"Dynamic Behavior of Various Structural System for Tall Buildings Subjected to Wind Load"

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Abstract - *The increased population in urban societies and the constant pressure of limited land area with expensive prices have caused the evolution of high-rise buildings in India and rest of the world. High-rise buildings may be considered as a symbol of development and civilization. From structural point of view, these are buildings of which height will be affected by lateral forces resulting from earthquake and wind loads to the extent that such forces will play a major role in the design process.*

The present study is carried out on analysis and design of high rise tall buildings using ETABS 18 software. Modeling of S+17 storey structure considered for analytical investigation based on IS16700:2017 guidelines. Various Indian standards like IS 456:200, IS 875:2015 and IS 1893 (part 1):2016 were used. The said structure is modeled as three dimensional structure and all the loads are applied, gravity loading such as dead load and live load in the direction of gravity, lateral loads such as seismic and wind, and the behavior of the structure has been studied. All models have been analyzed for the same peak ground acceleration (PGA) and material characteristics. Then the outrigger and shear walls are placed for different height and behavior of structure for wind and modal studied. Investigation results show that provision of shear walls with response reduction factor 4 as per IS 1893 (Part-I):2016 and optimum location of outrigger system efficiently reduce the deflection and enhance the structural stiffness and dynamic behavior for tall buildings.

Key Words*: *IS 875 (part 3):2015, IS 16700:2017, Tall Buildings, Outrigger System, Shear Wall, Wind analysis.

1. INTRODUCTION

A building is said to be a high-rise when its appearance and proportion is slender to give a tall building or it's reasonably higher than the surrounding buildings. As per IS 875(Part 3):2015 building with height more than 50m and having height to smaller dimension more than 6. Also when wind interacts with a building, both positive and negative pressures occur simultaneously, the building must have sufficient strength to resist the applied loads from these pressures to prevent wind induced building failure. Load exerted on the building envelope are transferred to the structural system and they in turn must be transferred through the foundation into the ground, the magnitude of the wind pressure is a function of exposed basic wind speed, topography, building height, internal pressure, and building shape. According to the provisions of Bureau of Indian Standards for earthquake load, IS 1893(Part 1):2016, height of the structure, seismic zone, vertical and horizontal irregularities, soft and weak storey necessitates dynamic analysis for earthquake load. The contribution of the higher mode effects are included in arriving at the distribution of lateral forces along the height of the building. The common factor which affects the results in wind and seismic analysis is height of structure. Recently published Indian Standard on IS 16700: 2017 on 'Criteria for structural Safety of Tall Concrete Buildings', to covers structural safety and serviceability aspects relating to reinforced concrete buildings of height greater than 50 m and up to 250 m.

This standard is based on prescriptive approach and covers the following design and serviceability aspects of reinforced concrete tall buildings:

As the building goes higher and higher, the selection of cross-sections should be considered carefully along with materials and structural systems keeping in mind the demand of functionality. Unexpected deflections, wind and earth quakes leads to change in deflections and acceleration in horizontal loading are some of the major factors that need to be considered. Inhomogeneous sites result in causing imperfections in elements taking place during manufacture or maybe uneven foundation leading to unexpected deflections. Wind causes horizontal loading resulting in sway of the building. This is because high-rise buildings are susceptible to oscillation. Therefore, wind has to be considered as a static load inclusive to be considered as a dynamic load. Wind tunnel experiments are conducted usually to find the response of buildings under wind loads.

The observation of sway and the maximum horizontal deflection by the people inside shows that oscillation affects the building in many ways.

1.1 outrigger and various structural system

The structural configuration of an outrigger system includes central core tied to the exterior periphery column by means of rigid member names as outrigger beam/truss. The central core can be of steel braced element or reinforced concrete core wall, and mainly situated at central location (i.e Lift/ Staircase) of building with outrigger connected to the exterior columns of building. The outrigger system consists of combined shear walls with outriggers that are capable to restrict inter-storey displacement subjected to wind as well as seismic loads and also reduces moment of central core and its dimension.

