International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 12 Dec 2023, pp: 255-262 www.ijaem.net ISSN: 2395-5252

Comparative Study of Diagrid Plan Geometry Steel Structures with Buckling Resistance Braces

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Date of Submission: 15-12-2023 Date of Acceptance: 25-12-2023

ABSTRACT
High rise building development was facilitated by recent improvements and developments in construction technology, structural systems, building materials, and analysis and design methodologies. Because lateral stresses from earthquakes or winds are more likely to cause damage to high-rise buildings or structures, these loads are taken into consideration while designing these structures. As a result, lateral load resisting devices are crucial for preventing lateral loads in high-rise structures. Both internal and external systems are capable of withstanding lateral loads. Braced tube systems, tubular systems, and diagrid systems are often used interior resisting systems, whereas braced core, shear wall core, outrigger systems, and their combinations are external resisting systems. Due to its structural versatility and use in high-rise structures, the diagrid structural system has seen an upswing in popularity recently.

The junction of the diagonal and horizontal components results in the formation of the particular type of space truss known as the diagrid. It is made up of perimeter grids joined by horizontal rings made of triangular trusses. The diagonal members of diagrid structural systems can support both gravity loads and lateral forces because of their triangulated structure. Because lateral shear is carried by the axial action of the diagonal components, diagrid constructions are better at decreasing shear deformation. The diagonal elements placed on the periphery of diagrid constructions may carry lateral shear, hence they often do not require high shear stiffness cores.

I. INTRODUCTION

The rapid global population growth and the resulting strain on available land have had a significant impact on how a community has grown residentially. The need to preserve major agrarian productions, the high cost of land, and the desire to avoid a continuous conurbation all contributed to the upward thrust of residential and commercial structures. In comparison to the structural system resisting gravitational loads, the structural system resisting horizontal loads becomes more significant as a building rises in height. Shear walls, rigid frames, braced tube systems, wall-frames, tubular systems, outrigger systems, and diagrid systems are some of the commonly utilized horizontal load resistance systems. For taller buildings, the diagrid - diagonal grid - framed system has recently been growth and the resulting strain on available land have had a significant impact on widely used due to its structural proficiency and artistic potential The rapid global population how a community has grown residentially. The need to preserve major agrarian productions, the high cost of land, and the desire to avoid a continuous conurbation all contributed to the upward thrust of residential and commercial structures. In comparison to the structural system resisting gravitational loads, the structural system resisting horizontal loads becomes more significant as a building rises in height. Shear walls, rigid frames, braced tube systems, wall-frames, tubular systems, outrigger systems, and diagrid systems are some of the commonly utilized horizontal load resistance systems. For taller buildings, the diagrid - diagonal grid - framed system has recently been widely used due to its structural proficiency and artistic potential

Buckling resistance braces (BRBs)

In the early 2000s, buckling-restrained braces (BRB) were introduced into the United States' construction practice to mitigate some of the shortcomings of traditional bracing members. BRBs consist of a thin steel-core plate designed to yield in tension and compression and braced in compression by a grout-filled steel tube.

The main advantage of BRBs is their ductility and stable response under reversed seismic loading. As a result, the building code allows BRB systems to be designed for reduced seismic loads.

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While there are economies in designing for lower seismic forces, the redundancy provisions of the building code can still result in numerous bays of bracing, which in turn require a large number of BRBs, adversely affecting cost and architectural programming. Lastly, research and analysis has shown that the relatively soft BRB systems are susceptible to weak-story mechanisms.

