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Evaluation of Seismic Performance of Combined Horizontal and Vertical Structural System for High-rise Buildings

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Abstract

Summary In this study, the seismic performance of hexagrid structures which are composed of horizontal and vertical hexagrid by using a transitional story, has been investigated. To this end, 10 models of 50-story hexagrid structures were designed. 9 models with horizontal hexagrid cells which transited to vertical cells using a transitional story, and a model of completely horizontal hexagrid have been designed. Finally, the seismic performance of these models were investigated and compared to the horizontal hexagrid structure to obtain the optimum location of the transitional story. According to the analyses results, combining horizontal and vertical hexagrid cells can strongly affect the seismic performance of the structure. Thus, choosing the optimum location of transitional story, regarding design priorities, is of significant importance.

Keywords: *Hexagrid, Tall Building, Seismic Performance, Nonlinear Analysis*

1. Introduction

In the early structures at the beginning of 20th century, structural members were assumed to carry primarily the gravity loads. As a general rule, when other things being equal, the taller the building, the more necessary it is to identify the proper structural system for resisting lateral loads [1]. Hexagrid is composed of hexagonal grids in the outer perimeter of the building. The configuration of hexagonal grids can be either horizontal, which are called horizontal hexagrid or vertical, which are known as vertical hexagrid. This structure is inspired by natural pattern of honeycombs. Among all structural systems, the most efficient is the one with tube-type performance [2]. In fact, locating a major lateral load-resisting system at the building perimeters has led to efficient use of structural capacity. The main idea of tubular system is to arrange the structural elements on the perimeter of building, so that the system can effectively resist lateral loads acting on the building. Hexagrid system, due to its arrangement of bearing elements, is a kind of tubular systems. The hexagonal shape of the grids make them participate in carrying both gravity and lateral loads acting on the structure. Hence, hexagrid is suitable for buildings with large spans; even the corner columns can be eliminated in need of architecture.

Previous researches on hexagrid structures has focused on horizontal or vertical grids independently, and the combination of these two types of grids has received no attention. Montouri et al. have determined the optimal angle of diagonal members and intended to make a first insight to hexagrid structural performance [3]. Nejad and Kim have modeled an 80 story tall building with the optimized angle and topology of horizontal hexagon members [4].

In this study, horizontal hexagons have been changed in to vertical ones through a transitional story. The location of the transitional story, has been changed every 5 story in each model to obtain more accurate results. Thus, 9 models have been generated and what was distinguished each model, was the location of the transitional story. A model has also been designed with just horizontal hexagrid to compare whether locating a

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transitional story can result in better performance of the building or not.

2. Hexagrid structural system

As mentioned earlier, locating a major lateral load-resisting system at the building perimeters has led to the efficient use of structural capacity. The main idea of tubular system is to arrange the structural elements on the perimeter of building, so that the system can effectively resist lateral loads acting on the building. In hexagrid structural system, hexagons were located at the periphery of the building, thus this system acts like a tube system. A perspective view of hexagrid structure is shown in Figure1.

Typically two types of hexagonal grids are used in buildings, horizontal hexagrid and vertical hexagrid which are shown in Figure 2.

In this study, horizontal hexagrid converted into the vertical one by means of a transitional story. Figure 3 depicts the arrangement of grids around the transitional story.

