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A COMPARATIVE STUDY ON PERFORMANCE OF TALL STRUCTURAL SYSTEMS FOR SEISMIC AND WIND LOADS

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Abstract— This paper investigates the performance of G+55 storeyed tall structures with different lateral load resisting systems for seismic and wind loads using ETABS 2016 (Version 16.2.1) software. Different lateral load resisting systems viz. Conventional moment resisting frame, Framed tube, Tube in tube, Bundled tube, Outrigger with belt truss, Diagrid and Braced tube are considered for the analysis. Seismic parameters such as storey displacement, storey drift ratio, storey shear, storey stiffness and time period are captured using Response Spectrum Analysis for seismic zone III (Moderate : Mumbai) considering IS 1893–Part 1 (2002) codal provisions. Further, Lateral displacements due to Wind Load Analysis are also determined as per IS 875– Part 3 (2015) codal provision considering a wind speed of 44 m/s for Mumbai city. For the considered plan, properties, dimensions of components and number of stories, all the tall structure models except Diagrid system resist the earthquake and wind loads safely. However, the tube tall structural systems viz. Framed tube, Tube in tube, Bundled tube and Braced tube are more efficient from the point of view of least displacement, least drift ratios and high stiffness, thus making them more stable than the other considered tall structural systems.

Keywords— Tall buildings, ETABS 2016, Response spectrum analysis, Wind load analysis, Tube structures, Diagrid structure, Outrigger with belt truss.

I. INTRODUCTION

An earthquake is a natural phenomenon due to sudden release of stored energy in the Earth's crust, which creates the seismic waves. At the Earth's surface, earthquake manifests itself by shaking of the ground which leads to destruction of property and loss of life. The great number of observations and ground motion records of past earthquakes worldwide have indicated that the earthquake is a very difficult phenomenon to understand. Despite the considerable amount of data available so far and having a relevant literature on these topics, it is tough to predict the nature of earthquake.Wind is a random time-dependent load. All structures usually undergo oscillations due to the gustiness of the wind. Tall buildings undergo a dynamic response to the gustiness of the wind. Tall buildings are 'wind sensitive' and should be designed for dynamic wind loads.

Tall buildings emerged in late nineteenth century in USA. Population worldwide has grown rapidly and migration of population from rural areas to urban has resulted in high-density mega cities. Denser cities with tall structures are more efficient in terms of energy consumption and land use. As per IS 16700 (2017), a building of height greater than 50 m, but less than or equal to 250 m is defined as the tall building. A building of height greater than 250 m is considered as a super tall building. These tall buildings are analysed for earthquake and wind forces.

As per IS 1893–Part 1 (2002), height of structure, seismic zones, vertical and horizontal irregularities, weak and soft storey govern the seismic analysis of buildings. Wind speed, topography and building height govern the wind analysis of the building as per IS 875–Part 3 (2015). To resist the earthquake and wind forces, buildings are incorporated with different lateral load resisting structural systems as per the design requirements.

II. BUILDING DESCRIPTION

Table 1 shows the parameters and description of the developed models.

TABLE I
DESCRIPTION OF THE MODELS

Sl. No.	Parameters	Description
1	Structure type	Mercantile
2	Total No. of stories	G+55
3	Total height of building from GL to terrace	215.6 m
4	Total height of building from Base to terrace	220.1 m
5	Bay width in X and Y directions	9 m
6	No. of bays in X-direction	7

