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Comparative Study On Diagrid, Rigid Frame and Shear Wall Structural Systems in High Rise Buildings

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ABSTRACT: The evolution of tall structures is based on new structural concepts with newly adopted high strength materials and construction methods have been towards "stiffness" and "lightness". As per the previous records, there is an increase in the demand for use of earthquake resisting structures. So, it is necessary to design and analyze the structures by considering seismic effect. For designing tall buildings there are various lateral load resisting systems, such as moment resisting frame, shear wall system, bracing system, space trusses, tubular structures etc. Diagrid is one of the most unique and new structural systems which is adept for designing tall buildings. In this paper, a comparative study between diagrid system, rigid frame system and shear wall system has been put forth. An 18-storeyed diagrid building, rigid frame building and a building with Shear wall systems have been modelled and analyzed with two different plan configurations namely, octagon and square. A total of 6 buildings have been modelled and analyzed to compare which system performs better as a lateral load resisting system. The modelling and analysis have been performed on ETABS. The dynamic analysis is performed by using Response Spectrum Method. All the loadings and the checks are provided as per Indian Standards. the parameters like storey displacement, storey drift, base shear and time period are considered for the investigation.

KEYWORDS: Comparative study, Diagrid structure, Shearwall system, Rigid frame system, Dynamic analysis.

I. INTRODUCTION:

The development of high-rise buildings associates numerous complex aspects such as economics, scientific knowledge, aesthetics, government policies. The financial factor will be the primary determining factor. These structures demand a lot of technical support without which its origination is not possible. As the height of the structure is increases the lateral forces acting on the structure also rapidly increases. Hence the lateral load resisting systems becomes very critical.

Over the years the structural engineering saw the development of many lateral resisting systems. The twentieth century saw dramatic changes in the structural systems since the decline of traditional rigid frame as primary type of structural system for concrete or steel structures. The economic demands and technological development of realistic structural analysis and design empowered by the arrival of high-speed digital computer.

The new era of high-rise structures leads to innovation of structural systems like core and outrigger system, diagrid system, tube system, mixed concrete systems. In this paper following lateral load resisting systems have been analyzed and compared:

Simple Frame Structure (Moment Resisting Frame): In structural engineering, a rigid frame is the load-resisting skeleton constructed with straight or curved members interconnected by mostly rigid connections, which resist movements induced at the joints of members. The lateral forces generated are primarily resisted by rigid frame action i.e., by development of shear force and bending moment in joints and frame members. The rigidity of joints and frame itself is the source of lateral stiffness in the structure.

Shear Wall System: Shear wall system is a lateral load resisting system where in shear walls i.e., either steel paneled walls or reinforced walls are designed from the foundation continuously to the top end of the structure. Shear walls resist lateral loads by cantilever action. The performance or effectiveness

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of the shear walls is depended upon their position. Thus, in this paper different shear wall systems have been analyzed and compared to find the optimum position to provide shear walls. Example of a shear wall is as follows:

Fig 1: Tehran International tower, Tehran, Iran

Diagrid Structure: Diagrid structural system is a perimeter frame structure made up of diagonal members which form a diamond shaped element that inherits triangular module or configuration. The RC core acts as a cantilever and the diagrid resists the shear and thus acting together increasing the stiffness of the structure. The main advantage of this system is that is more efficient at resisting lateral loads than other systems. Other advantages of this systems include redundancy i.e., it can transfer the load from a failed portion of the structure to another, it consumes less amount of steel, it has column free exterior, it has no need of providing façade, it has high degree of aesthetics and beauty. Following are two examples of diagrid buildings:

Fig.2 Hearst Tower, New York

Fig 3. Poly International Plaza, Beijing

The following are the principleobjectives of the current study:

1. To compare the performance of Diagrid structural system, Shear wall system and Rigid frame system.
2. To study the effects of lateral forces such as wind and earthquake forces on diagrid structural system.
3. To analyze the above structures with different plan configurations for seismic loading.
4. To perform the comparative study in terms of parameters such as displacement, storey drift, base shear and time period.

II. LITERATURE REVIEW

Ravikiran et. al. (2019) [1] have performed a comparative study on the seismic behavior of diagrid structure and shear wall structure for all the zones as per the Indian Standards (IS: 1893-part 1). ETABS 2015 software was used for the response spectrum analysis. In the study, 16 storey diagrid and shear wall buildings were modelled which had same dimensions and the interior core structural elements such as beams and columns had the same property. From the study it was concluded that, as far as displacements are concerned, diagrids perform well as a lateral load resisting system where as the seismic vibrations are considered, shear wall performs better in reducing the acceleration of the building.