In outrigger and belt truss mechanism, the function of core wall is to resist lateral forces and weighty part of the loading is carried by the perimetral columns by means of axial load due to which windward columns subjected to tension and leeward columns subjected to compression.

2. OBJECTIVE OF STUDY

To study the behavior of Tall building and determine efficiency of RCC structural system as follows.

a) Study the behavior of tall high rise buildings subjected to wind load

b) With provision of outrigger

c) With provision of shear wall

d) With provision of combination of outrigger and shear wall

e) Modeling and analysis of tall high rise RCC frame structure using E-TABS software.

Using above lateral load resistance system particularly for tall buildings as per IS 16700:2017 calculating the shear force, bending moments and the sway of the wind load on high rise buildings, also modal behavior of structure.

3. PROBLEM STATEMENT

In this investigation we have chosen high rise S+17 RCC framed structure situated at Nagpur. As per location of structure seismic zone, wind zone and other essential data considered as per IS 1893:2016 and IS 875:2015 also the IS 16700:2017 codal provisions has been considered for tall building criteria. From this analytical investigation we are able to study the behavior of tall high rise buildings subjected to wind load and efficiency of outrigger and shear wall system for tall buildings.

4. METHODOLOGY

The building rests on isolated foundation having depth of 1.6 m below ground level. Vertical/ lateral force resisting system is consisting of RCC frames of columns/shear walls, beams and slabs. All vertical elements in lateral resisting system are continuous to foundation. All shear walls are 230 mm thick to full height. No geometric irregularities like storey variation in the dimension of lateral force resisting system are considered in the building. No torsional irregularity is considered.

Three dimensional space frame of S+17 storied four building model considered having RCC beam column and slab. The slab at each floor level and roof level was modeled as a shell element and assumed to act as a rigid diaphragm. The slab was not considered as a load resisting system; rather, it was modeled to transfer dead and live loads to the load carrying frames. Beam column joints were modeled as rigid joints by assigning rigid offset at ends of the member. Slab beam and columns are assigned with modifiers as per IS 1893:2016. The rigid zone factor was taken 1, and the rigid zone was taken as the full connection zone. Also shear wall modelled as thin shell with modifier as per IS 16700:2017. Framing with and without outrigger at 0.5H and 0.67H with respect to height of building considered. The same configuration of model with beam, shear wall and slab framing with and without outrigger at 0.5H and 0.67H with respect to height of building considered for analysis. Response spectrum method using finite element code ETABS v 18.0, and wind/seismic parameters such Lateral displacement, Story drift, modal behavior, bending moment and shear force for vertical element using SRSS modal combination.

5. MODELLING FOR SOFTWARE ANALYSIS

This study investigates the behavior of multi storey (S+17) buildings with and without shear wall considering effect of outrigger system provided at 0.5H and 0.67H with respect to height (H) of buildings. Three dimensional space frame analysis is carried out for four different configurations i.e. i) Bare frame Model (Refer fig.1 and 2) ii) Bare frame with outriggers at 0.5H and 0.67H (Refer fig.1 and 2) iii) Shear wall beam and slab model (Refer fig.3 and 4) iv) Shear wall beam and slab model with outriggers at 0.5H and 0.67H (Refer fig.3 and 4) under the action of seismic and wind load. Dynamic response of these buildings, in terms of base shear, fundamental time period, mode shapes and top floor displacement is presented, and compared within the considered configuration as well as with other configurations.

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The analysis is based on following assumptions.

i) Material is homogenous, isotropic and elastic.

ii) The values of modulus of elasticity and Poisson's ratio are 31622.78 N/mm2 and 0.20, respectively.

iii) Secondary effect P-Δ, shrinkage and creep are not considered.

iv) The floor diaphragms are rigid in their plain.

v) Axial deformation in column is considered.

vi) Each nodal point in the frame has six degrees of freedom, three translations and three rotations.