Sl. No.	Parameters	Description
7	No. of bays in Y-direction	5
8	Plan dimension	63 x 45 m
9	Size of column	1200 x 1200 mm
10	Size of beam	1000 x 1000 mm
11	Thickness of slab	200 mm
12	Thickness of shear wall	1100 mm
13	Typical storey height	3.85 m
14	Base storey height	4.5 m
15	Height of parapet wall	1.25 m
16	Grade of concrete for beams	M 60
17	Grade of concrete for columns	M 60
18	Grade of concrete for slabs	M 60
19	Grade of steel (rebar)	Fe 550
20	Poison's ratio of concrete	0.2
21	Density of concrete block	17.65 kN/m^3
22	Density of concrete	24 kN/m^3
23	Shape of bracing	X-bracing
24	Type of bracing	Steel pipe
25	Angle of bracing	23.16 $^{\circ}$
26	Dimension of bracing	0.8 m in diameter with thickness of 0.15 m
27	Grade of steel bracing	Fe 345
28	Live load on floor	5 kN/m^2
29	Dead load on floor	1.5 kN/m^2
30	Live load on terrace	1.5 kN/m^2
31	Dead load on terrace	3 kN/m^2
32	Live load on parapet	0.75 kN/m
33	Concrete wall load	12.40 kN/m
34	Parapet wall load	5.43 kN/m
35	Damping ratio	5%
36	Soil type	Medium
37	Zone	III (Moderate : Mumbai)
38	Zone factor	0.16
39	Importance factor (EQ)	1.5
40	Response reduction factor	5
41	Basic wind speed	44 m/s : Mumbai
42	Terrain category	3
43	Risk coefficient factor (k1)	1
44	Terrain roughness and height factor (k2)	1.276
45	Topography factor (k3)	1
46	Importance factor (k4, Wind)	1
47	Windward coefficient	0.8
48	Leeward coefficient	0.5

Seven different models of tall structure with tall structural systems are considered. These are,
Model M1 : Conventional Moment Resisting Frame
Model M2 : Framed Tube
Model M3 : Tube in Tube
Model M4 : Bundled Tube
Model M5 : Outrigger with Belt Truss
Model M6 : Diagrid
Model M7 : Braced Tube
Figure 1 shows the details of different tall structural systems having plan dimension 63 m x 45 m and height 215.6 m from the GL.