Thota Sai Charan et. al. (2019) [2] investigation mainly focused on the seismic examination of symmetrical diagrid and shear divider structures, with G+30 storey buildings, which had 36mx36marrangement region.These models were analysed for three seismic zones (Zone III, Zone IV, Zone V).

Displaying and investigation of the structure was done in ETABS 2016 software. The model of the structure with shear divider and diagrid framework were executed in the product and was broke down for reaction range and time history technique.

Mohammad Rafi Uzzama et. al. (2018) [3] worked on the design and analysis of Diagrid and Shear wall structures subjected to seismic loads. both the structures of 18 storey each were designed and analysed for different seismic zones. a customary arrangement of 20m x 20m was considered with 3.5m storey stature and 2m for the base storey. The structure is examined using ETABS 2015 and the outcomes such as storey displacement, storey drift and base shear were studied. It is inferred that the structures with diagrids are efficient when compared to that with shear dividers.

Viraj Baile and Dr.A.A. Bage (2017) [4] work dealt with the comparative study of diagrid, simple frame and shear wall system. A total number of 12 models were analysed, 10 of which were shear wall systems with different positioning, one a simple frame and other one was a diagrid. Shear walls were provided as tube at hollow core, at the middle of edges, L-shaped at corners and C-shape at core to obtain optimum position for shear walls to be placed or designed. The dynamic analysis using response spectrum analysis was performs in ETABS. The outcome showed that diagrid performs better as a lateral load resisting system, it is lighter than other models and thus more economical. Also, shear wall provided as a tube at hollow core is recommended so that the building becomes seismic resistant.

Nischay J and M.R. Suresh (2016) [5] worked on the behaviour of the tall structures with the diagrid systems as the major lateral load resisting part of the structure. Three distinct shapes of the plans were considered namely Square, octagon and circular, which were symmetric in plan. For each shape, three different storey heights were modelled that is 30 stories, 45 stories and 60 stories. From the comparison of different shapes of plans like square, octagon and circular for diagrid system, the lateral displacement was found least in the octagon plan and highest in circular plan. It was observed that the most efficient model with diagrid for 60 storey was octagonal shape model with 36.72 % reduction in lateral displacement against shear wall model.

V.Abhinav et. al. (2016) [3] have performed seismic examination of multi-story working with the shear divider utilizing STAAD Pro. a RCC working of 11 stories presented to tremor stacking in zone V is considered and quake burden has determined by a seismic coefficient technique utilizing IS 1893 (Part I): 2002. The three models of a 11-story building have been made with the shear divider at corner, shear divider along outskirts and shear divider at the centre of the structure.

Nandeesh and Geetha (2016) [4] have performed near investigation of 52 story hyperbolic round steel diagrid basic framework restored at focal centre with shear divider and steel propped outlines. This work essentially included two models with moving floor zone and focus divider system. The outside periphery includes diagrid channel portion for the two models. These models are analysed for two particular seismic zones (zone II and zone III).

III. MODELLING AND ANALYSIS:

The essential objective of the project was to study the behaviour of high-rise buildings with diagrid systems. For the comparative purpose we have used shear wall system and a rigid frame system as external load resisting system. For the analysis, G+18 storey Diagrid, Shear wall and Rigid frame structures are modelled in India's zone III, as defined in IS 1893(Part1):2016. A total number of 6 models have been analysed, as each structural system has been modelled for two different plan shapes, namely square and octagon. Hence each type of load resisting system is modelled for two different shapes. For diagrid system steel pipe sections have been utilized as diagrid. From the past researches it was found that the optimum angle for diagrid is around 70°. The modelling and analysis is performed in ETABS software and response spectrum method has been utilized for dynamic analysis. This analysis can be used to understand which type of structural system is more seismic resistant. Following are the details of the models:

3.1 MODEL SPECIFICATIONS:

A. Material Properties:

- Grade of Concrete=M25
- Grade of Steel =HYSD500

B. Sectional Properties:

- Column =800*800 mm
- Beam =400*300 mm
- Tie beam=300*230 mm
- Slab thickness =125 mm
- Shear wall thickness=500 mm
- Circular Steel pipe, (Diagrid)
  Outer diameter =300 mm
  Wall thickness =20 mm