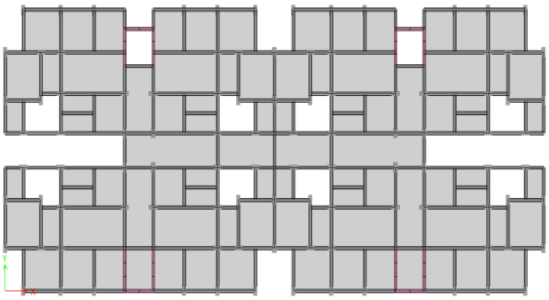


Fig. 1 Plan of Model –A and C (Bare Frame)

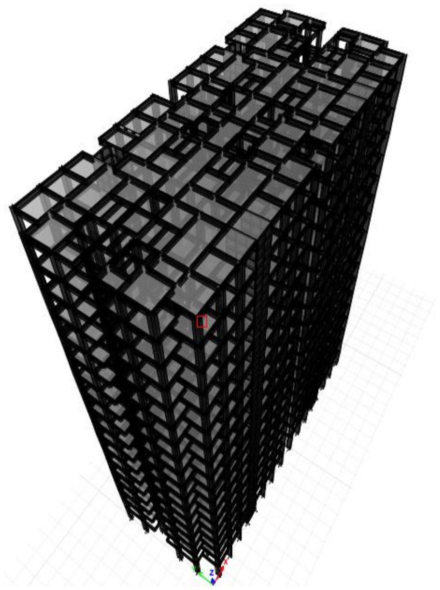


Fig. 2 3D View A and C (Bare Frame)

Table -1: Data Used in Analytical Investigation of (S+17) Storey Building Models.

	Model -A	**Model- B**	**Model -C**	**Model -D**
Description	Bare Frame Model	Slab Beam and shear wall Model	Bare frame with outrigger at 0.5 H and 0.67 H	Shear wall Model with outrigger at 0.5 H and 0.67 H
Material Properties	Concrete grade - For Slab and Beam -M40 and for columns and shear wall -M50 Reinforcement-Fe 500			
Section Properties	Slab Thickness 150 to 175mm based on span modelled as shell element			
	All Beams are 230x500 modelled as line element			
	All shear walls are 230 mm thick modelled as shell element			
	Outriggers -300x1000 mm			
Gravity loading	Dead Load - Based on RC element size (density of concrete 25kN/m3)			
	SDL - 1.5 kN/m2 on slab and wall load on beam as per Arch dwg.			
	Live Load – 2 kN/m2, 3 kN/m2			
	Terrace Live load – 3 kN/m2 (Functional gathering considered)			
	Terrace SDL-3 kN/m2 for water proofing			
	Wall load 230 mm thk. – 9.00 kN/m including plaster			
	Wall load 150 mm thk. – 6.00 kN/m including plaster			
	parapet wall load – 3.8 kN/m			
Seismic loading	Location - Nagpur			
	Zone -II			
	Zone factor – 0.10			
	IS1893:2002 Building Frame Systems – SMRF Response reduction factor – 5	IS1893:2002 Building Frame Systems – Ductile shear walls Response reduction factor – 4	IS1893:2002 Building Frame Systems – SMRF Response reduction factor – 5	IS1893:2002 Building Frame Systems – Ductile shear walls Response reduction factor – 4
	Soil Type – I, Hard soil			
	IS1893:2016 Importance factor – 1.2			
	Modifiers checked for Slab beam column and shear wall			
	Time Period – user defined based on IS 1893:2016 formula 0.09H/SQRT (dX/dY)			

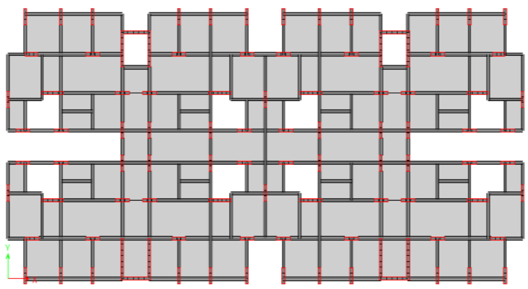


Fig. 3 Plan of Model –B and D (With Shear Wall)