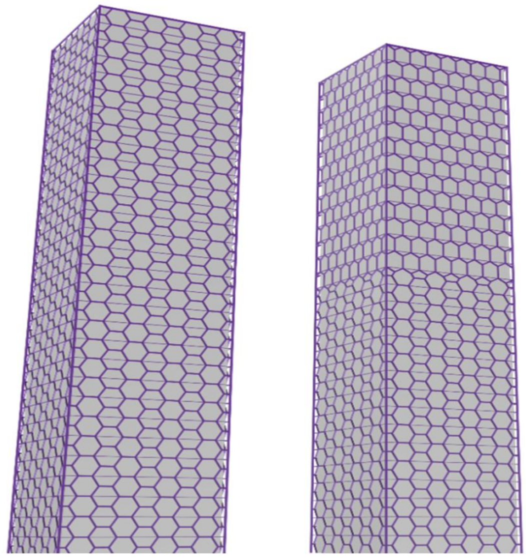

Figure 1. Hexagrid structure a. horizontal b. combined horizontal-vertical

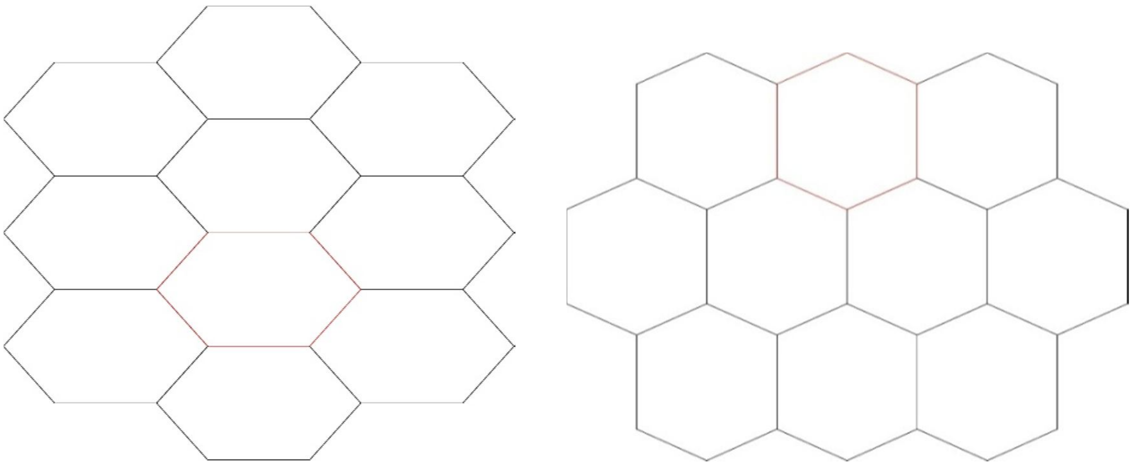

Figure 2. Conventional hexagrid a. horizontal b. vertical

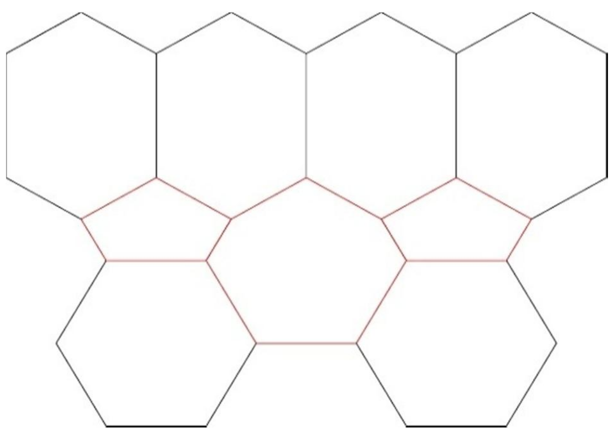

Figure 3. Transitional zone from horizontal hexagrid to vertical one

3. The analyses procedure

All 10 models are 50 story buildings with the story height of 3.464 m. The typical plan and 2-D elevation of each model are shown in Figure 4 and Figure 5, respectively. The design dead and live loads on floor slabs are 600Kg/m2 and 250 Kg/m2 respectively.Table 1 represents geometrical properties of studied models. The design earthquake load is computed based on the zone factor of 0.35, soil II, importance factor of 1 and response reduction factor of 6. The yield strength of steel is considered as 2400 Kg/cm2.
Recognizing the limitations of linear analysis, its deficiencies and potential for inaccurate conclusions, the behavior of buildings has been studied by nonlinear static pushover and nonlinear dynamic time history analyses using PERFORM-3D [5]. The models are first modeled and designed using ETABS software [6] to obtain the elements cross sections. Then they've been subjected to nonlinear static pushover and time history analysis in PERFORM-3D [5]. The PERFORM-3D models were composed of nonlinear beams and columns. Beams are modeled via the use of FEMA beam elements, columns and hexagonal elements were also modeled via FEMA column elements as they behave like a column in both flexural and axial manner. All 10 models are modeled in PERFORM-3D and for the verification of modeling in PERFORM-3D and ETABS [6], the first mode period of all models have been compared in Table 2. As it can be seen, there has been an acceptable difference of periods for all models. For nonlinear dynamic analyses 7 pairs of earthquake time-history records are selected and scaled according to Iran's 2800 seismic provision requirements [7]. All records are selected from far fault ground motion records, and covered a range from 5.9 to 7.3 of magnitude as represented in Table 3. Figure 6 depicts the pseudo acceleration response spectrum of the selected ground motion records.