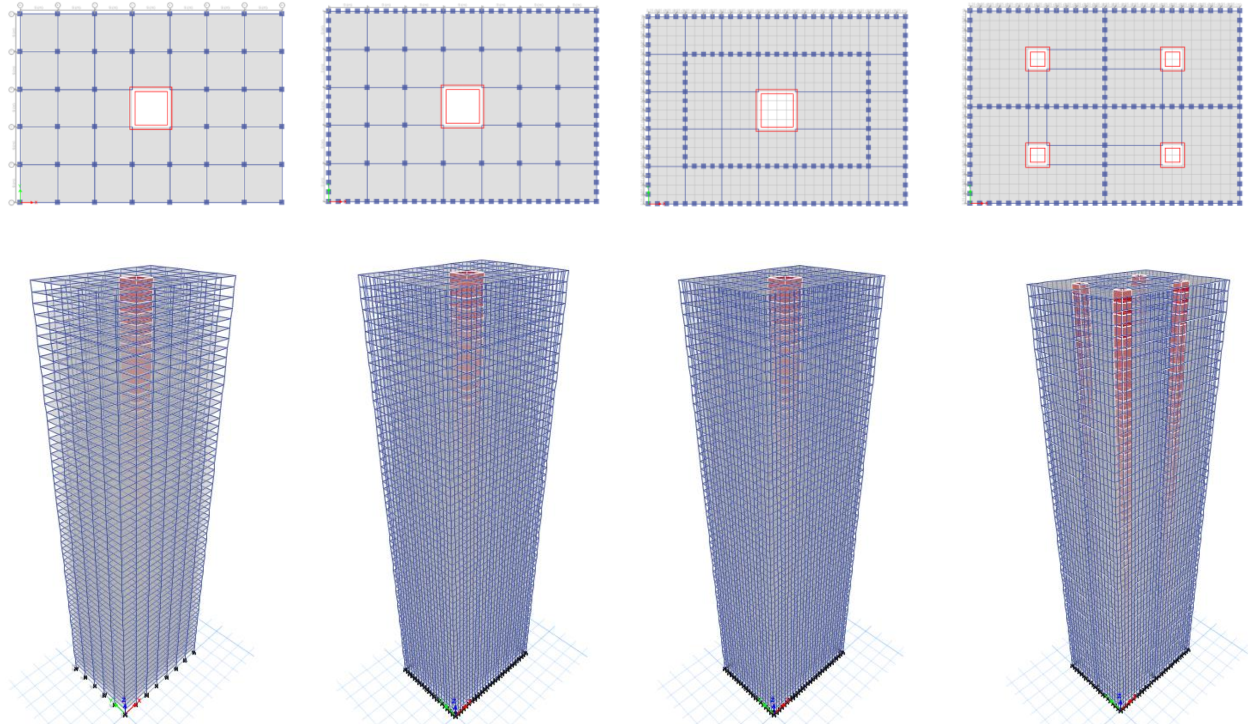


Fig. 1(a) : Model M1 Fig. 1(b) : Model M2 Fig. 1(c) : Model M3 Fig. 1(d) : Model M4

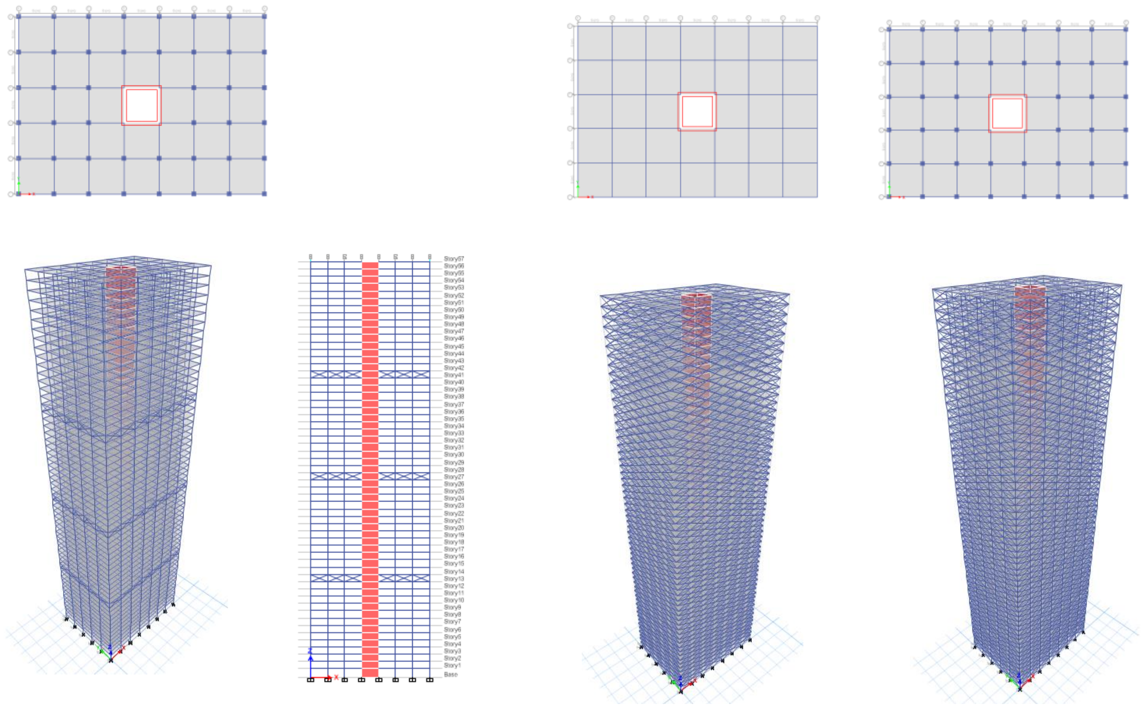


Fig. 1(e) : Model M5 Fig. 1(f) : Model M6 Fig. 1(g) : Model M7

Fig. 1 : Plan and 3D views of all the developed models with different tall structural systems

III. SEISMIC AND WIND ANALYSES OF MODELS

Using ETABS 2016 (Version 16.2.1) software, the developed tall structure models are subjected to Response Spectrum Analysis (RSA) as per IS 1893–Part 1 (2002) and Wind Load Analysis (WLA) as per IS 875–Part 3 (2015) codal guidelines. Seismic parameters viz. storey displacement, storey drift ratio, storey shear, storey stiffness, time period and lateral displacement due to wind forces are obtained from the analyses for all the developed tall structure models.

