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Comparitive Structural Analysis of High Rise Buildings with different Geometrical Plan using Floor Diaphragm

Abhishek Soni
Department of Civil Engineering
University Institute of Technology
(RGPV)
Bhopal, India
abhishek.soni91@gmail.com

Aruna Rawat
University Institute of Technology
(RGPV)
Bhopal, India
augupta2001@gmail.com

Suresh Singh Kushwah
Department of Civil Engineering
University Institute of Technology
(RGPV)
Bhopal, India
skushwah@rgtu.net

Abstract— In this study, comparative structural analyses of three-dimensional (3-D) G+20 high-rise buildings with and without rigid floor diaphragm have been considered. The three different building plans hexagonal, pentagonal and square are considered. The buildings are also considered with different elevation floors that are 5 floors, 10 floors, 15 floors and 20 floors. The building are analyzed for four different Indian seismic zones (zone II, III, IV and V) as per IS 1893-2002. Total 96 buildings are analyzed with 27 load combinations. The buildings are critically analyzed to quantify the effects of various parameters for maximum axial forces, bending moment and shear force in beams, seismic forces, wind forces and floor displacements. The results show that using rigid diaphragm is more efficient in reducing above parameters in buildings for lateral forces. Rigid diaphragm concept is reasonable for building square in plan rather than pentagonal or hexagonal building plan.

Index Terms— Bending moment, Displacement; Rigid floor diaphragm, Seismic loading.

1 Introduction

To overcome the scarcity of space in the urban areas, high-rise buildings are the hallmark of modern society. The need for high-rise buildings is increasing in our country day by day as land is becoming scarce which is encouraging the commercial utilization and the construction of high-rise buildings. Behaviour of high-rise buildings to seismic lateral forces has to be critically examined considering various geometrical, parameters. Most commonly used horizontal structural systems for strengthening buildings against lateral force are diaphragm and trussing system. Diaphragm is a building component that transmits lateral force to vertical force resisting components. Some of the prominent research works carried out on the floor diaphragm is as follows:

Moon and Lee (1994) proposed efficient model for high-rise structure including inplane floor slab flexibility without reducing the accuracy of the analysis, and also proposed a floor flexibility index whose impacts are researched through parametric studies in terms of seismic base shear and its distribution, and displacement at the roof. The result shows that it is desirable to include the inplane deformation of floor slabs in the earthquake analysis of structures for economical and safe design when the inplane deformation of floor slabs is expected to be large.

Kim et al. (2003) modelled the building structures without the floor slabs assuming that they would have negligible effects on the response of a structure. The floor slabs are simply replaced by rigid floor diaphragms for the efficiency in the analysis. Beams and floor slabs are divided into several elements thus more time is required for the analysis procedure and resolved the problems, efficient analytical modelling methods employing the sub structuring techniques, superelements, and rigid diaphragms were adapted. The analytical results of time history analysis and the computational time of various analyses for example structures were compared to investigate the validity of the proposed modelling techniques proposed.

Basu and Jain (2004) studied the center of rigidity for rigid floor diaphragm buildings that has been extended to unsymmetrical buildings with flexible floors. They proposed a procedure ensures that the resultant member force is close to that of rigid floor buildings as the floor diaphragm rigidity increases. A superposition-based methodology was proposed to execute code-specified torsional provisions for structures with flexible floor diaphragms. The result showed that resultant member force is close to that of rigid floor diaphragm buildings as the floor diaphragm rigidity increases and also it was seen that treating the diaphragms of structures as rigid for torsional analysis may cause considerable error.

Bull et al. (2008) explored the trends and magnitude of forces in concrete floor diaphragms for seismic loading. A new pseudo-Equivalent Static Analysis (pESA) method for determining inertial forces in floor diaphragms was analyzed.