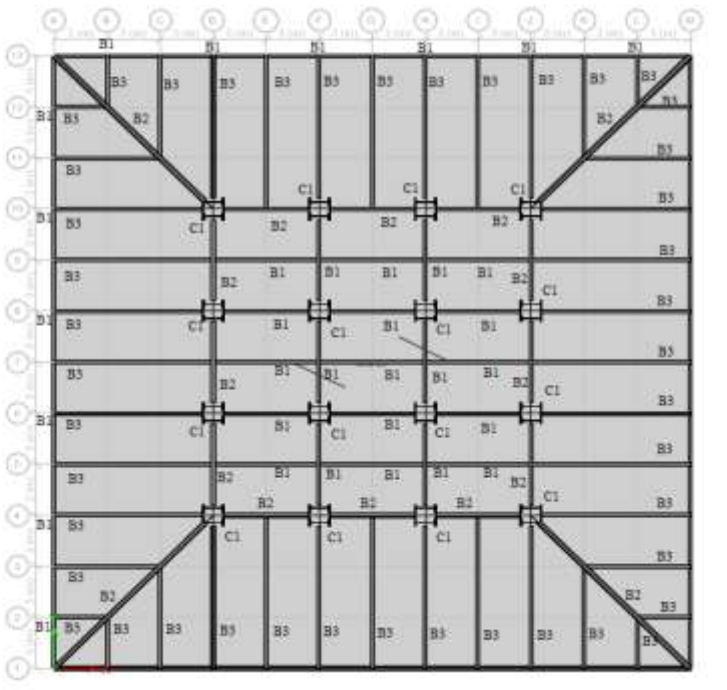
STRUCTURAL MODELING OF DIAGRID STRUCTURE

This chapter presents diagrid and conventional construction configurations. The details of various structural configurations of forty-storey traditional buildings are shown includes the details of various structural configurations of forty-storey diagrid buildings with the different plan geometry as square, pentagonal, hexagonal, and octagonal.

Details of the different loadings that were applied to the structures for analysis are described. There is a brief explanation of these materials in for creating models made of steel and concrete. The size of the construction components is discussed in at the conclusion of the chapter. **Diagrid Buildings**

The 40 story diagrid structures with a plan area of (350 ±50) m2 and a storey height of 3.0 m are taken into consideration. The ETBAS 2018 software is used to simulate each of these structures. Buildings employ 125 mm thick deck slabs and are symmetrical about both axes. Approximately (25±10)% of the plan's core area is taken into account, and core columns are spaced 6 m apart. The space between diagonal columns in all diagrid structures is 12 meters. At the end supports of the diagrid diagonals and vertical columns, fixed support is offered, and the end condition of the diagrid diagonals is presumed to be hinged. demonstrates the three diagrid structures' layout.

With the numerous plan geometries, such as square, pentagonal, hexagonal, and octagonal, and as stated in chapter 4, it has been discovered that the diagonal angle of a forty storey diagrid structure should be preserved at around 63 degrees. The elevation and three-dimensional perspective of the forty-story diagrid skyscraper are shown in figures , respectively.