IV. RESULTS AND DISCUSSION

Figures 2 to 12 show the variation of storey displacement, storey drift ratio, storey shear, storey stiffness, time period and lateral displacement over the number of storeys in both X and Y directions obtained for all the tall structure models by RSA and WLA.

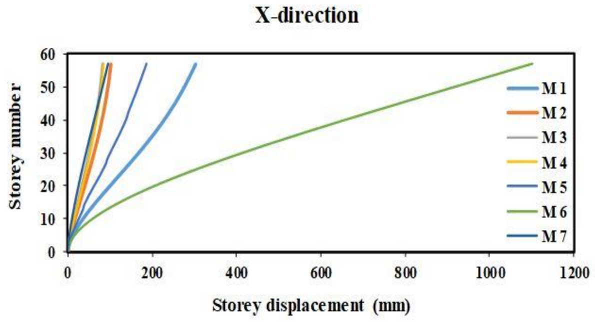


Fig. 2 : Variation of storey displacement in X-direction

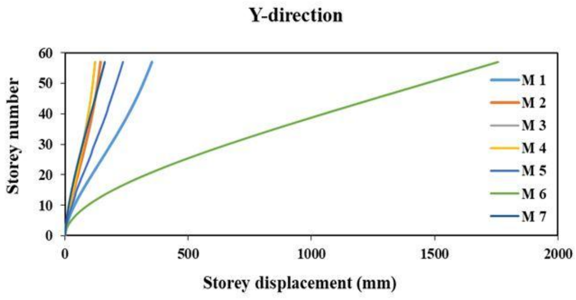


Fig. 3 : Variation of storey displacement in Y-direction

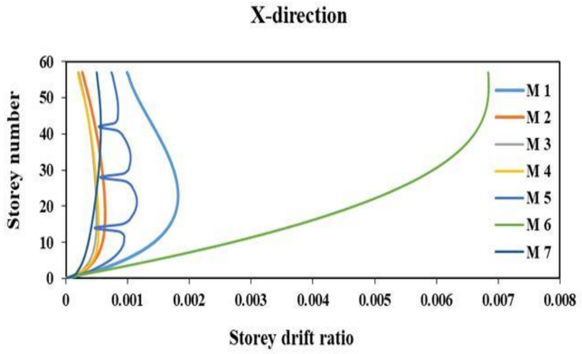


Fig. 4 : Variation of storey drift ratio in X-direction

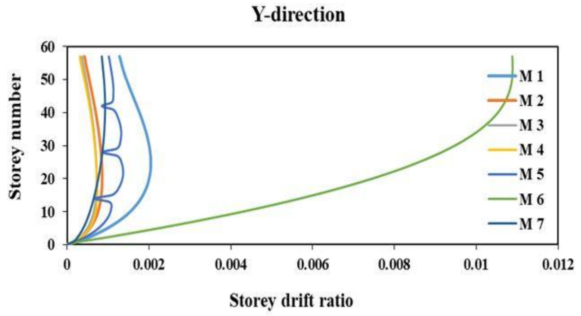


Fig. 5 : Variation of storey drift ratio in Y-direction

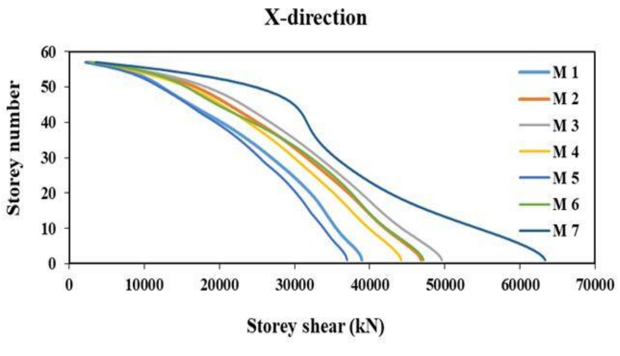


Fig. 6 : Variation of storey shear in X-direction

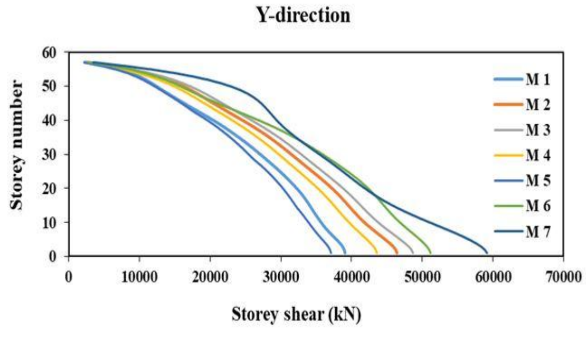


Fig. 7 : Variation of storey shear in Y-direction

