Wind Analysis of Tall Building with Floor Diaphragm

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Abstract - *In this study, wind analyses of three-dimensional (3-D) G+20 tall buildings with and without rigid floor diaphragm is considered. The effect of diaphragm on three different geometrical plans hexagonal, pentagonal and square is also studied. The buildings are considered with different elevation floors that are 5 floors, 10 floors, 15 floors and 20 floors for all the geometrical plan buildings. The buildings are analyzed as per IS 875-1987 part 3 for wind zone II. In this way total 24 buildings are analyzed with 27 load combinations. The responses in terms of bending moment, shear force in beams and floor displacements are analysed and these responses are compared with building without rigid floor diaphragm.*

Key Words: Displacement, Floor diaphragm, Bending moment, Wind loading.

1.INTRODUCTION

Recent years, many tall buildings and structures are constructed and more are being planned in the world. Wind loads and responses are the key factors for their structural designs. The need for tall buildings is increasing in our country day by day as land is becoming scarce which is encouraging the commercial utilization and the construction of the tall buildings. Behaviour of tall buildings to wind loading has to be critically examined considering various geometrical and wind parameters. For strengthening buildings against lateral force horizontal structural systems such as diaphragm and trussing system are used. Diaphragm is a building component that transmits lateral force to vertical force resisting components. Some of the prominent literatures on the topic are as follows

Phillips et al. (1993) constructed full-scale single-storey wood house and tested under lateral loads at various stages of loading to evaluate the load-sharing characteristics and structural response. Different sheathings, fastener arrangements, and openings are incorporated to create shear walls with varying stiffness. The results showed that roof diaphragm affected the distribution of lateral load to the shear walls of the building.

Lee et al. (2007) described an easy and accurate method to estimate peak interstorey drifts for low rise shear wall structures having rigid or flexible floor diaphragm. The method was based on principal modes acquired from a principal components analysis (PCA) of computed dynamic response data and is applicable for both elastic and inelastic response.

Ambadkar and Bawner (2012) considered wind loads as specified in IS: 875 (Part 3) - 1987. G+11 storey building was analyzed by using STAAD PRO. The analysis was done for variations in obstructions height.

Bhuiyan and Leon (2013) investigated the impact of diaphragm flexibility on structural response of tall buildings. A model of floor was constructed which consist of all primary structural members and an equivalent shell element floor model was constructed. The result showed that accelerations and displacements in flexible diaphragm structural model was more than rigid diaphragm structural model. And also the fundamental periods of vibration was more in case of flexible diaphragm structural model.

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 was better alternative for earthquake and wind forces.

Patil et al. (2015) analyzed and designed a high rise building under wind load. G+19 storey building was studied for its behaviour in wind loading. The results of the study were in terms of diaphragm displacement due to wind force, change in reinforcement in column, change in behaviour of beam, storey drift, storey shear, displacement of the structure, and torsion due to wind force. Due to high wind pressure in tall structures displacement of the diaphragm is more and this creates additional stresses in building components.

Wakchaure and Gawali (2015) considered different shapes of building of height 150 m having equal stiffness of column and equal plan area for wind load analysis. Wind loads are determined based on gust effectiveness factor method. Building models of different shapes were prepared by ETAB's software and were compared for different aspects such as storey shear, storey drifts, storey displacement. The results showed that with the change in shape of building from square to elliptical the wind intensity, storey drifts, the lateral displacements, storey shear of the building decreases. Finally, it was concluded that wind load can be reduced by maximum percentage with an elliptical plan.

Suneetha P. (2015) investigated the difference between a building with diaphragm discontinuity and a building without diaphragm discontinuity. Discontinuous diaphragms are designed without stress calculations and are thought-about to be adequate ignoring any gap effects.

The objectives of the present study are as follows:

(i) to investigate the effect of tall building with different geometrical plans square, hexagonal and pentagonal under wind loading with and without rigid floor diaphragm.

(ii) to analyse the buildings with different elevation floors that are 5 floors, 10 floors, 15 floors and 20 floors.

(iii) to calculate the responses in terms of maximum bending moment, shear force and displacement and to carry out the comparison of these responses for buildings with and without rigid floor diaphragm.

