise steel projects. Comparison of analysis results in terms of time period, storey displacement, storey shear and storey drift with conventional building. And concrete diagrid structure is analysed and compared with conventional concrete building. Structural design of high-rise buildings is governed by lateral loads due to earthquake.

KEYWORDS: RCC Frame structure, Bracing, Lateral displacement, Wind Analysis, Earthquake Analysis.

I. INTRODUCTION

The origins of diagrid typology lie at the crossroads of engineering and architecture. Initial explorations were done by the Russian Er. Vladimir Shukhov. It is significant that Norman Foster has referenced the work of Shukhov as an inspiration for his diagrid exploration. This affirms the role of Shukhov’s tower as a precedent for building such as the Swiss Re tower and the Hearts Magazine Tower. It also allows us to examine the changes that were made to method of detailing and construction. This was a tremendous change in role of structure, with significant implications on design, detailing, and construction.

Actually, Tall buildings is emerged in the late nineteenth century in the U.S.A. They constituted a so-called “American Building Type,” meaning that most important tall buildings were built in the U.S.A. Today, they are a worldwide architectural phenomenon. Many tall buildings are built worldwide, especially in Asian countries, such as China, Korea, Japan, and Malaysia. Based on data available and published in the 1980s, about 49% of the world’s tall buildings were located in North America. The distribution of tall buildings has changed radically with Asia now having the largest share with 32%, and North America’s having 24%. This data demonstrates the rapid growth of tall building construction in Asian countries during this period while North American construction has slowed. In fact, eight of the top ten tall buildings are now in Asia and only two of them namely- the Sears Tower and the Empire State Building, are in North America.

A. What is Diagrid: -Diagrid is the combination of words - ‘Diagonal’ ‘Grid’ = Diagrid.

Diagrid is formed by Intersecting the diagonal and horizontal components. Diagrid buildings are widely used for tall steel buildings due to its **structural efficiency and aesthetic potential** provided by the unique geometric configuration of the system. A diagrid structure is a form of a space truss which is effective in reducing shear deformation, as they carry the lateral load by an axial action of diagonal members. Diagrid structure consists of perimeter grid made up of series of triangulated truss system. Diagrid structural system that is single-thickness in nature and gains its structural

integrity through the use of triangulation. Perimeter diagrid normally carry the lateral and gravity loads of the building and are used to support the floor edges.

There are some engineering-based reasons that would suggest the use of a diagrid Some of them are:

- Increased the stability due to triangulation.
- Combination of the gravity and lateral load-bearing systems, potentially providing more efficiency.

B. Load Transfer Diagram Diagrid:

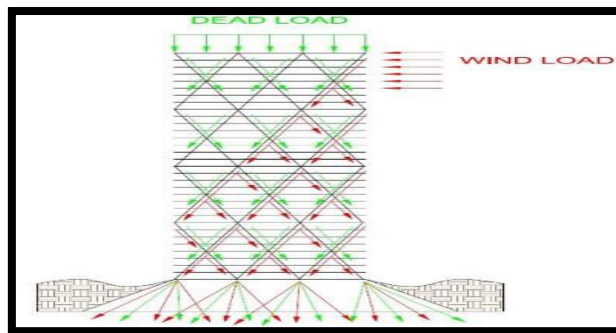


Fig no.1

The Distribution of Load In Diagrid Structure

The term “diagrid” is a combination of the words “diagonal” and “grid” and refers to a structural system that is single-thickness in nature and gains its structural integrity through the use of triangulation. Perimeter diagrids normally carry the lateral and gravity loads of the building and are used to support the floor edges. There are engineering-based reasons that would suggest the use of a diagrid. Some of them are:

1. Increased the stability due to triangulation.
2. Combination of the gravity and lateral load-bearing systems, potentially providing more efficiency.
3. Provision of alternate load paths (redundancy) in the event of a structural failure (which lacks in case of conventional framed building).
4. Reduced weight of the superstructure can translate into a reduced load on the foundations.