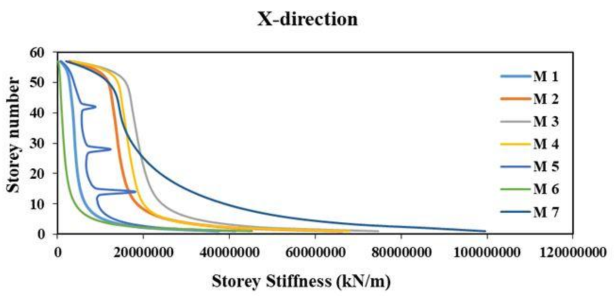


Fig. 8 : Variation of storey stiffness in X-direction

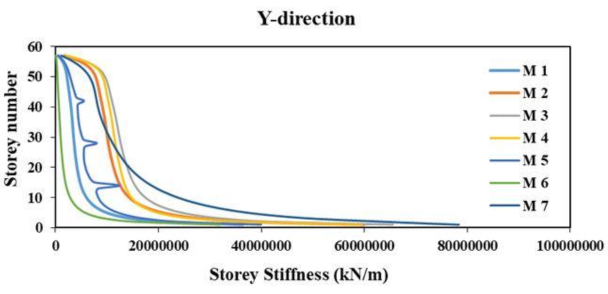


Fig. 9 : Variation of storey stiffness in Y-direction

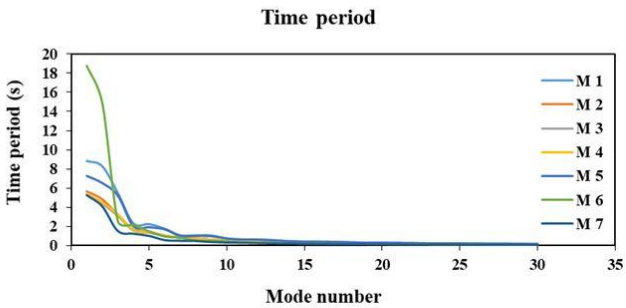


Fig. 10 : Variation of Time period

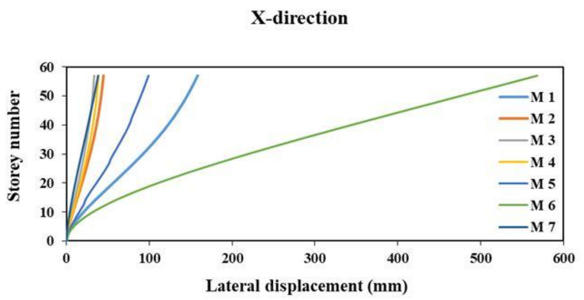


Fig. 11 : Variation of lateral displacement in X-direction

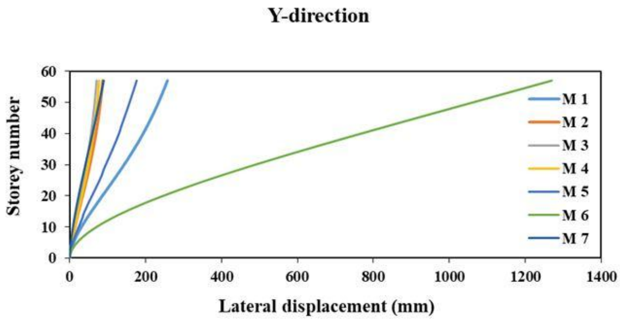
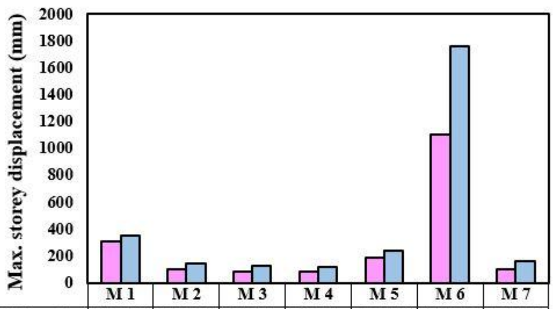


Fig. 12 : Variation of lateral displacement in Y-direction

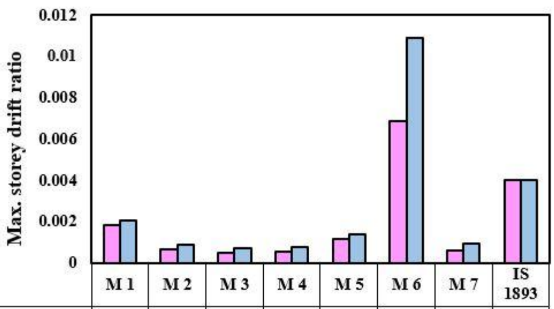
From Figs. 2 to 12, it can be observed that all the models show different kind of variation w.r.t. storey displacement, storey drift ratio, storey shear, storey stiffness and lateral displacement. However, similar kind of variation is exhibited from all the models w.r.t. time period.