Hadianfard and Sedaghat (2013) studied the non-linear response of flexible concrete floor diaphragm with braced steel building under both dynamic ground motions and static lateral loads. The results were compared with rigid diaphragms. The study explained that span ratio was important parameter in flexibility of floor diaphragm. The results showed that the maximum drift and displacement of flexible floor diaphragm was higher than in rigid floor diaphragm. Yield base shears and initial stiffness of flexible floor diaphragm were higher than for rigid diaphragm. For span ratio greater than 3:1 in low rise buildings the ultimate base shear capacities reduces significantly in flexible floor diaphragm rather than in case of the rigid floor diaphragm analysis.

Rehan and Mahure (2014) discussed the design and analysis of G+15 stories R.C.C., steel and composite building under effect of earthquake and wind using STAAD Pro. The result showed that steel-concrete composite building performed better.

Shivare et al. (2014) carried out earthquake analysis of high- rise buildings considering four buildings of same area but different geometrical plan. The result showed that diaphragm modelling has major influence on moment and displacement.

The objective of the present study is (i) to compare the structural analyses of three-dimensional (3-D) G+20 high-rise buildings with and without floor diaphragm, (ii) to perform the analysis on three building plans, viz. hexagonal, pentagonal and square. The buildings are also considered with different elevation floors that are 5 floors, 10 floors, 15 floors and 20 floors, (iii) to carry out the analyzed for four different Indian seismic zones (zone II, III, IV and V) as per IS 1893-2002. Total 96 buildings are analyzed with 27 load combinations, and (iv) to quantify the effects of various parameters minimum and maximum bending moment, axial forces, and shear forces in columns and beams, seismic forces and floor displacement on buildings with and without rigid floor diaphragm.

2. METHODOLOGY

A comparative study of G +20 high- rise building for different geometrical plans and diaphragm constraints under seismic loading. . A comparison of results in terms of minimum and maximum moments, axial forces, shear forces in columns and beams, seismic forces and displacements are carried out. Following steps are adopted in the present study:-

Step-1 Selection of building geometries and story (3 geometry plan and G+20 storeys)

Step-2 Selection of diaphragm models – with and without rigid floor (2 types)

Step-3 Selection of four seismic zones (II, III, IV, V)

Step-4 Formation of load combination (27 load combinations)

Step-5 Modelling of building using STADD.Pro software

Step-6 Comparison of results in terms of minimum and maximum bending moment, axial forces, and shear forces in columns and beams, seismic forces and displacement.

STRUCTURAL MODELLING AND ANALYSIS

(a) Modelling of building frames

Building frame with the following three geometrical configurations in plan as shown in Fig. 1 are considered for analysis-

CASE-1: Square building frame 15 m × 15 m in plan area and 20 storey height.

CASE-2: Pentagonal building frame inscribed in 15 m × 15 m plan area and 20 storey height.

CASE-3: Hexagonal building frame inscribed in 15 m × 15 m plan area and 20 storey height.

Building frame with different elevations are considered for analysis for all the above mentioned plans as follows:

TYPE 1: Regular building frame.

TYPE 2: Regular building frame having section cut from 5th floor to 20th floor.

TYPE 3: Regular building frame having section cut from 10th floor to 20th floor.

TYPE 4: Regular Building Fame having section cut from 15th floor to 20th floor.

The Fig. 2 shows the different elevation for square plan building and similar elevations are for the pentagonal and hexagonal plan buildings.

Number of beams and columns for these cases are given in Table 1.

(b) Types of diaphragm

The following two types of diaphragm conditions have been considered for analysis-

Type-A: Model without rigid floor diaphragm constraint.

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Type-B: Model with rigid floor diaphragm constraint

(c) Material and geometrical properties

Material properties have been considered in the modelling are density of RCC: 25 kN/m3, density of masonry: 20 kN/ m3 Young's modulus of concrete: 2.17185 × 1016 N/m2, Poisson ratio: 0.17

The foundation depth is considered at 3.5m below ground level and the typical storey height is 3.5 m. The column size is 450 mm × 450 mm, and the beam size is 350 mm × 500 mm.