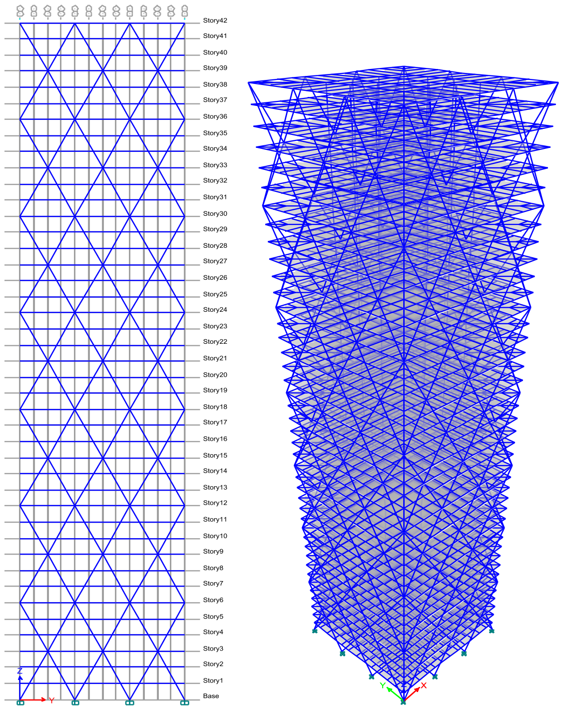


Figure 1 Modelling of square diagrid plan

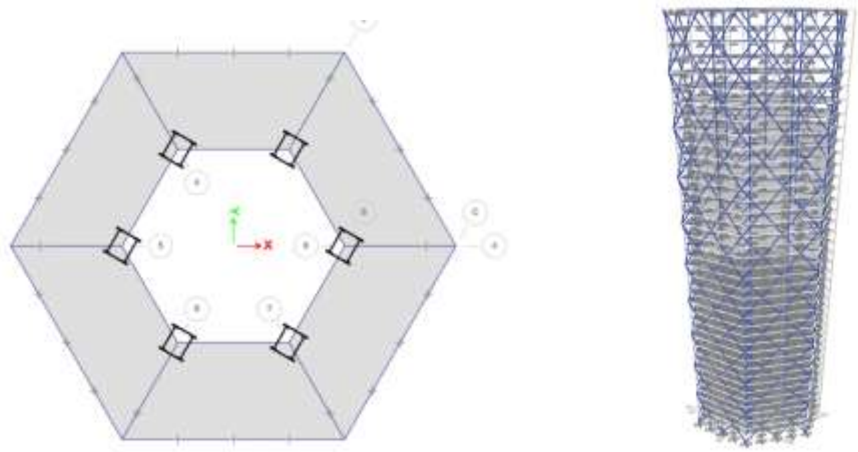


Figure 2 Modelling of hexagonal plan geometry diagrid plan

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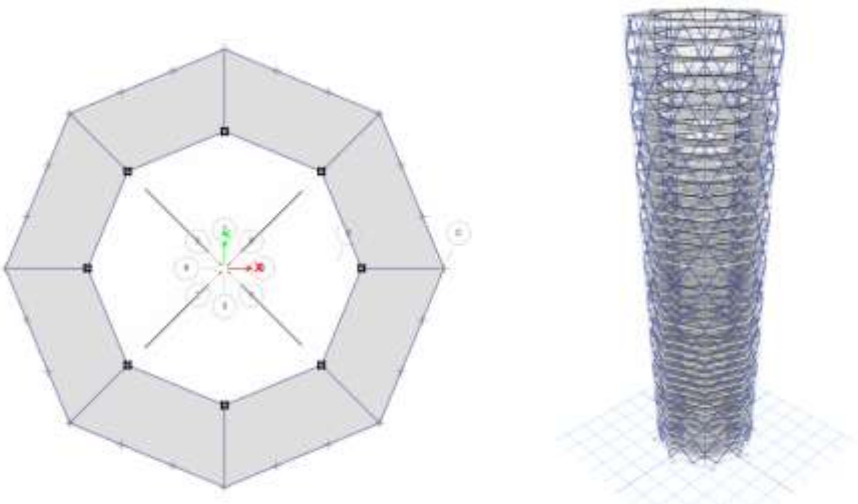

Figure 3 Modelling of octagonal plan geometry diagrid plan

ANALYSIS AND DESIGN

The approach based on stiffness is used for an approximate analysis of 40storey diagrid buildings. The maximum lateral displacement, H/500 is used as the permitted displacement of top storey. The peripheral diagrids are allotted all the required lateral stiffness. Taking into account lateral loadings, shear forces and bending moments are determined at different modules. shows the maximum allowable lateral displacement of buildings.

Table 1: Maximum allowable lateral displacement.

Storey	Height (m)	Allowable Lateral Displacement {H/500} (m)
40Storey	120.0	0.320

According to IS 1893 (Part 1): 2016 [21], all structures in this study were examined using the Equivalent Static Method, Response Spectrum Analysis, and Time History Analysis in ETABS 2018 [22]. Below is a quick summary of various techniques;

A. Equivalent Static Method (ESM)

A quick way to replace the dynamic loading caused by an impending earthquake with a static force applied laterally to a structure is to use the comparable static technique. The general seismic force V applied is measured in two horizontal directions that are parallel to the principal axis of the building. It is assumed that the structure is reacting in its default lateral mode. The structure must be low rise and generally symmetrical to be applicable of this strategy in order to prevent torsional movement under earthquake ground motion [21].