Figures 13 to 18 show the variation of maximum storey displacement, storey drift ratio, storey shear, storey stiffness, time period and lateral displacement for all the tall structure models models by RSA and WLA.



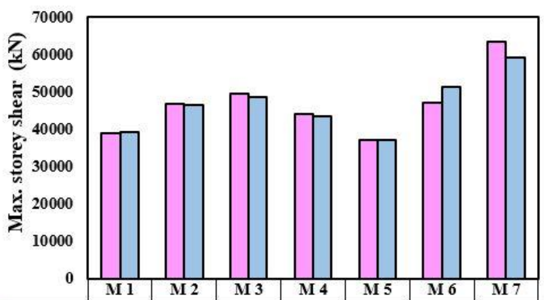
	M 1	M 2	M 3	M 4	M 5	M 6	M 7
X-direction	304.267	103.588	81.454	84.891	185.684	1102.206	96.876
Y-direction	352.632	144.137	122.469	121.314	235.173	1757.047	161.408

Fig. 13 : Maximum storey displacement in X and Y directions



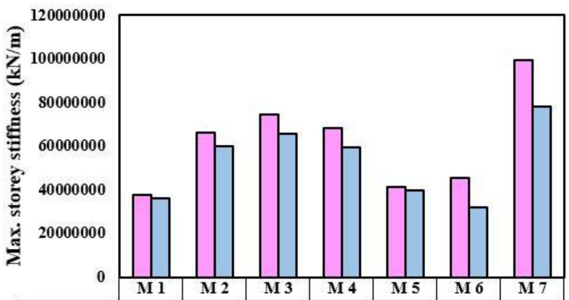
	M 1	M 2	M 3	M 4	M 5	M 6	M 7	IS 1893
X-direction	0.00182	0.00064	0.0005	0.00053	0.00115	0.00685	0.00057	0.004
Y-direction	0.00205	0.00086	0.00072	0.00074	0.00137	0.01089	0.00093	0.004

Fig. 14 : Maximum storey drift ratio in X and Y directions



	M 1	M 2	M 3	M 4	M 5	M 6	M 7
X-direction	38954.35	46853.39	49603.55	44190.87	36994.53	47159.46	63378.08
Y-direction	39089.84	46432.65	48693.69	43583.66	37099.4	51174.54	59164.59