C. Merits of Diagrid Structure:

- The diagrid structures have mostly column free exterior and interior, hence free and clear, unique floor plans are possible.
- The use of diagrids results in roughly 20% reduction in steel as compared to braced frame structures.
- The construction techniques involved are simple, yet they need to be perfect.
- The diagrids make maximum exploitation of the structural material.
- The diagrid structures are aesthetically dominant and expressive.

. Demerits of Diagrid Structure: -

- As of yet, the Diagrid Construction techniques are not thoroughly explored.
- Lack of availability of skilled workers, Construction crews have little or no experience creating a Diagrid skyscraper.
- The Diagrid can dominate aesthetically, which can be an issue depending upon design intent.
- The Diagrid is heavy-handed if not executed properly.

II. RELATED WORK

In recent trends, the construction development has been rapidly increasing towards tall building structures. For “stiffness” and “lightness” to structural system has been evaluated based on new structural concept with newly adopted high strength materials and construction methods. Recently different structural system like braced tub structure, spaced truss, Diagrid structural system, etc. Area adopted in tall building due to its structural efficiency and flexibility in architectural planning. Diagrid structure consists of inclined columns on the exterior surface of building, compared to closely spaced vertical columns in framed tube.

III. METHODOLOGY

With the help of traditional method by calculating forces acting on structures seismic analysis performed on the E-TAB software using static method of structural analysis.

A. Definitions:

1. Storey: It is the space between two adjacent floors.
2. Storey Drift: It is the displacement one the level relative to the other level above or below.
3. Base Shear: It is the amount of external lateral forces acting on the base of the structure due to the earthquake.
4. Seismic weight: It is the total dead load plus appropriate amount of specified imposed load.
5. Importance Factor: It is a factor used to obtain the design seismic force depending on the functional use of the structure.
6. Zone Factor: It is a factor to obtain the design spectrum depending on the perceived maximum seismic risk characterized by Maximum Considered Earthquake (MCE) in the zone in which the structure is located. The basic zone factors included in this standard are reasonable estimate of effective peak ground acceleration.
7. Response Reduction Factor: It is the factor by which the actual base shear force, that would be generated if the structure were to remain elastic during its response to the Design Basis Earthquake (DBE) shaking, shall be reduced to obtain the design lateral force.

B. Equivalent Static Method: This approach defines a series of forces acting on a building to represent the effect of the earthquake ground motion, typically defined by a seismic design response spectrum. It assumes that the building response in its fundamental mode. For this to be true, the building must be low rise and not twist significantly when the ground moves. The response is read from a design response spectrum, given the natural frequency of the building (either calculated or defined by the building code). The applicability of this method is extended in many building codes by applying factors to account for higher building with some higher modes, and low levels of twisting. To account for effect due to “yielding” of the structure, many codes apply modification factor that reduce the design forces.



C. Fundamental Natural period:

1. The approximate fundamental natural period of vibration (T_a), is second, of a moment-resisting frame building without brick infill panels may be estimated by the empirical expression:

$$T_a = 0.075 h^{0.75} \text{ for RC frame building}$$

$$T_a = 0.085 h^{0.75} \text{ for steel frame building}$$

2. The Approximate fundamental natural period of vibration (T_a), in seconds, of all other buildings, including moment-resisting frame buildings with brick infill panels, may be estimated by the empirical expression:

$$T_a = 0.09 h/\sqrt{d}$$

Where,

h = height of building in m. This excludes the basement stories, where basement walls are connected with the ground floor deck or fitted between the building columns. But it includes the basement stories, when they are not so connected.

d = base dimension of the building at the plinth level, in m, along the considered direction of the lateral force.

D. Design Seismic Base Shear:

Along any principal direction, the design Seismic base shear or total design lateral force (VB) can be determined by the following Expression:

$$V_B = A_h \times W$$

$$A_h = (Z/2) \times (S_a/g) \times (I/R)$$

Where,

A_h = Design Acceleration spectrum along horizontal with the help of fundamental natural period “T” in that particular direction of vibration.