B. Response Spectrum Analysis (RSA)

A technique for linear dynamic analysis is the response spectrum approach. This approach takes into account various structural mode forms. Depending on the modal frequency and the modal mass, a response from the design spectrum is read for each mode. They are then merged using modal combination techniques to give an estimate of the structure's overall reaction. There are three ways to combine things, which include the following: Square Root Sum of Squares (SRSS), the Complete Quadratic Combination (CQC), and the Absolute Sum technique [21]. This approach can be used with structures whose response is strongly influenced by modes other than the basic one. This method superimposes modal responses to represent the response of the multi-degree of freedom system.A single degree of freedom system's spectrum analysis is used to estimate each modal response, which is then combined to determine the overall response.

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Table 2 : The 40-story diagrid building's modal features are seen. The basic period is 3.387 seconds. The seismic mass participation ratio is 93.72 and 95.07percent, respectively, in the X- and Y-direction.

Mode	Period (Sec)	Modal Participating Mass Ratio X (%)	Modal Participating Mass Ratio Y (%)	Sum of Modal Participating Mass Ratio X (%)	Sum of Modal Participating Mass Ratio Y (%)
1	3.387	13.83	53.24	13.83	53.24
2	3.381	53.22	13.87	67.05	67.11
3	1.12	0.00163	0.00214	67.05	67.11
4	0.91	0.92	18.21	67.97	85.32
5	0.906	18.09	0.91	86.06	86.23
6	0.456	0.04	4.93	86.1	91.16
7	0.455	4.97	0.04	91.07	91.21
8	0.408	0.00103	0.000127	91.07	91.21
9	0.312	0.00436	2.68	91.08	93.88
10	0.309	2.63	0.01	93.71	93.89
11	0.244	0.000084	0.03	93.71	93.92
12	0.232	0.01	1.16	93.72	95.07

Stiffness Based Design Methodology of diagrid

On the ground, a diagrid-framed structure is modeled as a vertical cantilever beam that is longitudinally split into modules in accordance with the repeating diagrid configuration. Every module has a single diagrid level that spans 'n' stories to represent it. A modular instance with six stories is shown in Fig. 4.7. In order to estimate the lateral rigidity provided by the diagonals of the diagrid framed system more precisely, the core structure is eliminated from this figure and all necessary lateral stiffness is provided to the periphery diagonals. Depending on the loading direction, the faces of this module serve as a web or flange plane.

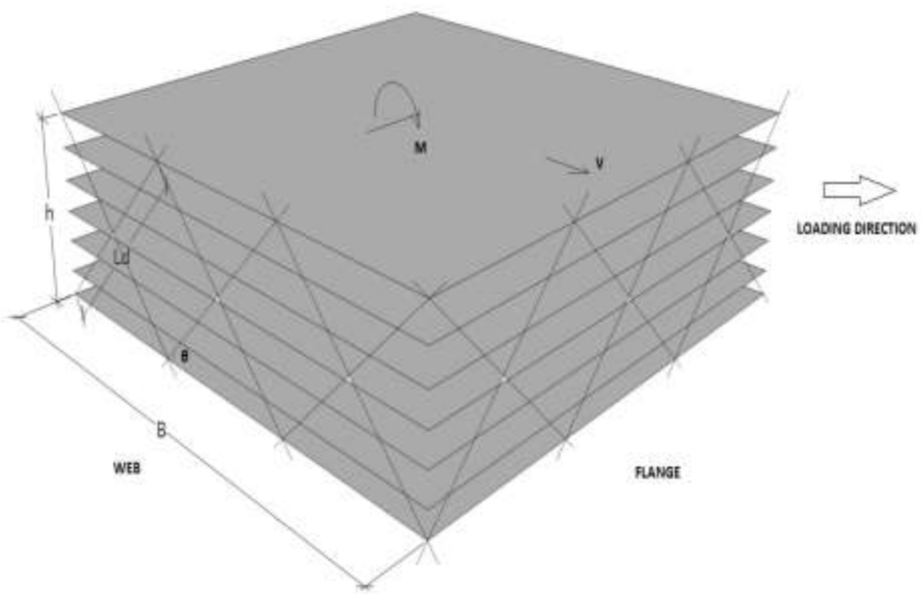

Figure 16 Typical diagrid module with six stories

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Flange planes and web planes are the two planes that are perpendicular to the lateral load. Since the diagrid components' ends are designed to be pin-ended, only axial action can withstand transverse shear and moments. According to this theory, the design challenge for each module is simplified to figuring out the cross-sectional area of the current web and flange members. The modules' members' sizes may be calculated using Equations (4.1) and (4.2).