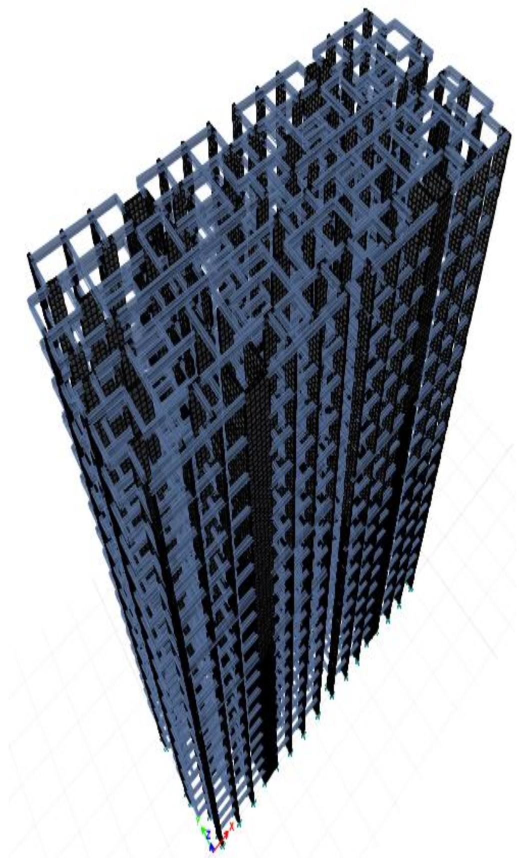


Fig. 4 3D view B and D (With Shear Wall)

Table -2: Gust Factor Calculations

GUST FACTOR CALCULATIONS	
Length	46.54 m
Width	20.59 m
height	52.7 m above ground level
HEIGHT OF BUILDING ABOVE GROUND LEVEL in	52.7

meter					
TERRAIN CATEGORY OF BUILDING	3				
CLASS OF BUILDING	C				
BUILDING LOACTION	NAGPUR -WIND SPEED 44 m/s				
FORCE COEFFICIANT	H ABOVE GL		52.7		
	a=	46.54	b=20.59		
FORCE COEFFICIANT IN X DIR	(h/a)=	1.13	(b/a)=0.44	PAGE 35 OF 875-2015	CX=1.3
FORCE COEFFICIANT IN Y DIR	(h/b)=	2.55	(a/b)=2.26		Cy=1.2
	Maximum		1.3		
GUST FACTOR CHECK	Check modal time period of building in 1st mode (3.69 Seconds)				

risk coeficient	K1	1.00		clause 6.3.1 OF 875-2015 table-1
terrain and height factor	K2	1.12		clause 6.3.2 OF 875-2015 5 table-2
topography factor	K3	1.00		clause 6.3.3 OF 875-2015
	K4	1.00		clause 6.3.4 OF 875-2015
bay in x direction	3.2mx3m	9.6	sq m	mid frame
bay in y direction	3mx3m	9	sq m	end frame
Gust Factor				3.0 based on IS 875:2015 calculations

6. RESULTS AND DISCUSSION

The results are obtained based on dynamic analysis of (S+17) storied analytical models in terms of Storey Displacement, Storey Drifts, Mode vs Time period (FTP), and Bending moment at core location for vertical element. Table 3 and Table 4 show Storey displacement in X and Y direction and Graph 1 and Graph 2 are respective graphs respectively. Table 5 and Table 6 show Storey drift in X and Y direction and Graph 3 and 4 are graphs respectively. From Modal analysis fundamental modes mode vs. Time period (FTP), results are obtained which shown in Table 7. Also the bending moment variation at core represented by table 8 and graph 6.