Table 1. Geometrical properties of studied models

Plan dimension	24x24 m
Story height	3.464 m
Gravity span length	6 m
ceiling	One-way slab
Live Load	250 Kg/m^2
Dead Load	600 Kg/m^2

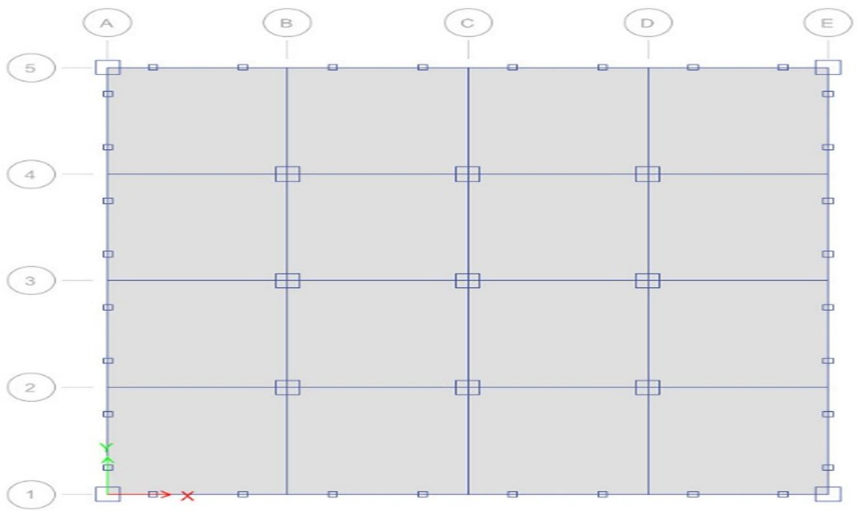

Figure 4. Typical plan used for studied models

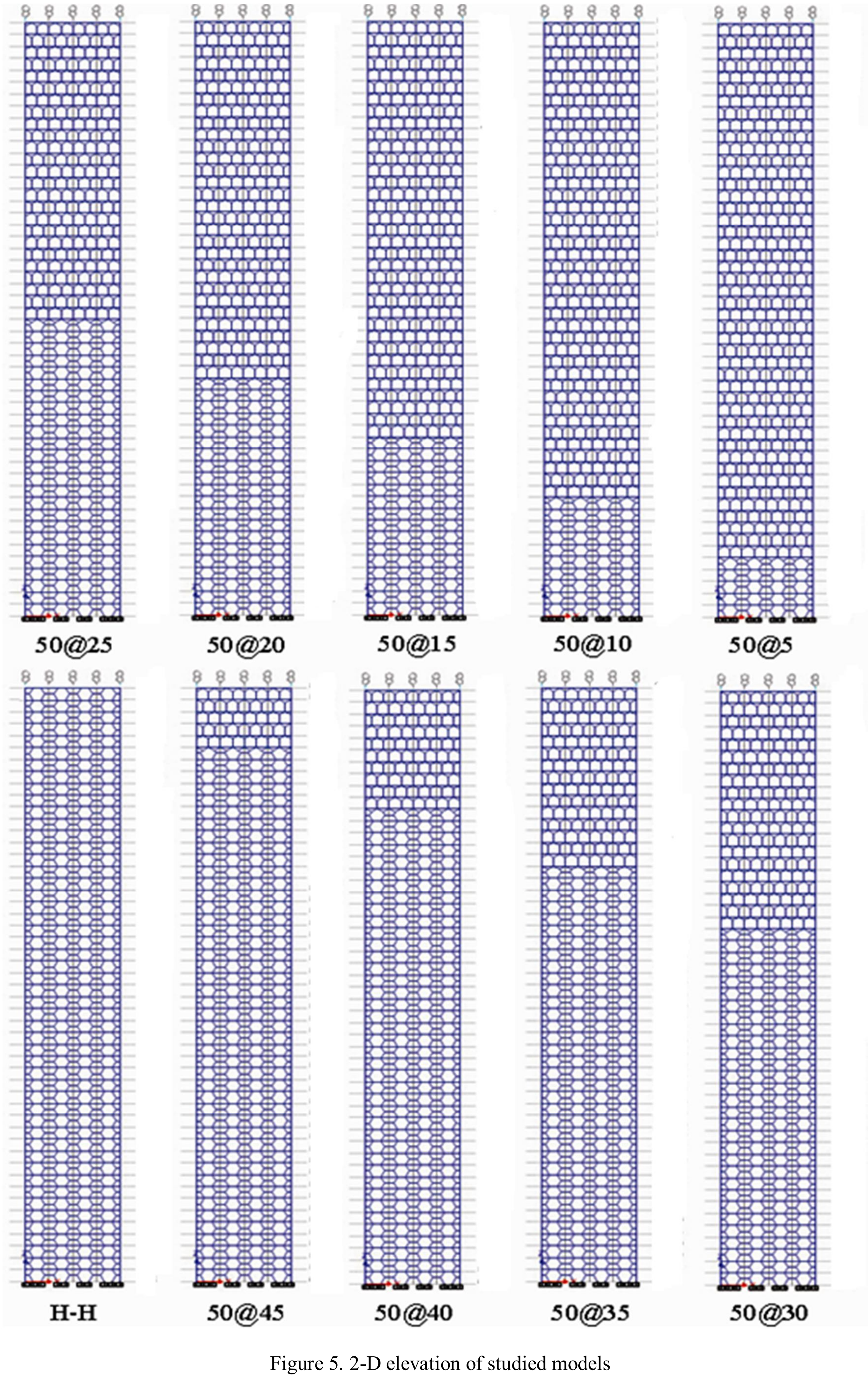

Figure 5. 2-D elevation of studied models

Table 2. Verification of models in ETABS and PERFORM-3D

model	Location of transitional story	First mode period (s) from ETABS	First mode period (s) from Perform 3-D	Difference percentage
1	5th story	4.95	4.62	6%
2	10th story	5.04	4.85	3.7%
3	15th story	4.73	4.54	4%
4	20th story	4.95	4.82	2.6%
5	25th story	4.57	4.33	5.2%
6	30th story	4.84	4.69	3%
7	35th story	5.12	4.92	4%
8	40th story	4.50	4.24	5.7%
9	45th story	4.66	4.43	4.9%
10	Horizontal Hexa	4.65	5.32	5.8%

Table 3. Properties of ground motion records used for nonlinear dynamic analysis

ID No.	Earthquake			Station	Soil Data	Site-Source Distance	Normalization Factor
	Magnitude	Year	Name	Name	NEHRP	Joyner Boore	
1	6.61	1971	San Fernando	Fairmount	C	25.6	7.3
2	6.5	1976	Firiuli	Barcis	C	49.1	3.3
3	5.9	1978	Santa Barbara	Cachuma	C	23.7	9.9
4	5.9	1979	Norcia	Bevagana	C	31.4	4.5
5	7.0	1992	Cape Mendocino	Shelter	C	26.5	58.4
6	7.3	1992	Landers	Silent Valley	C	50.8	2.5
7	6.7	1994	Northridge	Alhambra	C	35.7	3