$$A_{dw} = \frac{VL_d}{2N_{dw}E_d h\gamma \cos^2\theta} \quad (4.1)$$

$$A_{df} = \frac{2ML_d}{(N_{df}+\delta)B^2 E_d \mathcal{X} h \sin^2\theta} \quad (4.2)$$

Where,

A_{dw}: Area of each diagonal on the web of Module
A_{df}: Area of each diagonal on the flange of Module
V: Shear Force on Module
M: Moment on Module
L_d: Diagonal Length
B: Width of Building in the Direction of Force Applied
E_d: Elastic Modulus of Steel
θ: Diagonal Angle of Diagrid Module
ϒ: Transverse Shear Strain
$\mathcal{X}$: Curvature
N_{dw}: Total Number of Diagonals on Each Web Plane
N_{df}: Total Number of Diagonals on Each Flange Plane
δ: Web Diagonals contribution to the Bending Rigidity
h: Height of Module

The condition of consistent shear and bending deformation under the design's loading results from the stiffness-based optimal design. Only structures with a static determination may achieve this homogeneous condition of deformation. A homogeneous deformation state may be achieved for high rise building structures by modeling them on the ground as vertical cantilever beams (Connor, 2003) [17]. Consequently, the structure's top deflection, u(H), is given by,

$$u(H) = \gamma^* H + \frac{\mathcal{X}^* H^2}{2} \quad (4.3)$$

H: Height of Building
γ^*: Uniform Desired Transverse Shear Strain
$\mathcal{X}^*$: Uniform Desired Curvature

Here, $\gamma^* H$ is the shear deformation and $\frac{\mathcal{X}^* H^2}{2}$ is the bending deformation

Assigning the building's intended shear and bending deformations is the first step in the design process. 'S', a dimensionless variable, is included in order to assign the relative contributions of shear vs bending deformation. Equation (4.4) may be used to compute the "S" value, which is proportional to the difference between displacement caused by shear and displacement caused by bending at the top of the building.

$$S = \left(\frac{\mathcal{X}^* H^2}{2}\right) / (\gamma^* H) = \frac{H\mathcal{X}^*}{2\gamma^*} \quad (4.4)$$

The most crucial factor in stiffness-based design for high-rise structures is the maximum permissible displacement, which is often provided as,

$$u(H) = \frac{H}{\alpha} \quad (4.5)$$

Value of α is taken as 500 in this study. Now, from equation (4.3) and (4.4), equation (4.5) expands to

$$u(H) = (1+s)(\gamma^* H) = \frac{H}{\alpha} \quad (4.6)$$

Then,

$$\gamma^* = \frac{1}{(1+s)\alpha} \quad (4.7)$$

Similarly, χ^* is computed from equation (4.4).

$$\chi^* = \frac{2\gamma^* s}{H} = \frac{2s}{H(1+s)\alpha} \quad (4.8)$$

It is up to you to choose a value for "S". Buildings tend to behave more like bending beams as their height and aspect ratio (height to width ratio) rise, and bending deformation ends up being the deciding design consideration. Therefore, increasing the value of "S" is a sensible choice for a cost-effective design. The 'S' value selection is based on the building's aspect ratio as well as the minimal amount of material use .

Edge beams are crucial components in diagrid systems for completing the triangulation geometry. To prove both the stiffness and strength requirements, these edge beams, which are typically built for the gravity loads on each level, can also bear enough lateral loads by acting axially.The methodology of this design is predicated on the idea that motion restrictions, rather than strength constraints, control the construction of high rise buildings. IS 800: 2007 has been used to test the design's strength [18]. Necessary space for the usual diagonals in the web and flange of modules for forty-storey diagrid buildings with the different plan geometry as square, pentagonal, hexagonal, and octagonal.story diagrid structures with ideal angles.