Table 3: Displacement at Floor Levels for all Building for wind load in X direction

Story	model A	model B	model C	model D
Base	0	0	0	0
Story1	1.298	1.007	0.96	0.974
Story2	3.637	2.572	2.69	2.477
Story3	6.776	4.811	4.999	4.607
Story4	10.491	7.45	7.706	7.09
Story5	14.616	10.368	10.669	9.8
Story6	19.01	13.462	13.758	12.624
Story7	23.549	16.647	16.853	15.464
Story8	28.135	19.85	19.85	18.232
Story9	32.681	23.014	22.557	20.814
Story10	37.123	26.092	25.19	23.27
Story11	41.407	29.047	27.976	25.668
Story12	45.494	31.854	30.758	27.892
Story13	49.36	34.496	33.492	29.991
Story14	52.993	36.965	36.142	32.024
Story15	56.397	39.266	38.69	33.948
Story16	59.587	41.41	41.129	35.757
Story17	62.597	43.421	43.468	37.462
Story18	65.451	45.34	45.711	39.092

Table 4: Displacement at floor levels for building for wind load in Y direction

Story	model A	model B	model C	model D
Base	0	0	0	0
Story1	2.674	1.856	1.9	1.806
Story2	6.812	5.252	5.064	5.094
Story3	13.053	9.942	9.692	9.601
Story4	20.518	15.523	15.181	14.92
Story5	28.816	21.712	21.192	20.755
Story6	37.629	28.277	27.429	26.855
Story7	46.693	35.029	33.622	33.01
Story8	55.791	41.816	39.532	39.034
Story9	64.75	48.514	44.878	44.726
Story10	73.431	55.026	50.033	50.16
Story11	81.729	61.276	55.399	55.429
Story12	89.569	67.211	60.77	60.363
Story13	96.904	72.796	66.044	65.02
Story14	103.719	78.019	71.141	69.483
Story15	110.026	82.885	76.019	73.695
Story16	115.869	87.425	80.668	77.657
Story17	121.333	91.696	85.112	81.4
Story18	126.52	95.79	89.398	84.992

Table 5: Storey drift variation for all building under wind load in X direction

Story	model A	model B	model C	model D
Base	0	0	0	0
Story1	0.000346	0.000269	0.000256	0.00026
Story2	0.000775	0.00054	0.000573	0.000517
Story3	0.001012	0.000722	0.000744	0.000687
Story4	0.001198	0.000851	0.000873	0.000801
Story5	0.00133	0.000941	0.000955	0.000874
Story6	0.001417	0.000998	0.000996	0.000911
Story7	0.001464	0.001027	0.000998	0.000916
Story8	0.001478	0.001033	0.000966	0.000893
Story9	0.001466	0.001021	0.000873	0.000833
Story10	0.001432	0.000993	0.000849	0.000792
Story11	0.001381	0.000953	0.000898	0.000773
Story12	0.001318	0.000905	0.000897	0.000718
Story13	0.001247	0.000852	0.000881	0.000677
Story14	0.001172	0.000797	0.000855	0.000656
Story15	0.001097	0.000742	0.000821	0.000621
Story16	0.001029	0.000692	0.000786	0.000584
Story17	0.000971	0.000649	0.000754	0.00055
Story18	0.00092	0.000619	0.000723	0.000526

Table 6: Storey drift variation for all building under wind load in Y direction

Story	model A	model B	model C	model D
Base	0	0	0	0
Story1	0.000713	0.000494	0.000507	0.000481
Story2	0.001455	0.00112	0.001091	0.001084
Story3	0.002013	0.001514	0.001493	0.001455
Story4	0.002408	0.001801	0.001771	0.001717
Story5	0.002677	0.001997	0.001939	0.001883
Story6	0.002843	0.002118	0.002012	0.001969
Story7	0.002924	0.002179	0.001998	0.001986
Story8	0.002935	0.00219	0.001907	0.001944
Story9	0.00289	0.002161	0.001724	0.001836
Story10	0.0028	0.002101	0.001663	0.001753
Story11	0.002677	0.002016	0.001731	0.0017
Story12	0.002529	0.001914	0.001733	0.001592
Story13	0.002366	0.001802	0.001701	0.001502
Story14	0.002198	0.001685	0.001644	0.00144
Story15	0.002034	0.00157	0.001574	0.001359
Story16	0.001885	0.001465	0.0015	0.001278
Story17	0.001763	0.001378	0.001434	0.001207