(d) Loading conditions

Following loading are conducted for analysis -

Dead loads: as per IS 875-1987 (Part 1)

Self weight of slab for 150 mm thick. slab = 0.15 × 25 = 3.75 kN/m2

Floor finish load = 1 kN/ m2

Water proofing load on roof = 2.5 kN/ m2

Masonry wall load = 0.20 × 2.55 × 20 = 10.2 kN/m

Live loads: on typical floors = 2 kN/ m2 as per IS 875-1987 (Part 2)

Seismic load: All the building frames are analyzed for four seismic zones. The seismic load are derived for following seismic parameters as per IS: 1893-2002 (part 1)

a. Seismic zones: II, III, IV, V

b. Response reduction factor (R): 5

c. Importance factor (I): 1

d. Damping: 5%

e. Soil type: medium soil

(e) Structural Analysis

Structural analyses of the building frames are carried out using STAAD.Pro software. All the columns are rigidly supported at ground and 27 load combinations, given in Table 2, are considered for the analysis purposes. Application of boundary and loading conditions are done through the GUI mode of the software.

3. RESULTS AND DISCUSSION

The results of seismic analyses of G+20 building with and without rigid floor diapgragm are as follows:

a. Bending moments

The minimum and maximum bending moments in beams for different cases are shown in Figs. 3 and 4 and Tables 3 and 4, respectively. The minimum bending moment in beams are oserved in building frame having square plan with floor diaphragm and the maximum bending moment in beams are observed in building frame having pentagonal plan without floor diaphragm. The bending moment in beams decrease in series from pentagonal, hexagonal to square building plan. It can be observed that bending moments can be drastically reduced using rigid floor diaphragm by about 40 - 50%.

b. Axial force

Minimum and maximum axial force in columns is shown in Figs. 5 and 6 and Tables 5 and 6, respectively. The minimum axial force in column are observed in building frame having square plan with floor diaphragm and maximum axial force in column are observed in building frame having pentagonal plan without floor diaphragm. The axial force in columns has are not so much affected by using floor diaphragm.

c. Shear force

Minimum and maximum shear force in beam is shown in Figs. 7 and 8 and Tables 7 and 8, respectively. The minimum shear force in beam is observed in building frame having square plan with floor diaphragm. Maximum shear force in beam is observed in building frame having hexagonal plan without floor diaphragm. Maximum shear force in beams is lesser in building frame with floor diaphragm. And it has been reduced by about 45 - 55%.

d. Displacement

Maximum displacement in *X*- and *Z*- transmissions are shown in Figs. 9 and 10 and Tables 9 and 10, respectively. Maximum displacement is observed in building frame having pentagonal plan without floor diaphragm. By application of floor diaphragm the displacement is reduced by about 35 - 45 %

Table 1: Number of beams and columns in different cases

Member	Square	Pentagonal	Hexagonal
Columns	756	273	357
Beams	1260	420	588

Table 2: Different load combinations

Load case no.	Load case detail	Load case no.	Load case detail
1.	EQ IN X DIR.	14.	0.9 DL + 1.5 EQX
2.	EQ IN Z DIR.	15.	0.9 DL - 1.5 EQX
3.	DEAD LOAD	16.	0.9 DL + 1.5 EQZ
4.	LIVE LOAD	17.	0.9 DL - 1.5 EQZ
5.	1.5 (DL + LL)	18.	1.0 (DL + LL)
6.	1.5 (DL + EQX)	19.	1.0 (DL + EQX)
7.	1.5 (DL - EQX)	20.	1.0 (DL - EQX)
8.	1.5 (DL + EQZ)	21.	1.0 (DL + EQZ)
9.	1.5 (DL - EQZ)	22.	1.0 (DL - EQZ)
10.	1.2 (DL + LL + EQX)	23.	0.8 (DL + LL + EQX)
11.	1.2 (DL + LL - EQX)	24.	0.8 (DL + LL - EQX)
12.	1.2 (DL + LL + EQZ)	25.	0.8 (DL + LL + EQZ)
13.	1.2 (DL + LL - EQZ)	26.	0.8 (DL + LL - EQZ)
		27.	LOAD FOR CHECK