Fig. 15 : Maximum storey shear in X and Y directions



	M 1	M 2	M 3	M 4	M 5	M 6	M 7
X-direction	3.7E+07	6.6E+07	7.5E+07	6.8E+07	4.1E+07	4.5E+07	1E+08
Y-direction	3.6E+07	6E+07	6.6E+07	6E+07	4E+07	3.2E+07	7.8E+07

Fig. 16 : Maximum storey stiffness in X and Y directions

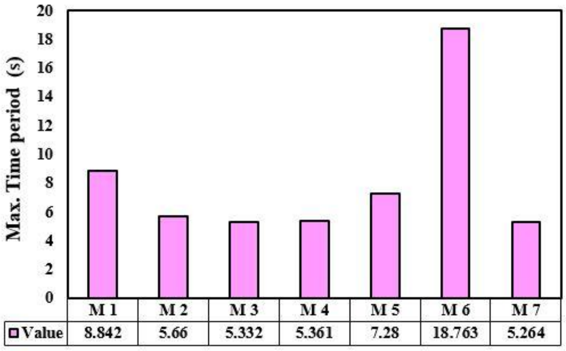


Fig. 17 : Maximum time period

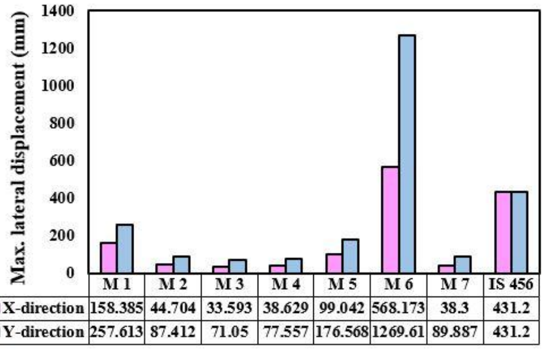


Fig. 18 : Maximum lateral displacement in X and Y directions

The maximum storey displacement values (i.e. at the top storey) obtained in both X and Y directions from RSA for all the developed tall structure models is shown Fig. 13. Maximum value of storey displacement is observed in Model M 6 : Diagrid system than the other developed tall structure models. Further least value is observed in Model M 3 : Tube in tube system and Model M 4 : Bundled tube system in X and Y directions respectively.

The maximum storey drift ratio values obtained in both X and Y directions from RSA for all the developed tall structure models are outlined in Fig. 14. Maximum value of storey drift ratio is observed in Model M 6 : Diagrid system than the other developed tall structure models. Further least value is observed in Model M 3 : Tube in Tube system in both X and Y directions. It can be inferred that, maximum storey drift ratio obtained for all the tall structure models except Model M 6 : Diagrid system are within the maximum allowable limit (i.e. 0.004) as specified by Cl. 7.11.1 of IS 1893–Part 1 (2002).

The maximum storey shear values obtained in both X and Y directions from RSA for all the developed tall structure models are outlined in Fig. 15. Maximum value of storey shear is observed in Model M 7 : Braced tube system than the other developed tall structure models. Further least value is observed in Model M 5 : Outrigger with belt truss system in both X and Y directions.

The maximum storey stiffness values obtained in both X and Y directions from RSA for all the developed tall structure are outlined in Fig. 16. Maximum value of storey stiffness is observed in Model M 7 : Braced tube system and Model M 3 : Tube in Tube system than the other developed tall structure models. Further least is observed in Model M 1: Conventional system and Model M 6 : Diagrid system in X and Y directions respectively.

The maximum time period values obtained from RSA for all the developed tall structure models are outlined in Fig. 17. Minimum time period is observed in Tube structures (viz. Framed tube, Tube in tube, Bundled tube and Braced tube) due to their high stiffness in both X and Y directions. Further maximum value of time period is observed in Model M 6 : Diagrid system due to its lesser stiffness in both X and Y directions.