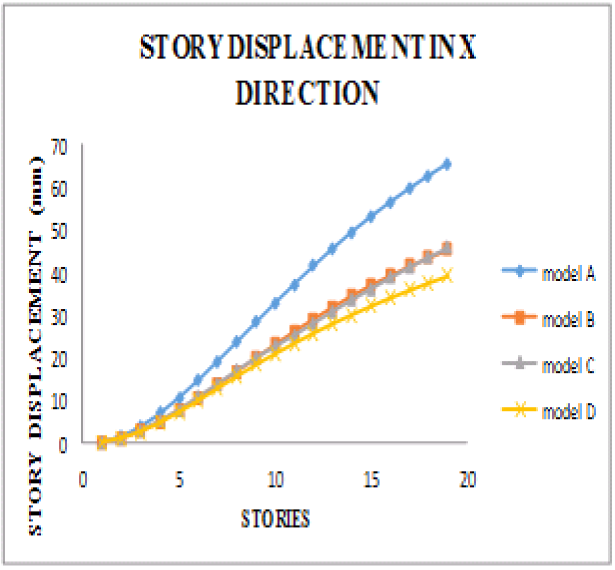
Story18	0.001673	0.001321	0.001382	0.001159

Table 7: Modal response for all model under wind load

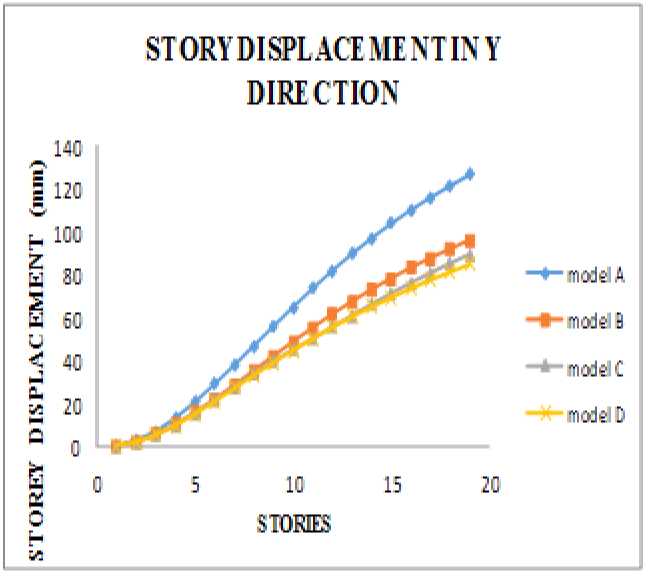
Mode	model A	model B	model C	model D
1	3.909	3.317	3.274	3.146
2	3.707	3.307	3.172	3.124
3	3.394	3.171	2.872	2.885
4	1.031	0.887	0.931	0.873
5	0.996	0.879	0.918	0.864
6	0.915	0.843	0.84	0.819
7	0.461	0.398	0.389	0.392
8	0.446	0.396	0.375	0.391
9	0.416	0.38	0.352	0.371
10	0.266	0.229	0.231	0.227
11	0.25	0.226	0.218	0.225
12	0.239	0.219	0.209	0.217