2. METHODOLOGY

This study includes comparative study of behaviour of tall building frames considering different geometrical plans and diaphragm constraints under wind forces. Following steps are adopted in this study:-

(i) Selection of building geometry plans and storey, (ii) Selection of diaphragm models - without rigid diaphragm and with rigid diaphragm, (iii) Selection of wind zone (II), (iv) Formation of load combination, (v) Analyses considering different diaphragm models, wind zone and each load combinations (24 cases) and (vi) Comparative study of results in terms of maximum bending moments and shear forces in beams and displacement.

The building frame 15 m × 15 m in plan area and 20 storeys with the following three geometrical plans as shown in Fig. 1 are considered for analysis:

CASE-1: Square

CASE-2: Pentagonal

CASE-3: Hexagonal

Building with the above mentioned three geometrical plans with different elevations as shown in Fig. 2 (isometric view of pentagonal building) are considered for analysis:

TYPE 1: Regular building.

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

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

TYPE 4: Regular building frame having section cut from 15th floor 20th floor.

The number of beams and columns for these cases are given in Table 1. The material and geometrical properties are density of RCC 25 kN/m3, density of masonry 20 kN/3, Young's modulus of concrete 2.17185× 1016 N/m2, Poisson ratio 0.17. The foundation depth is considered at 3.5 m 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.

The following loadings are conducted for analysis:

Dead Loads:

Self wt. of slab considering 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

Wind loads: All the building frames are analyzed for wind zone II as per IS: 875 (Part 3)1987. The basic wind speed: 33 m/s

The modeling of the buildings is carried out using the GUI of 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.

3. RESULT AND DISCUSSION

The results of wind analyses are as follows:

a. Maximum bending moment in beam

Maximum bending moment in beams is given in Table 3 and Fig. 3. The maximum bending moment in beams are observed in building frame without floor diaphragm of pentagonal shape. And also the maximum bending moment in beams is lesser in building frame with floor diaphragm.

b. Minimum bending moment in beam

Minimum bending moment in beams is given in Table 4 and Fig. 4. The minimum bending moment in beams are observed in building frame with floor diaphragm of square in shape. And the minimum bending moment in beams is lesser in building frame with floor diaphragm.

c. Maximum shear force in beam

The maximum shear force in beams is given in Table 5 and Fig. 5. The maximum shear force in beam is observed in building frame without floor diaphragm of hexagonal shape. And the maximum shear force in beams is lesser in building frame with floor diaphragm.

d. Minimum shear force in beam

The minimum shear force in beams is given in Table 6 and Fig. 6. The minimum shear force in beam is observed in building frame with floor diaphragm of square in shape. The minimum shear force in beams is lesser in building frame with floor diaphragm.

e. Maximum displacement

The maximum displacement in horizontal (X) direction for different frames is tabulated in Table 7 and Fig. 7. The maximum displacement is seen in building frame without floor diaphragm of pentagonal shape and minimum displacement is seen in building frame with floor diaphragm of square in shape. In structures with floor diaphragms displacement is very much less than that of structures without floor diaphragm.

The maximum displacement in horizontal (Z) direction for different frames is tabulated in Table 8 and Fig. 8. The maximum displacement is seen in building frame without floor diaphragm of pentagonal shape and minimum displacement is seen in building frame with floor diaphragm of square in shape.

4. CONCLUSIONS

The rigid diaphragm is more efficient in reducing bending moment, shear force and displacement than without diaphragms. Rigid diaphragm concept is reasonable for building square in plan rather than pentagonal or hexagonal building plan.