C. Loading Details:

- Dead load = 1KN/m^2
- Live load = 3KN/m^2
- Wind load:

Wind speed = 50 m/s
Terrain category = IV
Importance factor = 1.2
Risk factor = 1

- Earthquake load:

Seismic zone = III
Zone factor = 0.16
Importance factor= 1.2
Reduction factor = 5

D. Structure Plan Details:

- The square plan dimension is 10m*10m, modelled for 18 storeys building with the three required lateral load resisting system.
- The octagonal plan of sides 10m, is modelled for 18 storeys building with the three required lateral load resisting system.
- The diagrids are mounted at an angle of 69° for each shape of plan.

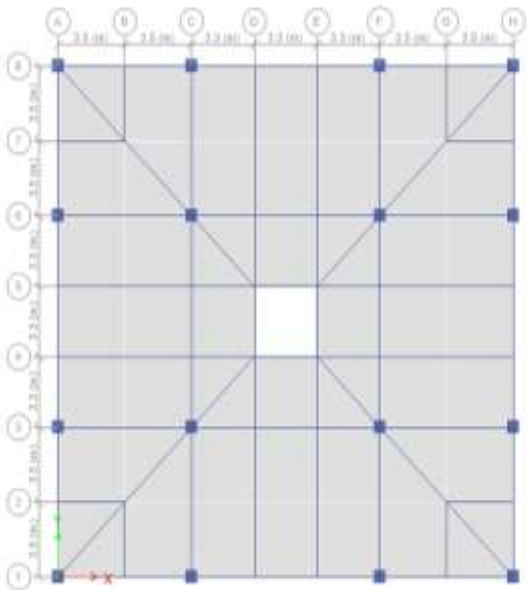

Fig 4.Square plan of Rigid Frame Structure

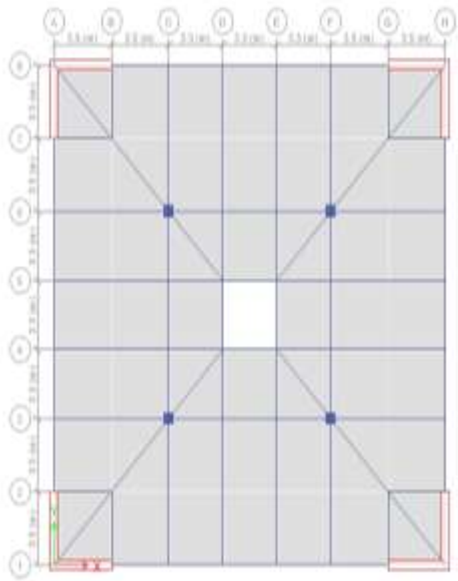

Fig 5.Square plan of Shear wall Structure

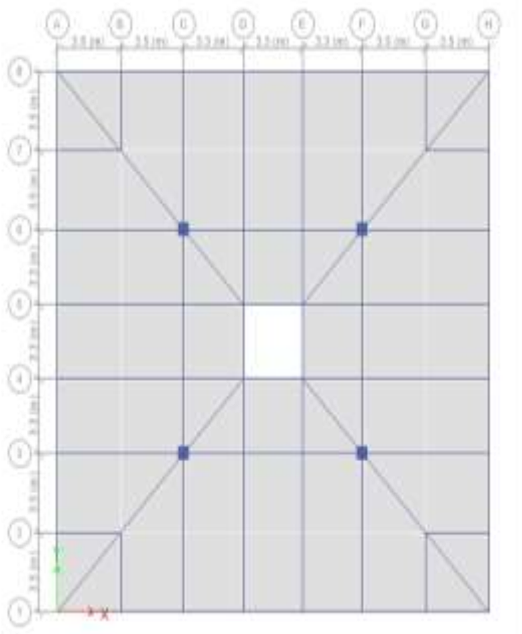

Fig 6. Square plan of Diagrid Structure

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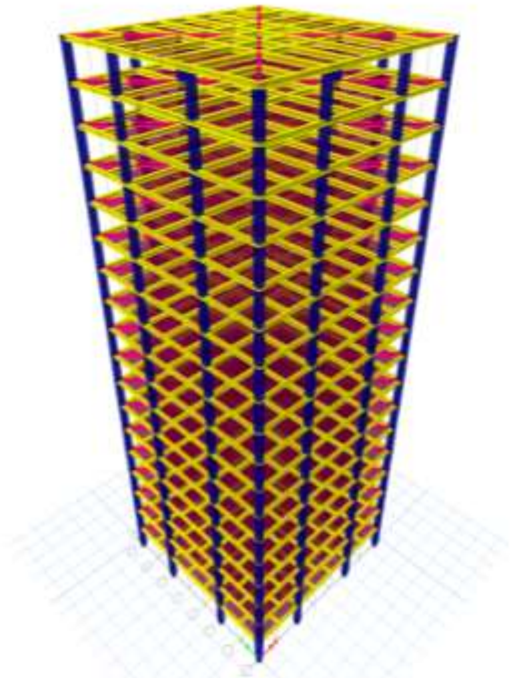