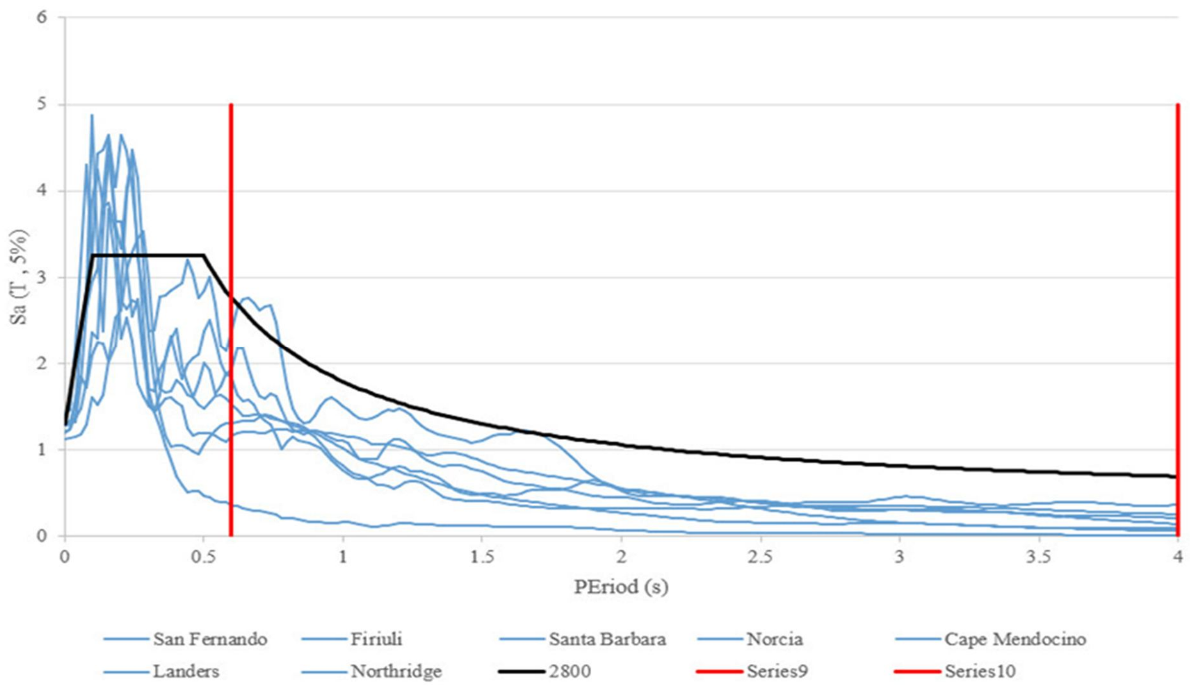

Figure 6. Pseudo acceleration response spectrum of the selected ground motions

4. Results

In this section, results obtained from the nonlinear static and dynamic analyses are investigated. Nonlinear static analysis results Pushover analyses have been carried out by means of uniform load distribution pattern, and capacity curves are demonstrated in Figure 7. As it can be inferred from Figure 7, horizontal hexagrid has the least stiffness and the model with transitional story in the 0.8 height of the building, has the most stiffness among the studied models. Moreover, the model with transitional story in the 0.4 height of building, represented a favorable ductility. Therefore, by locating the transitional story in this height, the ductile behavior of the building increases and more energy dissipation will be expected. Table 4, represents the impact of the location of transitional story on the amount of dissipated energy. Locating the transitional story in an inappropriate height, can lead to severe structural inefficacy. As it can be inferred from table 4, locating the transitional story in 0.3 height of the structure and also in 0.8 height of the structure can even decrease the absorbed energy compared to horizontal hexagrid structure, about 0.13 and 0.65 times respectively.

To make better sense of this numerical results, a comparison has been illustrated in figure 8 and the amount of absorbed energy in each model building has been compared. As it can be concluded from table 4 and figure 8, by locating the transitional story in the 0.4 height of the building, the absorbed energy increases about two times compared with the model with no transitional story.

5. Nonlinear dynamic analysis results

In this section, drift quantities of all the 10 models have been evaluated by subjecting the models to the 7 pairs of ground motion records as mentioned in Table 3. Figure 9 depicts the nonlinear inter story drifts of all models. As it can be observed, drift quantities for all models are less than the maximum drift, which is defined in Iran’s 2800 seismic provisions [7]. Maximum amount of average drift of structures has been represeneted in table 5.