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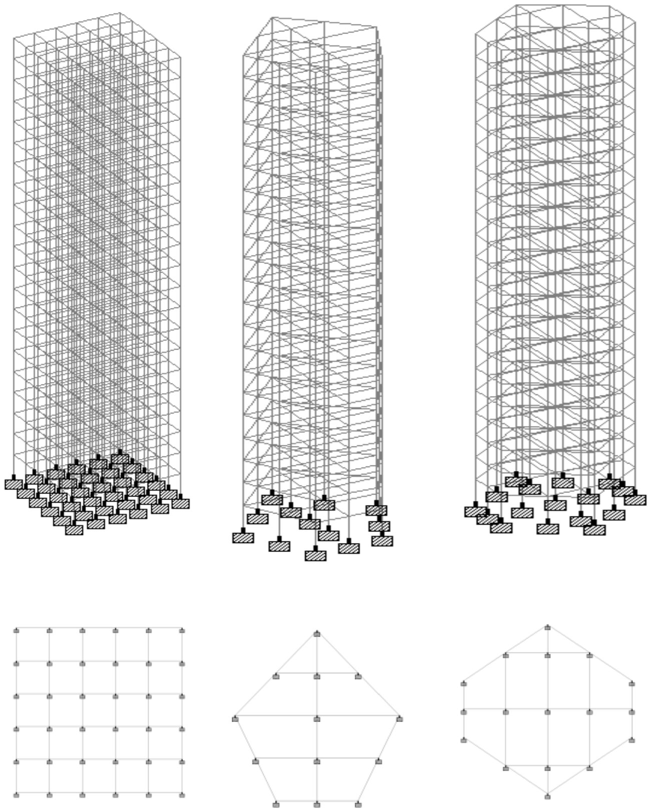
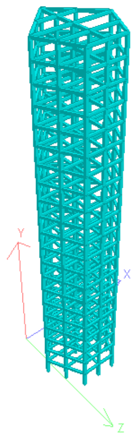
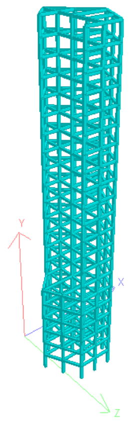


Case-1 (square) Case-2 (pentagonal) Case3 (hexagonal

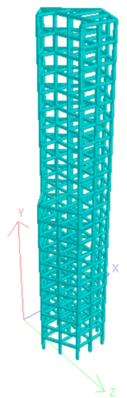
Fig. 1: Structural model of buildings



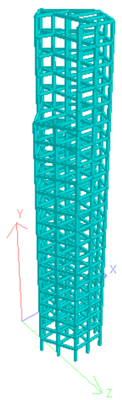
TYPE 1 (20th floor)