The maximum lateral displacement values obtained in X and Y directions from WLA for all the developed tall structure models are outlined in Fig. 18. Maximum lateral displacement obtained for all the tall structure models except Model M 6 : Diagrid system are within the maximum allowable limit [H/500, H being the total height of the structure from ground level] as specified by Cl. 20.5 of IS 456 (2000). Further least value is observed in Model M 3 : Tube in tube system in both X and Y directions.

V. CONCLUSIONS

In the present study, performance of G+55 storeyed tall structures with different lateral load resisting systems for seismic and wind loads is investigated using ETABS 2016 (Version 16.2.1) software. Different lateral load resisting systems viz. Conventional Moment resisting frame, Framed tube, Tube in tube, Bundled tube, Outrigger with belt truss, Diagrid and Braced tube are considered for the analysis. Seismic parameters such as storey displacement, storey drift ratio, storey shear, storey stiffness and time period are captured using Response Spectrum Analysis (RSA) for seismic zone III (Moderate : Mumbai) considering IS 1893–Part 1 (2002) codal provision. Further, Lateral displacements due to Wind Load Analysis (WLA) are also determined as per IS 875– Part 3 (2015) codal provision considering wind speed of 44 m/s for Mumbai city.
The important conclusions drawn from the present study on behaviour of tall structural systems considering the results obtained from RSA and WLA are explained below.

1. All the models exhibit different kind of variation in storey displacement and storey drift ratio. However displacement and drift ratios in X-direction are found to be lesser than that of Y-direction in all the models.

2. Maximum value of storey displacement and drift ratio is observed in Model M 6 : Diagrid system than the other developed tall structure models. Least value of displacement is observed in Model M 3 : Tube in tube system and Model M 4 : Bundled tube system in X and Y directions respectively. Whereas least value of drift ratio is observed in Model M 3 : Tube in Tube system in both X and Y directions.
3. Maximum storey drift ratio obtained for all the tall structure models except Model M 6 : Diagrid system are within the maximum allowable limit (i.e. 0.004) as specified by Cl. 7.11.1 of IS 1893–Part 1 (2002).
4. All the models exhibit different kind of variation in storey shear and storey stiffness. However storey shear and stiffness values in X-direction are found to be more than that of Y-direction in all the models.
5. Maximum value of storey shear is observed in Model M 7 : Braced tube system than the other developed tall structure models. Whereas, least value is observed in Model M 5 : Outrigger with belt truss system in both X and Y directions.
6. Maximum value of storey stiffness is observed in Model M 7 : Braced tube system and Model M 3 : Tube in tube system than the other developed tall structure models. Whereas, least value is observed in Model M 1 : Conventional system and Model M 6 : Diagrid system in X and Y directions respectively.
7. Similar kind of variation of time period for the first 30 modes of vibration is observed in all the models. Minimum time period is observed in Tube structures (viz. Framed tube, Tube in tube, Bundled tube and Braced tube) due to their high stiffness in both X and Y directions. Further, maximum value of time period is observed in Model M 6 : Diagrid system due to its lesser stiffness in both X and Y directions.
8. All the models exhibit different kind of variation in lateral displacement. However displacement in X-direction is found to be lesser than that of Y-direction in all the models.
9. Maximum value of lateral displacement is observed in Model M 6 : Diagrid system than the other developed tall structure models. Whereas, least value is observed in Model M 3 : Tube in tube system in both X and Y directions.
10. Maximum lateral displacement value obtained for all the tall structure models except Model M 6 : Diagrid system are within the maximum allowable limit [H/500, H being the total height of the structure from the ground level] as specified by Cl. 20.5 of IS 456 (2000). Further least value is observed in Model M 3 : Tube in tube system in both X and Y directions.

Concluding Remarks : For the considered plan, properties, dimensions of components and number of stories, all the tall structure models except Diagrid system resist the earthquake and wind loads safely. However, the tube tall structural systems viz. Framed tube, Tube in tube, Bundled tube and Braced tube are more efficient from the point of view of least displacement, least drift ratios and high stiffness, thus making them more stable than the other considered tall structural systems.

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