W = Seismic weight of the structure.

S_a/g = Spectral Acceleration taken from Response Spectrum

I = Importance Factor

R = Ductility / Over-strength Reduction Factor

E. Design lateral force at each floor i : The design lateral force, V_b shall be distributed along the height of building using equation as follow,

$$Q_i = V_b \times \frac{W_i \times h_i}{\sum_{j=1}^n W_j \times h_j^2}$$

Were,

Q_i = Design lateral force at floor i ,

W_i = Seismic weight of floor i ,

h_i = Height of floor i measured from base

n = Number of stories in the building is the number of levels at which the masses are located.

F. Stories Drift Limitation:

The storey drift in any storey due to the minimum specified design lateral force, with partial load factor of 1.0 shall not exceed 0.004 times the storey height.

G. Load Combination:

When earthquake forces are considered on a structure, these shall be combined as per IS 1893 (Part 1): 2002 where the term DL, IL and EL stand for the response quantities due to dead load, impose load and designated earthquake load respectively. In the limit state design of reinforced and prestressed concrete structure, the following load combinations shall be accounted for:

1.5 (DL + LL) 1.2 (DL + LL ± EL) 1.5 (DL ± EL) 0.9 DL ± 1.5 EL

H. Wind Analysis:

Buildings are subjected to horizontal load due to wind pressure acting on the buildings. Wind load is calculated as per IS 875(Part 3):1987. The horizontal wind pressures act on vertical external walls and exposed area of the buildings. Some of the pressure acting on exposed surfaces of structural walls and columns is directly resisted by bending of these members. The infill walls act as vertical plate supported at top and bottom by floor beams, thus transferring the loads at slab level. The parapet wall is at the terrace transfers the wind loads to the surface slab by cantilever action. For simplicity, the wind loads acting on exposed surfaces of a given storey are idealized to be supported by upper and lower floors.

I. Design Wind Speed (V_z):

The basic wind speed map of India is applicable to 10m height of building above mean ground level for different zones of country. Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 seconds and corresponds to mean height above ground level in an open terrain (Category 2). Basic wind speeds presented in map have been worked out for 50-year return period. Basic wind speed for some important cities/town is also given in Appendix A and shall be modified to include the following effect to get design wind velocity at height (V_z) for chosen structure:

- a. Risk level.
- b. Terrain roughness, height and size of structure and
- c. Local topography.

It can be mathematically expressed as follows;

$$V_z = V_b \times k_1 \times k_2 \times k_3$$

Were,

V_z = Design wind speed at height z in m/s

k_1 = Probability factor (risk coefficient)

k_2 = Terrain, height and structure size factor

k_3 = Topography factor

J. Risk Coefficient (IS 875.Part 3-1987):

The risk coefficient k_1 takes in to account the degree of reliability required and the expected life of structure.

- a. All general buildings (Design life 50 years)
- b. Temporary sheds (Design life 5 years)
- c. Less important buildings (Design life 25 years)
- d. Important buildings (Design life 100 years)

K. Terrain, height and structure size factor (IS 875.Part 3-1987):

It depends of terrain category and building class/size of structure. Four terrain categories are specified by the code depending on the availability of obstruction to the flow of wind.

Category 1: Refers to no obstruction available to the building.

Category 2: Refers to open terrain with scattered obstruction of 1.5m to 10m height. Category 3: Refers to areas of closed spaced buildings of height up to 10m.

Category 4: Refers to area with highly closed building of large heights.

Class A: Maximum of l, b, h < 20m

Class B: Maximum of l, b, h – 20m to 50m

Class C: Maximum of l, b, h > 50m

L. Topography Factor (IS 875.Part3-1987):

It depends on the topography i.e., hill region, cliffs and ridges.

If the upward slope $0 \leq 30$, value of k_3 shall be taken 1.0.