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



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



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

Fig. 2: Isometric views of pentagonal building

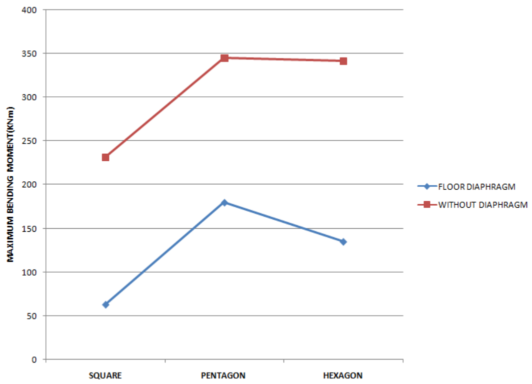


Fig. 3: Maximum bending moment in beam

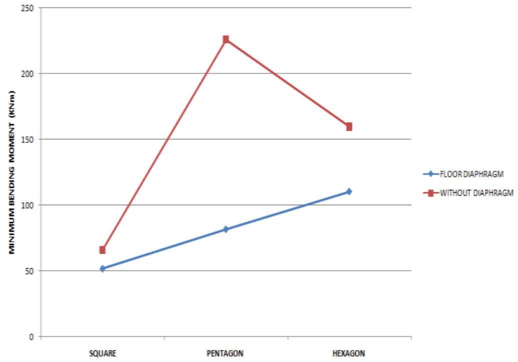


Fig. 4: Minimum bending moment in beam

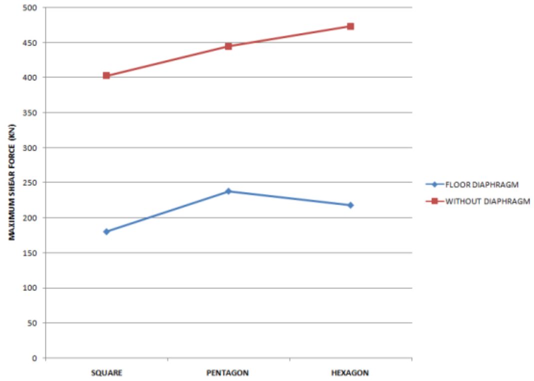


Fig. 5: Maximum shear force in beam

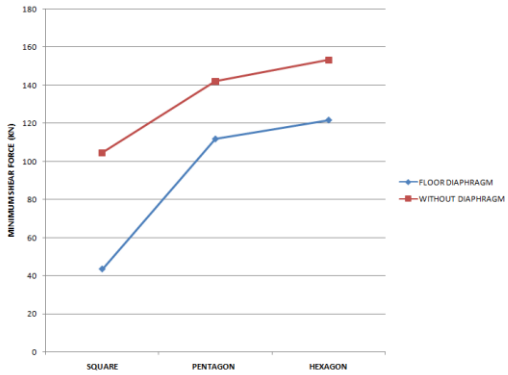


Fig. 6: Minimum shear force in beam

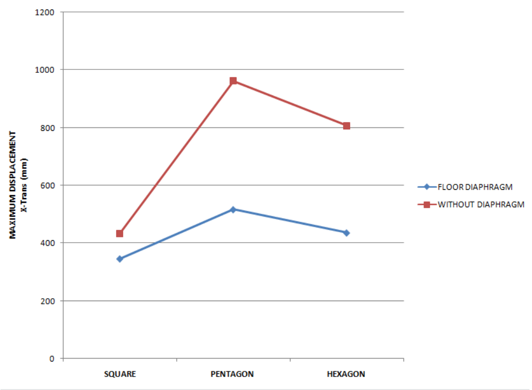


Fig. 7: Maximum displacement (*X*-direction)

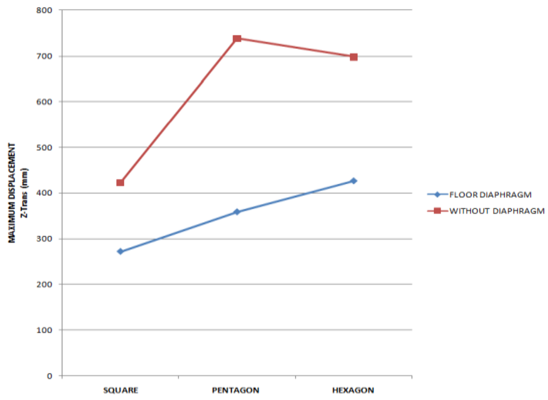


Fig. 8: Maximum displacement (*Z*-direction)

Table 1: Number of beams and columns in different cases

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

Table 2: Different load combinations for wind analysis

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

Table 3: Maximum bending moment in beams

Comparison of maximum moments in beams			
Case	Moment M_z in kNm [Beam] (Node)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	62.710 [837] (435) Type 2	179.604 [21] (16) Type 1	134.751 [272] (104) Type 2
Without floor diaphragm	231.669 [484] (296) Type 2	344.92 [167] (82) Type 2	341.757 [221](101) Type 2

Table 4: Minimum bending moment in beams

Comparison of minimum moments in beams			
Case	Moment M_z in kN.m [Beam] (Node)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	51.662 [799] (397) Type 3	81.603 [26] (8) Type 2	110.293 [29] (18) Type 4
Without floor diaphragm	66.232 [596] (266) Type 1	225.841 [33] (28) Type 1	159.696 [54] (9) Type 1

Table 5: Maximum shear force in beams

Comparison of maximum shear force in beam			
Case	Shear force f_y in kN [Beam] (Node)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	42.352 [241] (149) Type 1	111.900 [97] (52) Type 1	80.079 [132] (64) Type 1,2,3&4
Without floor diaphragm	188.367 [489] (302) Type 2	170.924 [230] (106) Type 1	217.66 [266] (118) Type 2

Table 6: Minimum shear force in beams

Comparison of minimum shear force in beam			
Case	Shear force f_y in kN [Beam] (Node)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	42.352 [241] (150) Type1,2,3&4	111.9 [86] (52) Type 1,2,3&4	80.079 [132] (68) Type 1,2,3&4
Without floor diaphragm	76.890 [472] (282) Type 1	152.306 [63] (36) Type 3	149.129 [75] (38) Type 1

Table 7: Maximum displacement in *X* direction

Comparison of maximum displacements			
Case	*X*-trans in mm (Node)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	89.569 (393) Type 2	214.721 (276) Type 2	151.013 (358) Type 2
Without floor diaphragm	97.487 (393) Type 2	345.894 (276) Type 2	235.567 (370) Type 2

Table 8: Maximum displacement in *Z* direction

Comparison of maximum displacements			
Case	*Z*-trans in mm (Node)		
	Square	Pentagonal	Hexagonal
Floor diaphragm	32.592 (127) Type 2	63.881 (276) Type 1	85.168 (358) Type 2
Without floor diaphragm	52.162 (129) Type 1	144.550 (276) Type 1	141.469 (362) Type 1