Fig 7 3D view of a square plan Rigid Frame Structure

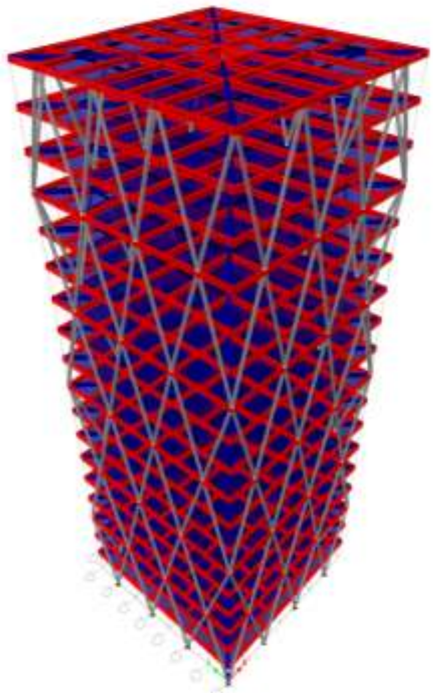

Fig.9 3D view of a square plan Diagrid Structure

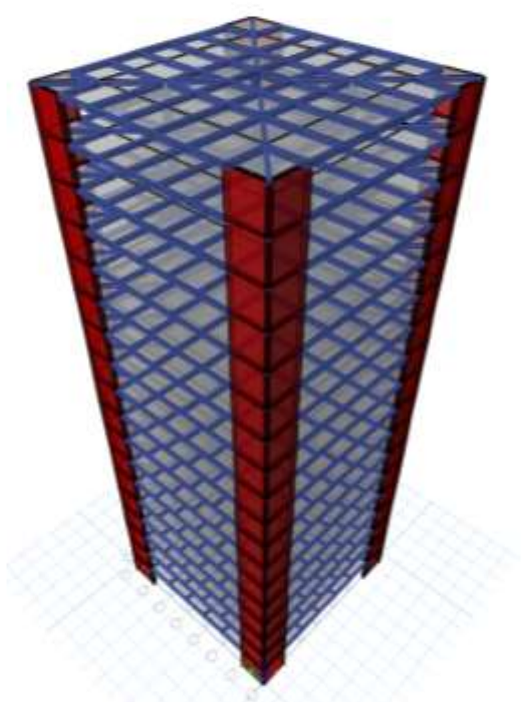

Fig 8 3D view of a square plan Shear wall Structure

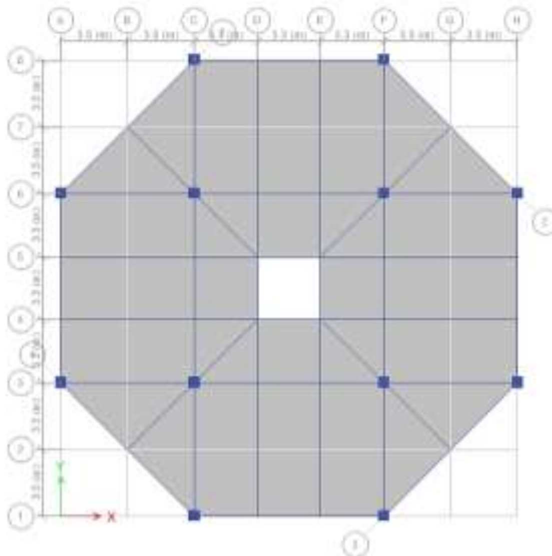

Fig 10 Octagonal plan of Rigid frame Structure

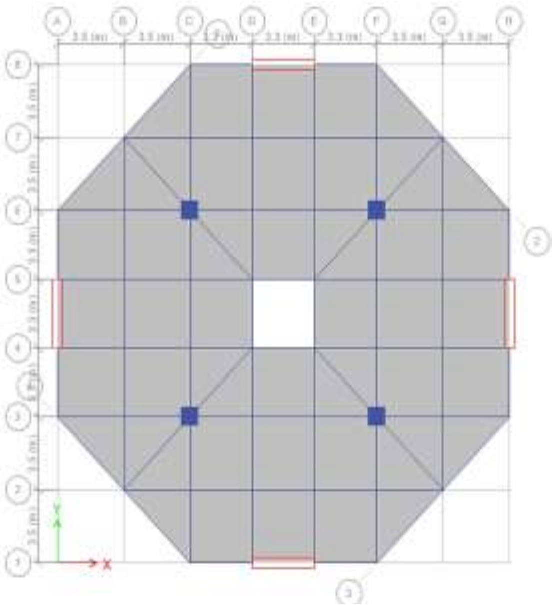

Fig 11 Octagonal plan of Shear wall Structure

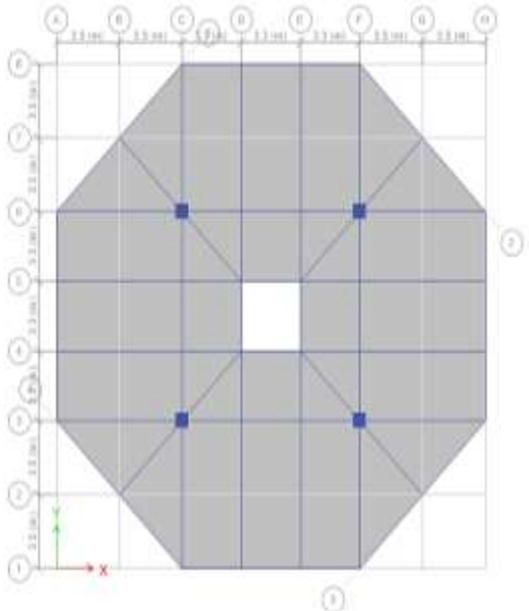

Fig 12 Octagonal plan of Diagrid Structure

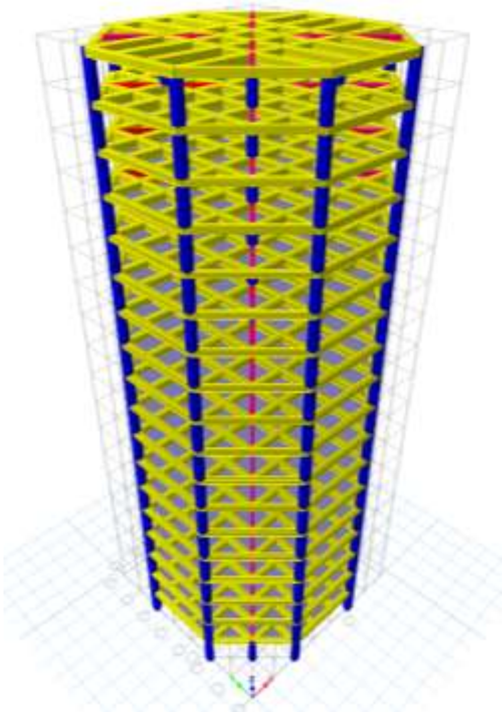

Fig 13 3D view of an octagon plan Rigid Frame Structure

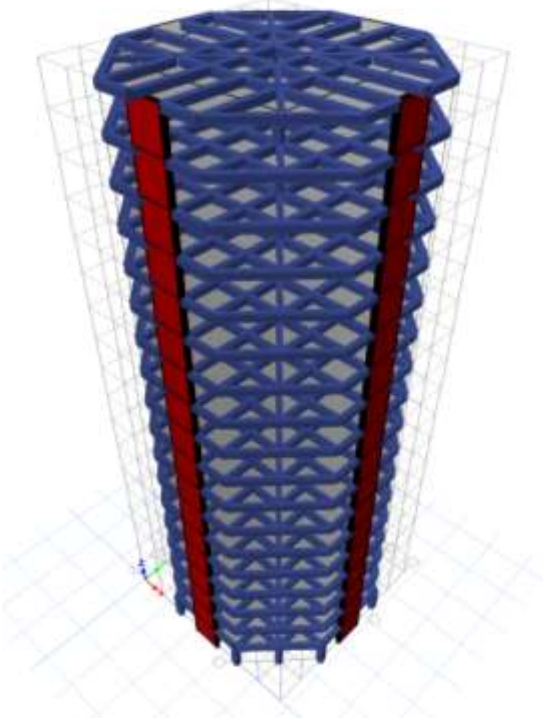