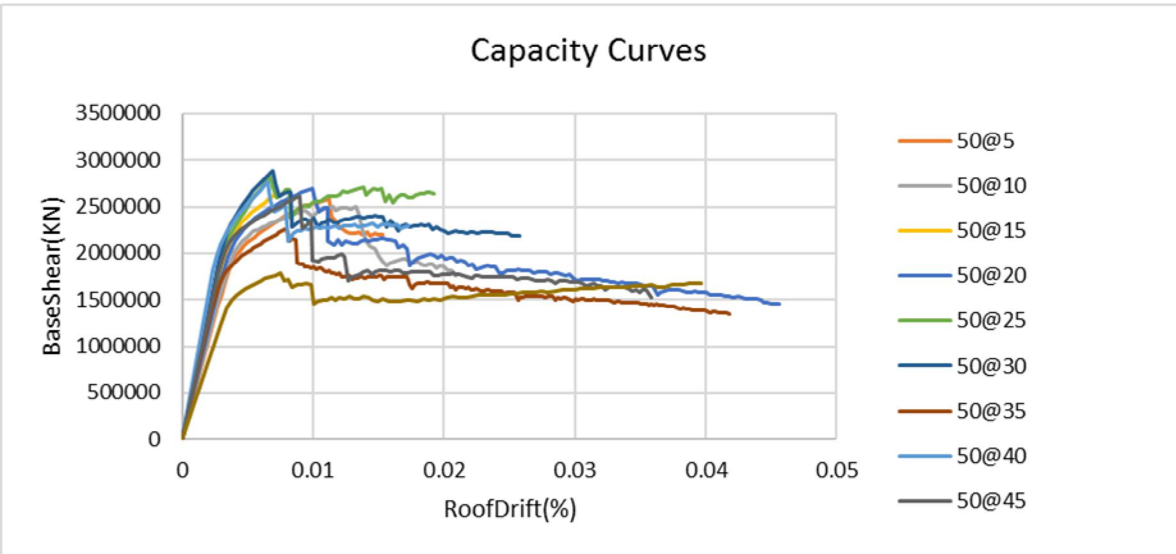

Figure 7. Capacity curves of models under uniform load distribution

Table 4. Absorbed energy of the studied models

Model	Absorbed Energy (KN)	Ratio of the absorbed Energy to the Horizontal Hexagrid
50@5	2.33E+06	0.50
50@10	3.93E+06	0.85
50@15	6.15E+05	0.13
50@20	8.80E+06	1.90
50@25	3.35E+06	0.72
50@30	4.97E+06	1.07
50@35	6.70E+06	1.45
50@40	2.96E+06	0.64
50@45	6.45E+06	1.39
H-Hexa	4.63E+06	1.00