For $0 > 3$, value of k_3 lies between 1.0 to 1.36.

M. Design Wind Pressure (P_z):

The design wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind velocity:

$$P_z = 0.6 \times V_z^2$$



Were,

P_z = Design wind pressure in N/m² at height z and

V_z = Design wind speed velocity in m/s at height z.

N. Analysis on E-TAB:

First of all, shape of analysing structure is finalized to compare in different condition such as providing column without bracing, diagonal bracing with and without column.

The models are prepared in E-TABs with an equal interval as shown in diagram

Load applied such as self-weight of a structure gravitational load, seismic load as per zone 4 and the properties beam, column, slab and bracing applied in the model.

O. The properties of model are as follows:

All Model: Geometry- size Length = 4m x 5m = 20m, width: 5m x 6 = 30m, Floor to Floor height: 3.65m, total height: 11 x 3.65m = 40.15m (total stories: 11)

Member properties- column = 900mm x 900mm, beam = 500mm x 600mm, slab thickness: 150mm, bracing ISMB: 450mm

Earthquake Analysis-Zone: 4

Important factor = 1.5 type of soil: II (medium) time period = $T_{dx} = 0.010$, $T_{dz} = 1.0122$

Wind Analysis- zone (terrain Category): 4

Wind speed- 42m/sec

Material Data-grade of concrete: M30, steel: $F_y = 500$, steel bracing - $F_y = 250$.

P. Description of structure:

Q. Geometrical Data:

Models that have been prepared for present investigational study along with other parameters for G+10 building for all is represented in the

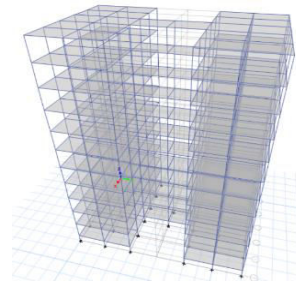
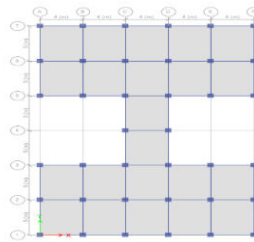
Sr.No.	1	2	3
Shape	I	I	I
Length in x-direction	20	20	20
Length in y-direction	30	30	30
Type of structure	Only with column	x-bracing	Diagonal bracing

Table No. 1.

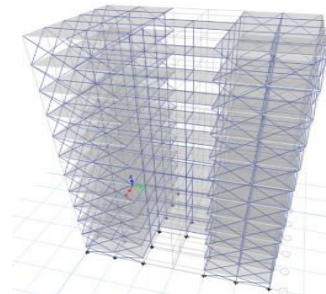
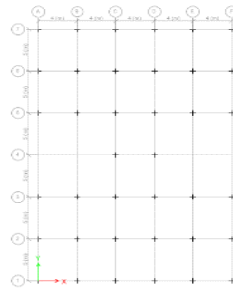
IV. MODELLING AND ANALYSIS

A. Typical Plans of Floor with side view

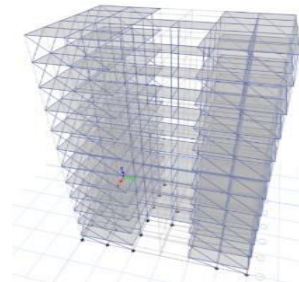
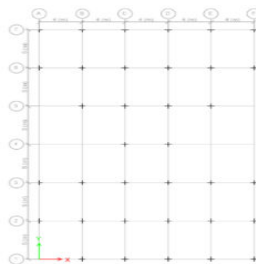
Structure with only Column: Fig no.2



Structure with X bracing Fig no.3



Structure with diagonal bracing Fig no.4





V. EXPERIMENTAL RESULTS

A. BASE REACTIONS IN ALL STRUCTURES.

Type of Structure	In Earthquake Load (KN)	
	In X-Direction	In Y-direction
Column only	10508.02	9406.09
X Bracing	8550.28	6936.35
Diagonal bracing	18307.74	15696.73