Fig 14 3D view of an octagon plan shear wall Structure

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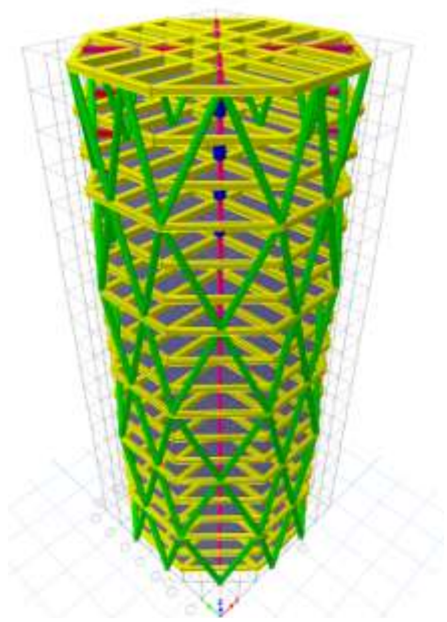

Fig 15 3D view of an octagon plan Diagrid Structure

IV RESULTS AND DISCUSSION:

All the 6 models have been modelled and analysed in ETABS. Dynamic analysis has been performed by Response Spectrum method. Comparative study has been performed between Diagrid, Shear Wall and Rigid Frame structure,under seismic loads, based on parameters such as lateral displacement, storey drift, base shear and time period. The results have been discussed below.

4.1 Storey Displacement:

Chart 1. Storey v/s displacement curve for all models

