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Study on the combination of Diagrid and Hexagrid structural systems for tall buildings

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ABSTRACT: Nowadays, the close confrontation between structure and architecture has led to the invention of new structural systems, such as the structural system of Diagrid and Hexagrid. These systems have attracted the attention of many architects and structural engineers due to their structural efficiency and architectural aesthetic potential provided by their unique geometric configuration. Hexagrid structural system has high ductility, and Diagrid structural system has high stiffness. One of the most important principles in the field of high-rise structures is the use of an appropriate structural system that have a significant architecture, in addition to satisfying the three requirements of stiffness, resistance, and ductility in the design of the structure. Therefore, in this study, the combination of two systems of Diagrid and Hexagrid at the height of the structure in order to take advantage of their benefits is proposed. For this purpose, four structures of Diagrid, Hexagrid, Diagrid-Hexagrid compound structure and Hexagrid-Diagrid compound structure were analyzed and designed using the linear dynamic method with ETABS software. Then, their seismic performance was evaluated with PERFORM 3D software using non-linear static analysis in terms of lateral displacement, stiffness, ductility, lateral resistance and behavior factor. Comparison of the structural analysis results shows that the Diagrid-Hexagrid compound structure has a more favorable performance against lateral forces than the two systems of Diagrid and Hexagrid.

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1- Introduction

In tall structures, the importance of the lateral force effect increases rapidly with increasing building height. On the other hand, stiffness, strength and ductility are all necessary to meet the design needs and tall structures should take advantage of these properties in combination. Basically, the degree of hardness and ductility depends on the type of structural system. The diagrid system is more difficult than other structural systems. Due to the use of diagonal members, this system creates considerable shear strength compared to the system with orthogonal members. Another external structural system is the hexagrid system. This system has behavioral structures similar to the diagrid system, except that it uses hexagonal grids to withstand both gravitational and lateral loads in the structural view.

Hardness-based design principles were applied by Moon in 2009 [1] to steel diagrid structures with different heights and lattice geometry to determine the optimal configuration of the diagrid structure within a certain height range. In 2010, Chao Huang et al. [2] proposed two types of connections for diagrid structures. Each connection consists of four diagonally intersecting columns of steel pipe filled with CFST concrete and two beams. They also provided a relation for calculating the bearing capacity of joints according to the Chinese design regulations for CFST columns. In 2013 [3], in order to investigate and determine the optimal configuration of diagrid systems, braced pipes and truss systems in high-rise buildings, he conducted studies and achieved significant results, the most important of which is the effect of stiffness distribution difference on consumable steel with increasing The height of the building. To reduce the stress concentration in the joints of diagrid structural systems, Sung Mu Choi et al. In 2015 [4] proposed two methods to increase the thickness of the capillary and its length and to develop a hardening sheet. Between the two proposed methods, increasing the thickness of the headboard is more effective in terms of the amount of steel and the capacity of the connection structures. Trypty and Singla in 2016 [5] proposed a design method based on the difficulty of determining the initial dimensions of diagrid members for tall buildings. From the comparison of the analysis, the results showed that with increasing the diagrid angle, the time period of the structure and the maximum floor drift increase and the spectral acceleration coefficient and the base shear decrease. Sadeghi et al. In 2018 [6] calculated the response correction coefficient (R), resistance coefficient () and displacement correction coefficient () based on FEMA

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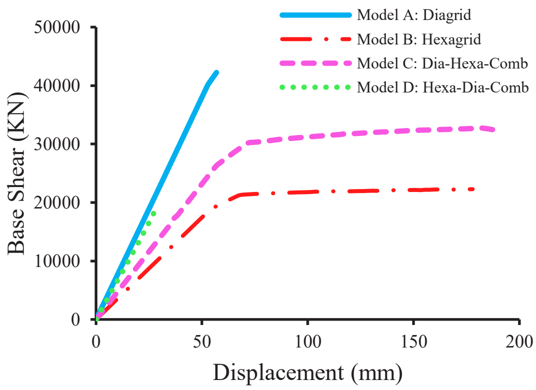