Table 3 Minimum bending moments in beams

Comparison of minimum bending moments in beams			
Case	Moment M_z in kNm [beam] (node number)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	76.711 [106] (1) Type 4 Zone 2	112.631 [199] (81) Type 2 Zone 2	97.910 [496] (188) Type 3 Zone 2
Without floor diaphragm	107 [606] (303) Type 1 Zone 1	171.120 [210] (92) Type 1 Zone 3	117.270 [376] (152) Type 1 Zone 2

Table 4 Maximum bending moments in beams

Comparison of maximum bending moments in beams			
Case	Moment M_z in kNm [beam] (node number)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	325.290 [144] (39) Type 2 Zone 5	428.524 [34] (1) Type 1 Zone 5	392.495 [271] (103) Type 2 Zone 5
Without floor diaphragm	568.368 [509] (326) Type 3 Zone 5	803.083 [230] (106) Type 1 Zone 5	791.320 [355](147) Type 2 Zone 5

Table 5 Minimum axial force in columns

Comparison of minimum axial force in columns			
Case	Axial force F_x (kN) [column] (node number)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	390.950 [106] (6) Type 3 Zone 2	747.389 [22] (2) Type 3 Zone 2	640.281 [29] (1) Type 2 Zone 2
Without floor diaphragm	518.870 [110] (5) Type 4 Zone 2	1008.540 [21] (1) Type 2 Zone 2	836.990 [29] (1) Type 2 Zone 2

Table 6 Maximum axial force in columns

Comparison of maximum axial force in columns			
Case	Axial force F_x in kN [column] (node number)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	5467.306 [111] (6) Type1&2 Zone 5	9108.521 [26] (21) Type 1 Zone 5	9815.012 [80] (19) Type 1 Zone 5
Without floor diaphragm	5645.997 [570](270)	10389.014 [21](16)	9422.435 [30] (19)

	Type1&2 Zone 5	Type 1 Zone 5	Type 1 Zone 5

Table 7 Minimum shear force in beams

Comparison of minimum shear force in beams			
Case	Shear force F_y (kN) [beam] (node number)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	43.480 [106] (1) Type 4 Zone 2	111.900 [86] (52) Type 1,2,3&4 Zone 2 & 3	121.828 [132] (68) Type 1,2,3&4 Zone 2 & 3
Without floor diaphragm	104.630 [496] (308) Type 1 Zone 2	142.097 [332] (134) Type 3 Zone 2	153.273 [400] (164) Type 1 Zone 2

Table 8 Maximum shear force in beams

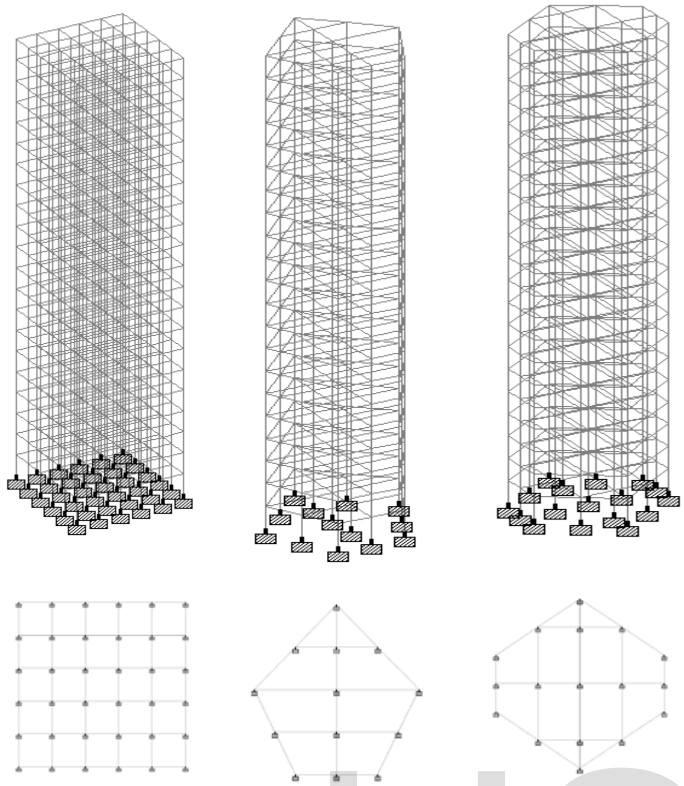
Comparison of maximum shear force in beams			
Case	Shear force F_y in kN [beam] (node number)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	180.517 [144] (39) Type 3 Zone 5	237.754 [21] (1) Type 1 Zone 5	217.956 [29] (1) Type 1 Zone 5
Without floor diaphragm	402.984 [509] (326) Type 3 Zone 5	444.671 [230] (106) Type 1 Zone 5	473.378 [68] (39) Type 4 Zone 5