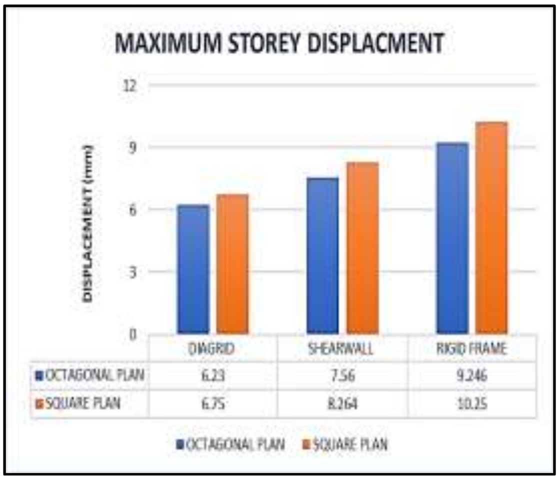

Chart 2. Maximum storey displacement data for all models

- Chart 1 shows that the storey displacement is maximum at the top storey. The maximum store displacements for all the three systems are within the limits. In chart2, the results shows that the displacement in octagon model is always less than the square model, also we observe that the diagrid model has less displacement as compared to the shear wall model and the rigid frame model.

4.2 Storey Drift:

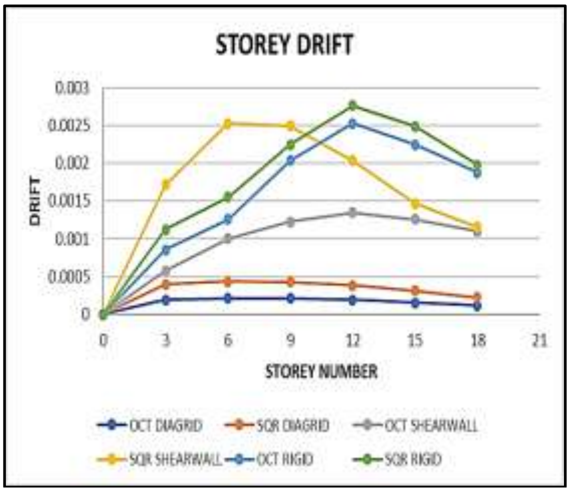

Chart 3. Storey v/s drift curve for all models

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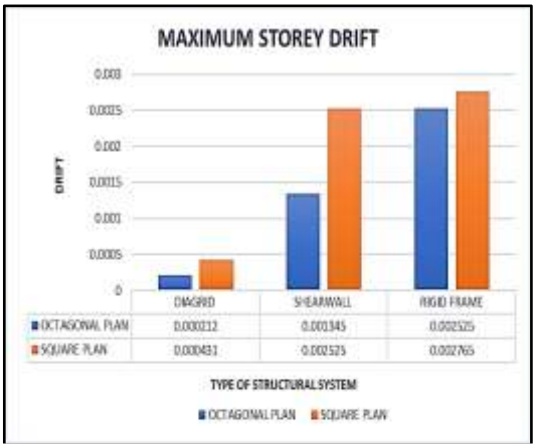