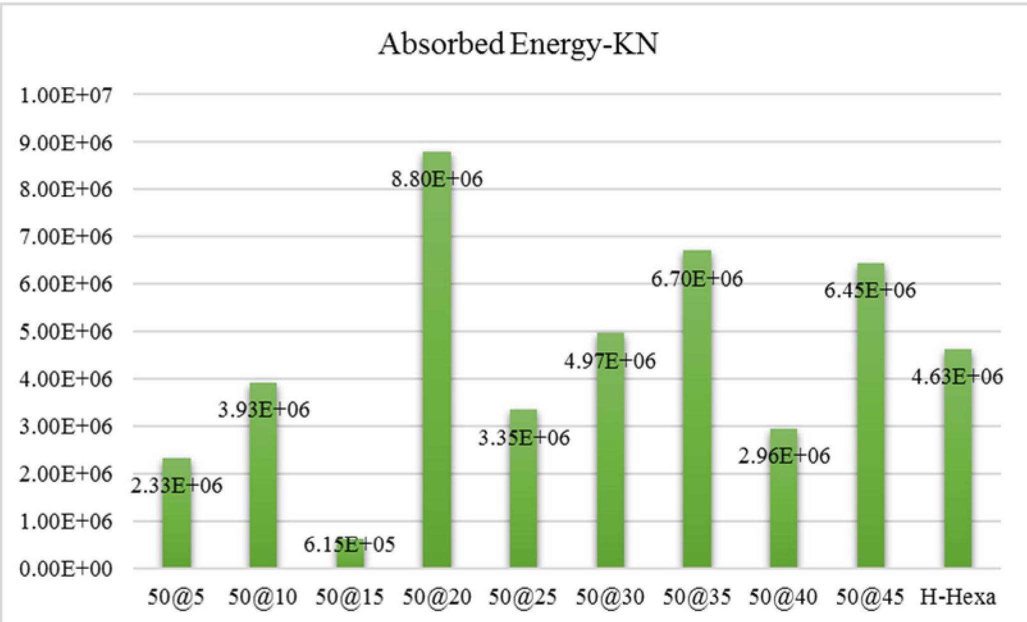

Figure 8. Amount of absorbed energy by each structure

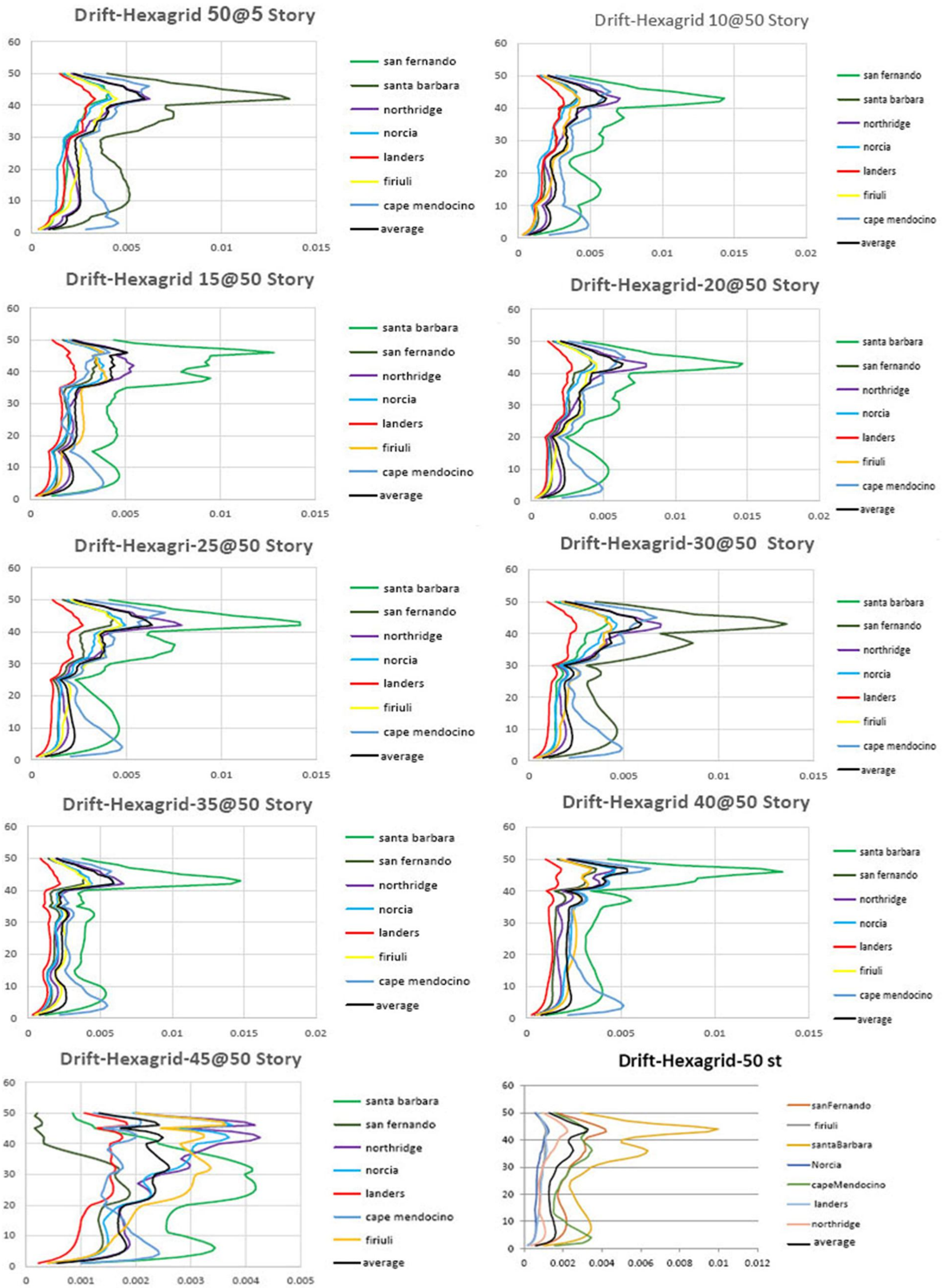

Figure 9. Inter story drift for all 10 models under 7 pairs of ground motion and the average of drifts

Table 5. Maximum amount of average drift

Model Number	Location of the transitional story	Maximum drift
1	50@5	0.006
2	50@10	0.006
3	50@15	0.005
4	50@20	0.006
5	50@25	0.007
6	50@30	0.007
7	50@35	0.007
8	50@40	0.005
9	50@45	0.003
10	H-Hexa	0.003

As it can be inferred from table 5, horizontal hexagrid has the least drift among the studied structures. The maximum average drift belongs to models number 5, 6 and 7, which is about 2.5 times greater than the maximum average drift in horizontal hexagrid system.

6. Discussion

The results obtained from the analyses are discussed as follows:

Locating the transitional story in the 0.4 height of a 50-story building can significantly increase the amount of dissipated energy (about 2 times compared to the horizontal hexagrid structural system), which is a great advantage of combined horizontal-vertical hexagrid structural system.

According to the capacity curves, the model with transitional story in the 0.4 height of building, has the most ductility and the capacity of this structure for dissipating the input energy as about 1.5 times more than the horizontal hexagrid structure. Horizontal hexagrid structural system has less stiffness in comparison to all models of combined horizontal-vertical hexagrid.

Therefore, locating the transitional story in the 0.4 height of a building, will significantly lead to more efficient use of the capacity of the load resisting system.

7. References

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