Table 9 Maximum displacement in *X* transmission

Comparison of maximum displacements			
Case	*X*-transmission in mm (node number)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	345.456 (129) Type 2 Zone 5	516.427 (276) Type 2 Zone 5	435.739 (358) Type 2 Zone 5
Without floor diaphragm	434.062 (393) Type 3 Zone 5	961.174 (276) Type 2 Zone 5	806.143 (370) Type 2 Zone 5

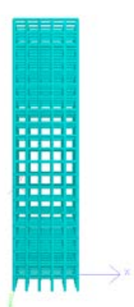
Table 10 Maximum displacement in *Z* transmission

Comparison of maximum displacements			
Case	*Z*-transmission in mm (node number)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	271.837 (127) Type 1 Zone 5	358.873 (281) Type 1 Zone 5	426.875 (358) Type 1 Zone 5
Without floor diaphragm	423.358 (132) Type 3 Zone 5	738.271 (276) Type 1 Zone 5	698.182 (362) Type 1 Zone 5



Case-1(square) Case-2 (pentago-nal) Case-3(hexagonal

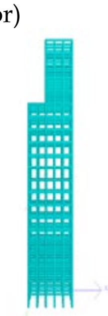
Fig. 1: Structural model of building frames



TYPE 1 (20^{th} floor)

TYPE 2 (cut from 5^{th} floor up to 20^{th} floor)

TYPE 3 (cut from 10^{th} floor up to 20^{th} floor)



TYPE 4 (cut from 15^{th} floor up to 20^{th} floor)