Chart 4. Maximum storey drift data for all models

- The results shows that the diagrid model has less drift as compared to the shear wall model and the rigid frame model. Also, from the above analysis, it has been observed that octagonal plan has lesser drift compared to the buildings with square plan. Diagrids reduces the maximum drift averagely about 38.2% as compared to other two systems considered

4.3 Base Shear:

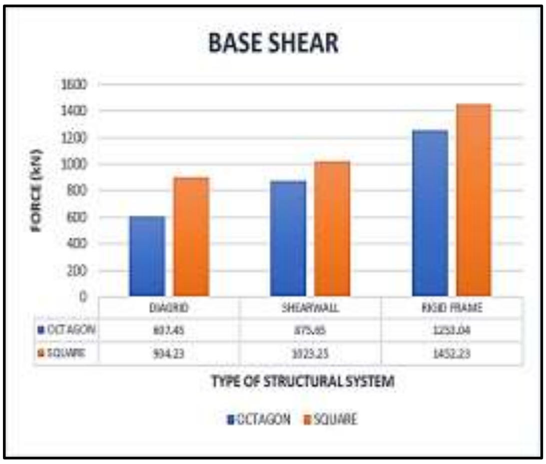

Chart 5. Base shear variation data among all models

- The base shear values are higher for square plan and lesser for the octagon plan as shown in chart 5.
- From chart it is also observed that base shear value for diagrid system is much smaller compared to shear wall and rigid frame systems. This shows that lesser seismic forces are acting on the octagon model with diagrid system

4.4. Natural Time Period:

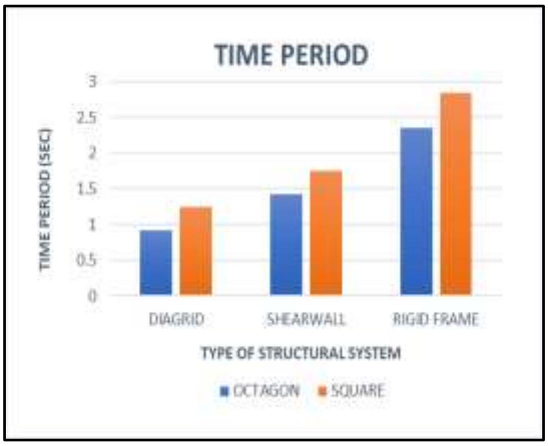

Chart6. Variation of Time period for all the models

- The time period values of the octagon model are the least as shown in chart-4.6. From the above observation it is found that octagon models have higher stiffness compared to square models. We observed that the time period is higher in rigid frame models than in shear wall and diagrid models.
- The time period of diagrid structure is the least suggesting that it has higher stiffness than others. The base shear is least for diagrid structure thus indicating that it is lighter structure than other, thus implying it is more economical than other structures

V. CONCLUSION:

From the analysis results and comparative study put forth in this paper following set of conclusions can be made:

- The introduction of diagrid systems in high rise structures is found to increase the seismic performance of the structure.
- Diagrid Structure overall performs better as lateral load resisting system than simple frame and shear wall systems.
- Diagrid Structure has least Maximum Lateral Displacement and Maximum Storey Drift, which indicates that this system, strengthens the building against lateral loads.
- Maximum storey drift is reduced by 38.2% in diagrids.
- The base shear values in diagrid models are lower than other models which shows that diagrids are lighter structures and thus economical.
- The time periods are less in diagrid system models.

- From the comparison of different shapes of plans like square and octagon for diagrid system, the lateral displacement is least in the octagon plan.
- From the base shear values, it showed that the octagon plans had minimum forces acting on it than square plan for all systems.
- Thus, a diagrid system with octagonal plan shall enhance the resistance of the building against seismic forces in high rise buildings.

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