Fig. 1. Comparison of the capacity curve of the studied structures

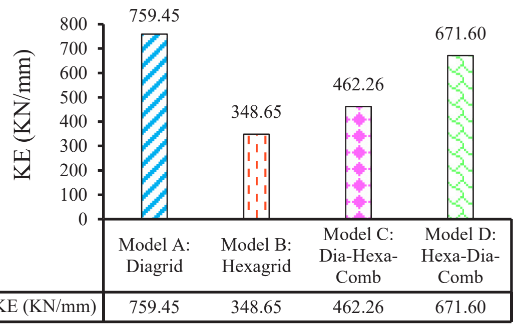

Fig. 2. Initial stiffness of the studied structures

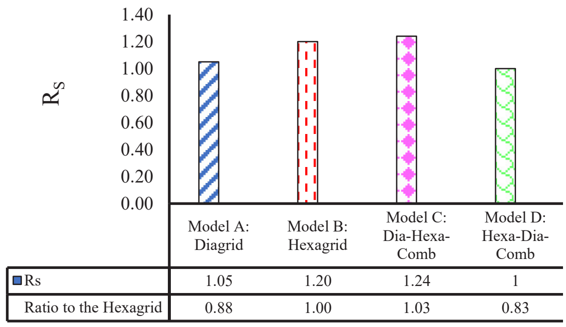

Fig. 3. Over-strength factor of the studied structures

P695 method. The results of their research showed that the R coefficient for steel diagrid systems depends on the angles of the oblique members. For diagrids with angles of 45, 4.63 and 5.71 degrees, the values of R coefficient are 5.1, 2 and 3, respectively. Mashhadi Ali et al. In 2019 [7] evaluated the R response correction factor for hexagrid instruments based on the FEMA P695 method. The results of his evaluation showed that the coefficient R, 4, meets the acceptance criteria. Mohsenian et al. In 2020 [8] analyzed the seismic reliability and estimated the multilevel response correction coefficient for steel diagrid instrument systems.

Examining the studies, it was found that the research in this field is focused on diagrid and hexagrid structures separately and in them, non-linear and dynamic static analyzes have been performed and also some studies have been done on joints and a study regarding the combination of these systems in height has not been done. Also, according to the studies done in the field of external structural systems, it can be pointed out that hexagrid instrument systems have high ductility and diagrid instrument systems have a very high hardness. Therefore, in this study, a combination of hexagrid and diagrid structural systems was considered to improve the stiffness, strength and ductility of high-rise structures. The design and analysis results of this composite instrument system were compared with diagrid and hexagrid systems separately, and the most suitable instrument system in terms of seismic parameters was proposed.

2- Methodology

In order to evaluate the seismic performance of the systems under study, they must first be designed and then evaluated. The selected structures are four 32-story steel buildings with similar plan, heights and loads. The first model is a structure with a diagrid system and the second model is a structure with a hexagrid system. The third model is a structure with a combination of diagrid and hexagrid structural systems at the height of the structure, 16 lower floors of the structure have a diagrid system and 16 upper floors of the structure have a hexagrid system. The fourth model is similar to the third model, except that the hexagrid system is used in the lower 16 floors and the diagrid system in the upper 16 floors. Diagrid systems have eight-tier modules with a diameter of 66.59 degrees and hexagrid systems have four-tier modules with a diameter of 30 degrees.

3- Results and Discussion

- **Structural capacity curve**

Structural capacity curve comparison of force-displacement diagrams of structures is shown in Figure 1. As can be seen, the hexagrid structure (model B) and the diagrid-hexagrid composite structure (model C) have nonlinear behavior and their cover curve has entered the inelastic region, but in the hexagrid-diagrid composite structure, the structure has a completely linear behavior. Each force-displacement diagram is linearized by Priestley and Pauli method and the values of stiffness, lateral strength, ductility and coefficient of the behavior of each model are calculated and compared with each other [9], [10], [11], which are described below in the results of each of them.

- **Lateral stiffness of the structure**

The initial stiffness values of the models are shown in Figure 2. As can be seen, the diagrid structure (model A) has the highest stiffness and the hexagrid structure (model B) has the lowest lateral stiffness, and the stiffness of model D is higher than the stiffness of model C. Hexagrid structure with the lowest slope of the capacity curve has less stiffness than other structures. The stiffness of models C and D is between the stiffness of diagrid and hexagrid models.

- **Lateral strength of the structure**

The obtained lateral strength for each of the structures is shown in Figure 3. The lateral strength of the hexagrid structure is higher than the lateral strength of the diagrid structure, so it has a higher bearing capacity to withstand lateral forces. The diagrid-hexagrid composite structure (model C) has the highest lateral strength. In fact, the nonlinear region in the curve has more capacity and more plastic joints are formed, so model C has the highest ultimate bearing capacity to withstand lateral forces. The extra strength coefficient of the hexagrid-diagrid composite structure is equal to one, as shown in its capacity curve in Figure 1. This structure has a linear behavior and its cover curve does not enter the nonlinear region, so its maximum base shear is equal to the shear. The base is when the first plastic joint is formed; this model does not behave well against the forces of the earthquake.

4- Conclusion

Due to the fact that the Model C structure is a combination of diagrid and hexagrid structures, so it has all the appropriate seismic properties of these two types of systems due to its higher lateral strength, medium stiffness and ductility than diagrid and hexagrid structures with better seismic performance. Also, in terms of economic efficiency and optimal architectural performance, the use of this combined structure is preferred for high-rise structures.

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