Fig. 2: Elevations of square building

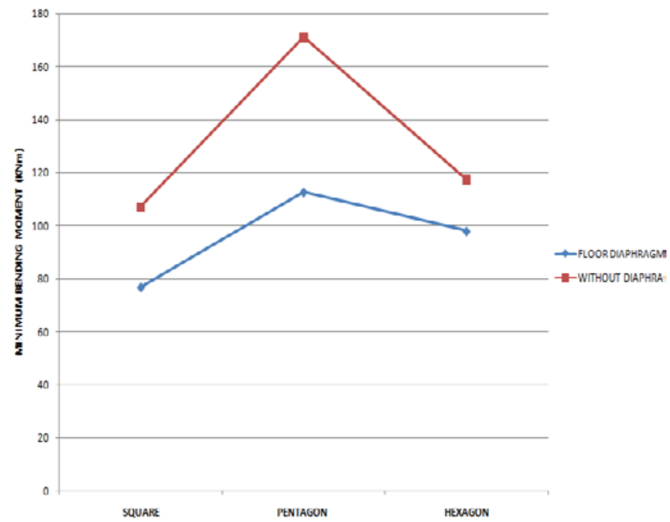


Fig. 3: Minimum bending moment in beam

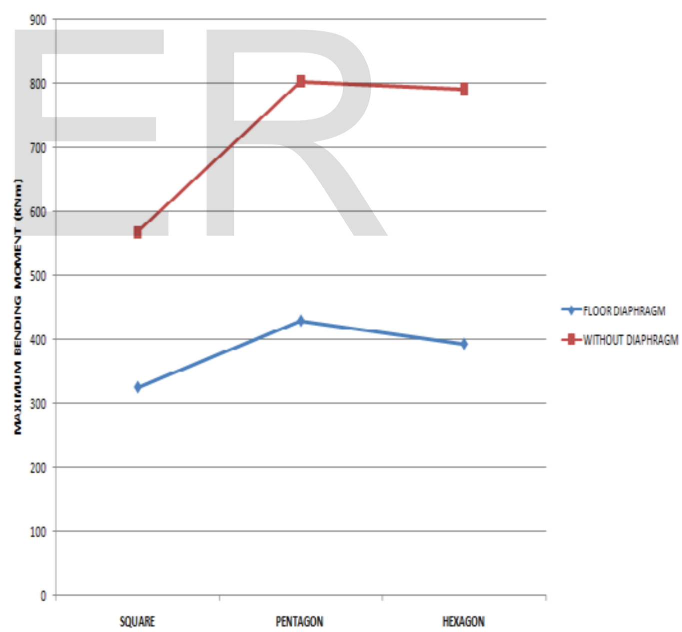


Fig. 4: Maximum bending moment in beam

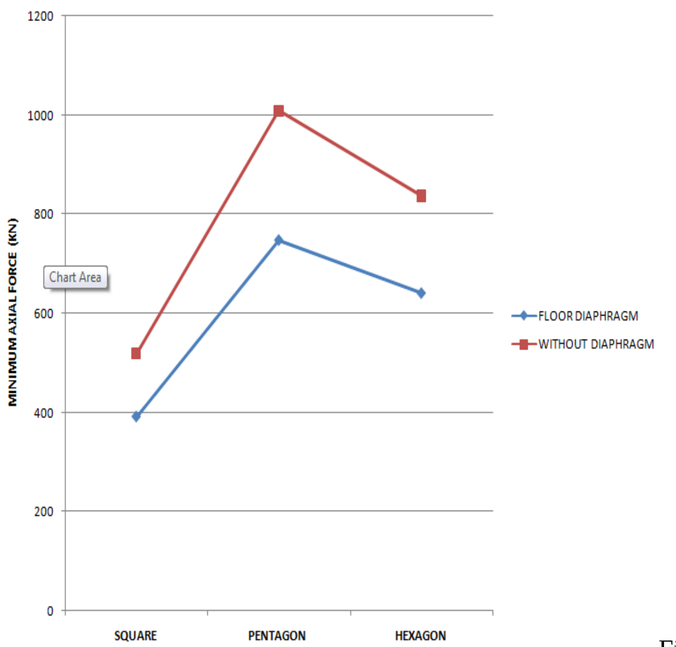


Fig. 5: Minimum axial force

Fig. 6: Maximum axial force

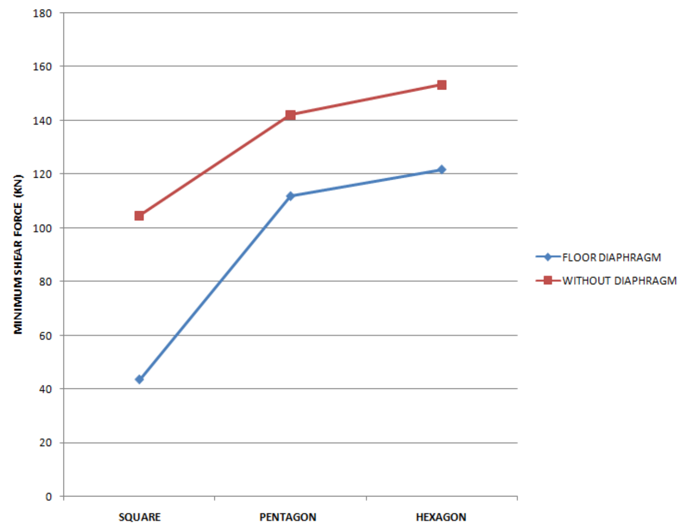


Fig. 7: Minimum shear force

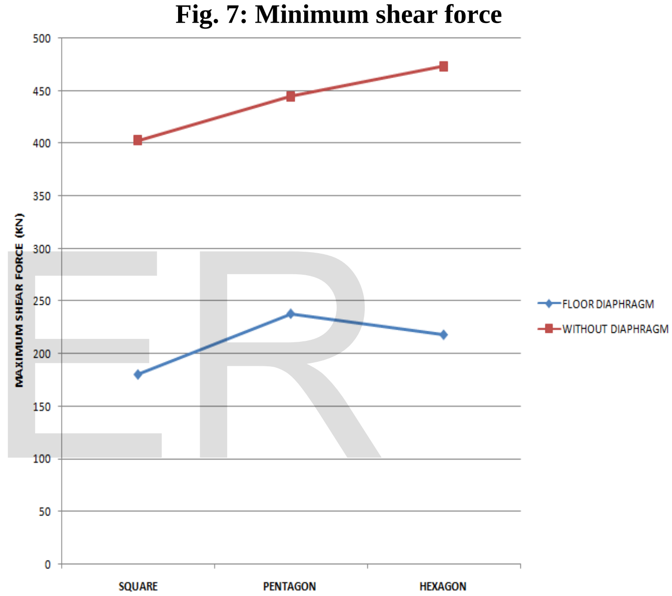


Fig. 8: Maximum shear force

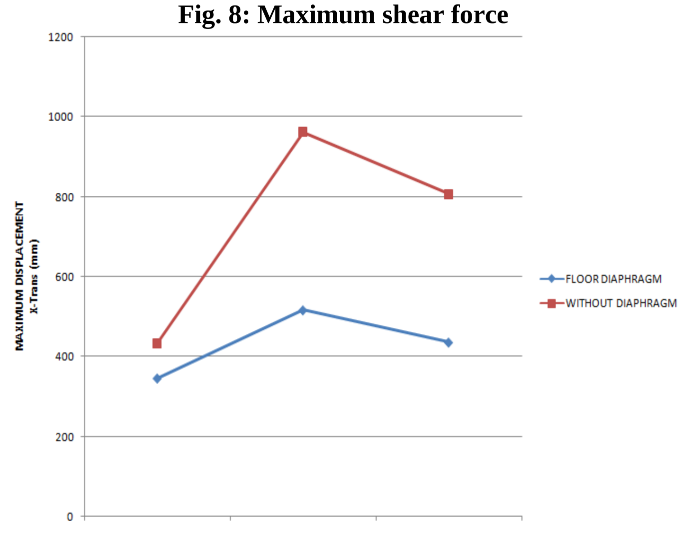


Fig. 9: Maximum displacement in *X* transmission

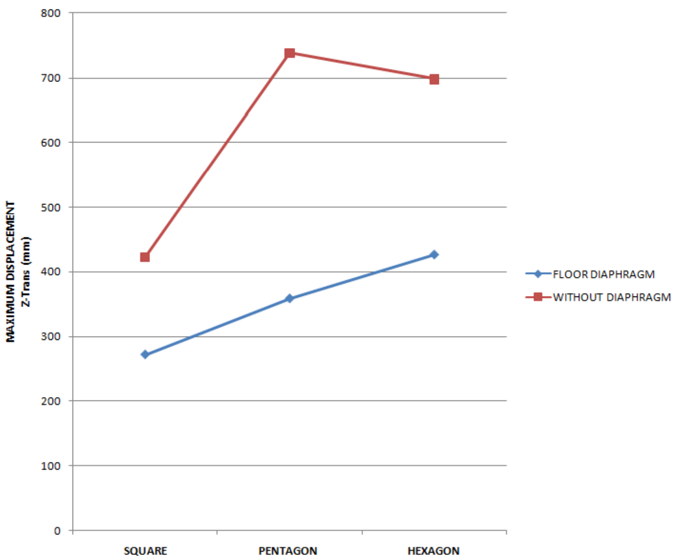


Fig. 10: Maximum displacement in *Z* transmission

4 Conclusion

In this study, a comparative structural analysis of 3-D G+20 high-rise buildings with and without rigid floor diaphragm is carried out. The results of this parametric study shows that rigid floor diaphragm modelling has major influence on bending moment, axial force, shear force and displacement of the high-rise buildings. The analyses show that the rigid floor diaphragm is more effective in reducing seismic responses in square buildings.

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