II. RESULTS AND DISCUSSION

The findings from the Equivalent Static Method (ESM), Response Spectrum Method (RSM), and Non-linear Time History Method are

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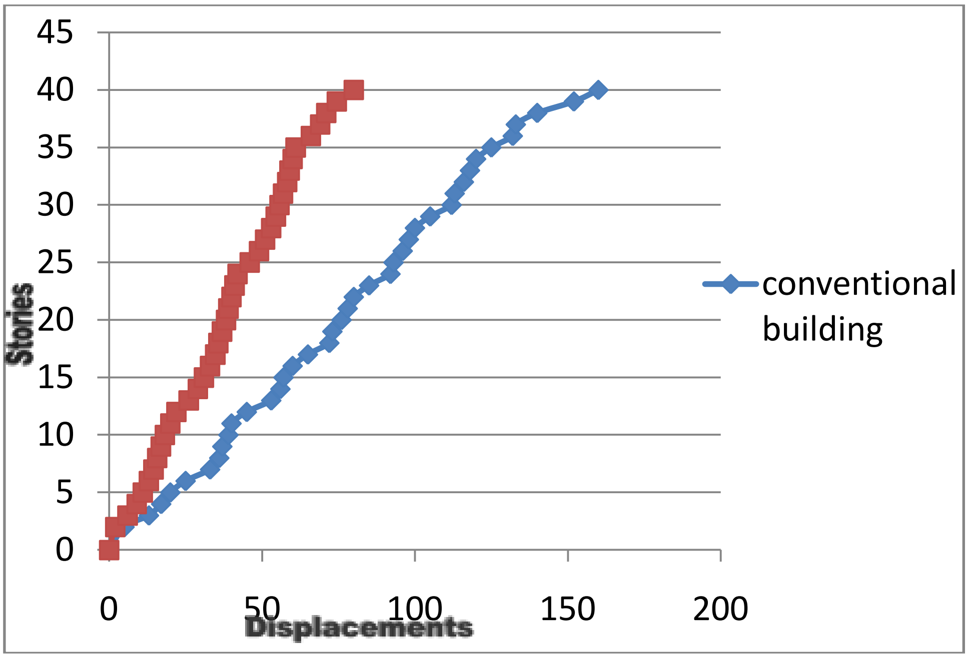
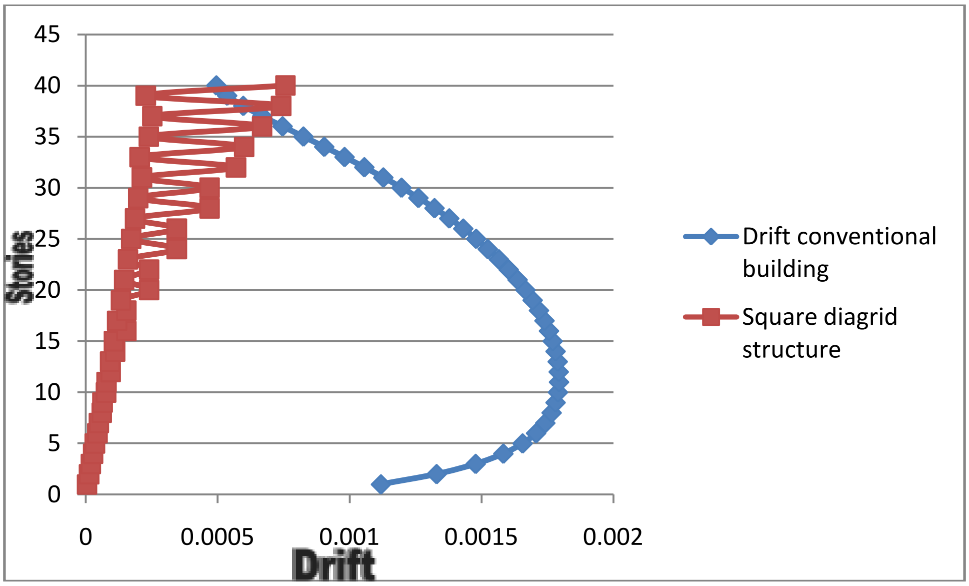
presented for the twenty, forty-two, and sixty story steel diagrid and conventional steel buildings in terms of story displacement, story drift, and story shear in the longitudinal and transverse directions. Roof acceleration, roof velocity, roof displacement, and foundation shear over time for each diagrid and conventional structure as a result of the 1940 ground accelerations in the Imperial Valley (El Centro) are also shown in the X and Y directions. The basic time period and steel usage of all structures are discussed in the conclusion.