Table no.2

B. STORY DISPLACEMENT

1. STORY DISPLACEMENT OF STRUCTURE WITH COLUMN IN EARTHQUAKE LOAD

Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Story12	41.65	Top	72.964	76.208

Table no.3

2. STORY DISPLACEMENT OF STRUCTURE WITH X BRACING IN EARTHQUAKE LOAD

Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Story12	41.65	Top	72.726	85.649

Table no.4

3. STORY DISPLACEMENT OF STRUCTURE WITH DIAGONAL BRACING IN EARTHQUAKE LOAD

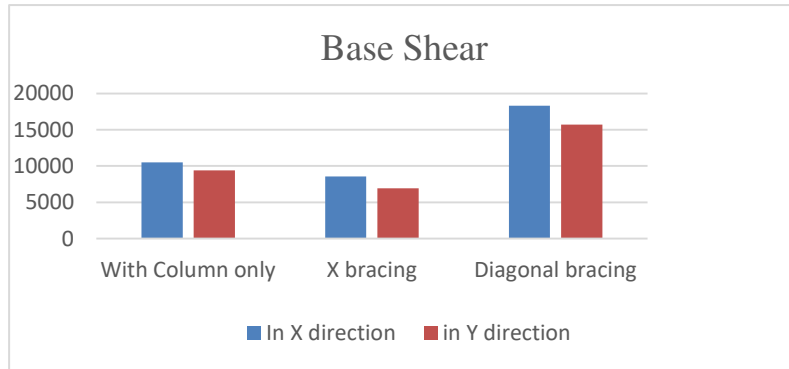
Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Story12	41.65	Top	109.281	185.886

Table no.5



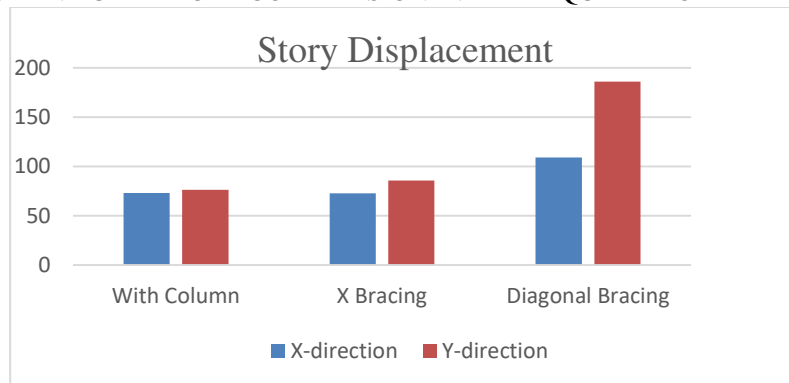
C. GRAPHICAL CHART

1. BASE SHARE GRAPHICAL COMPERISION



All units in KN.

2. STORY DISPLACEMENT GRAPHICLA COMPERISION IN EARTHQUAKE LOAD



All units in mm.

D. STORY DRIFT

The story drift of all structure pass the criteria of story drift as mention in IS-Code. with partial load factor of 1.0 shall not exceed 0.004 times the storey height.

VI. CONCLUSION

1. With the help of I-shape structure we analysed the structure and compared with providing column, x-bracing and diagonal bracing.Z
2. The base shear in x-bracing structure decreased by 18.63% with x direction and 26.25% in y direction as compare to structure having column only.
3. The base shear in diagonal bracing structure increased by 74.22% in x direction and 59.92% in y direction.
4. As above result we concluded that to reduce base shear of structure the x-bracing is more suitable as compare to column structure and diagonal bracing structure.
5. The story displacement Of x-bracing decreased by 0.33% in x direction and increased by 12.38% in y direction compared to column structure.
6. The story displacement of diagonal bracing increased by 49.77% in x direction and 143.93% in y direction.



7. The story drift of all structure pass the criteria of story drift as mention in IS-Code.

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