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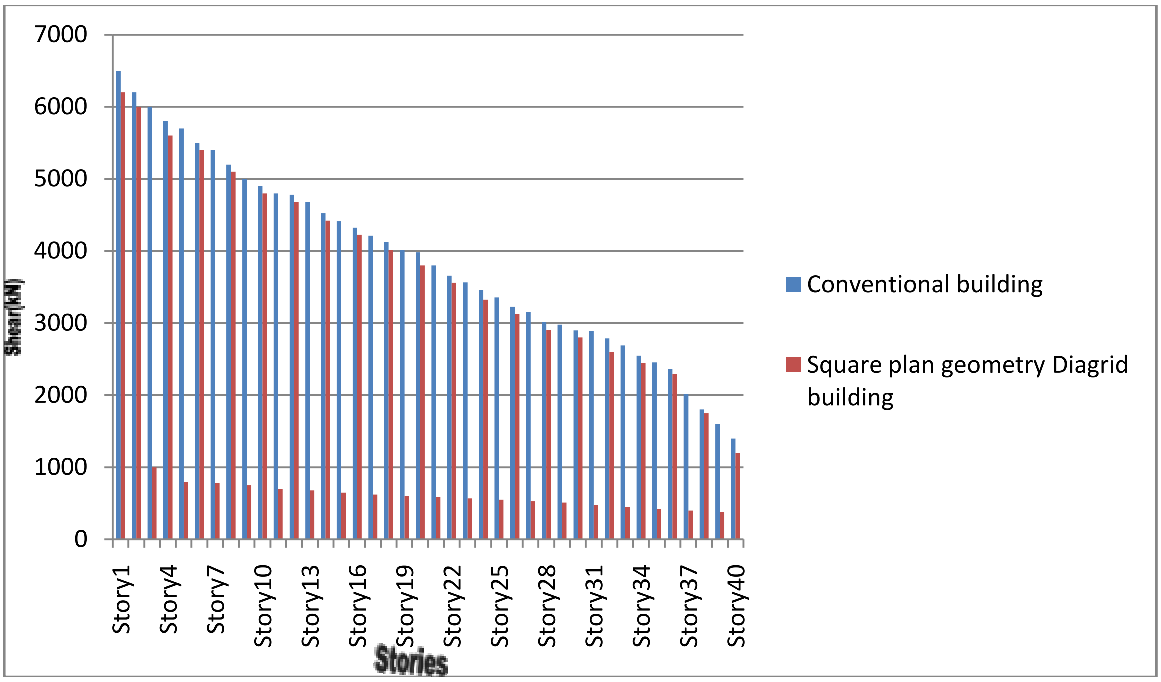

III. CONCLUSIONS AND SUMMARY

Diagrid structure without Buckling Resistance Braces (BRBs).

- Optimal angle of diagrid building is ranges from 50 to 65 degree.
- When using the equivalent static method, square diagrid buildings 67% less storey displacement than traditional 40 storey buildings.
- When using the equivalent static method, pentagonal geometry diagrid buildings 72% less storey displacement than traditional 40 storey buildings.
- When using the equivalent static method, hexagonal geometry diagrid buildings 73.5% less storey displacement than traditional 40 storey buildings.

Summary

The diagrid buildings offer superior seismic response than conventional structures under static and dynamic conditions, it may be concluded from the aforementioned points. The best angle range for a high polynomial design for a geometry diagrid building is between 50 and 65 degrees, and between 62 and 75 degrees for a structure with 40 stories. According to the Equivalent Static Method, Response Spectrum Analysis, and Non-linear Time History Analysis, all diagrid structures experience less lateral displacement, story drift, and story shear than conventional buildings. Due to ground acceleration in the Imperial Valley (El Centro) in 1940, roof velocity and base force in all diagrid buildings are also lower in comparison to conventional buildings in both directions.