Table 8: Bending Moment Variation at core for all model under wind load

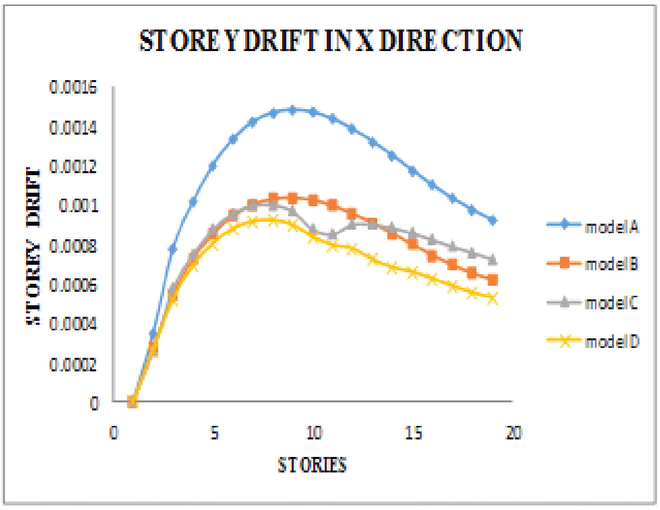
`	model A	model B	model C	model D
Story	M3	M3	M3	M3
	kN-m	kN-m	kN-m	kN-m
Story1	16626.06	6284.095	15328	1238.749
Story2	12401.14	3404.692	11381.19	3862.908
Story3	9264.39	1527.487	8359.779	5858.919
Story4	6948.323	261.4656	5838.836	7206.332
Story5	4934.726	-591.542	3687.35	10882.66
Story6	3280.561	-1149.19	1815.891	11865.54
Story7	1912.568	-1494.08	166.8673	13132.81
Story8	792.5137	-1689.17	-1268.16	14662.55
Story9	-115.046	-1781.86	-2796.51	-2042.87
Story10	-836.665	-1806.55	667.0293	-2017.09
Story11	-1391.27	-1786.38	623.6068	-980.98
Story12	-1792.18	-1735.89	-394.757	-1918.56
Story13	-2047.61	-1662.25	-935.899	23129.65
Story14	-2159.99	-1564.88	-1319.75	25279.27
Story15	-2125.08	-1435.38	-1504.05	26874.08
Story16	-1936.27	-1257.06	-1500.85	29987.34
Story17	-1561.09	-1002.54	-1287.95	33896.9
Story18	-1063.52	-650.214	-932.598	35093.9



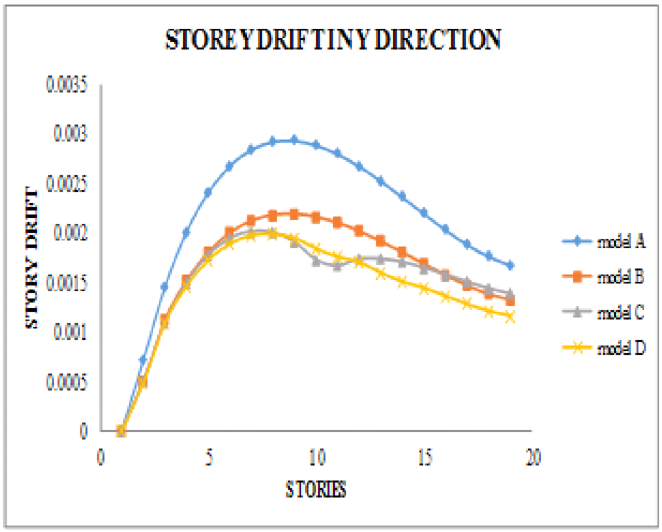
Graph 1: Displacement at floor levels for all building for wind load in X direction



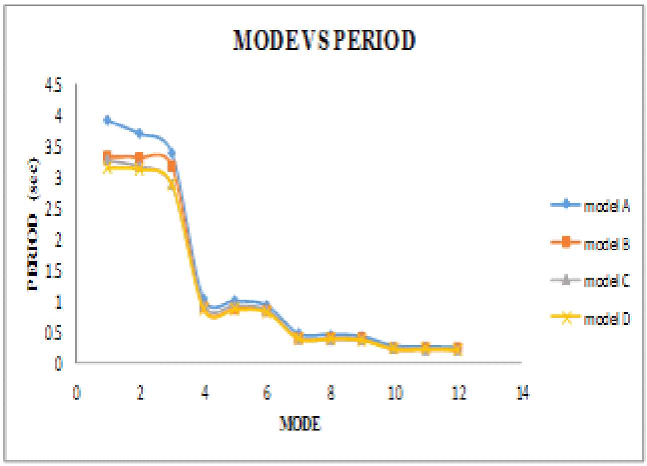
Graph 2: Displacement at floor levels for all building for wind load in Y direction



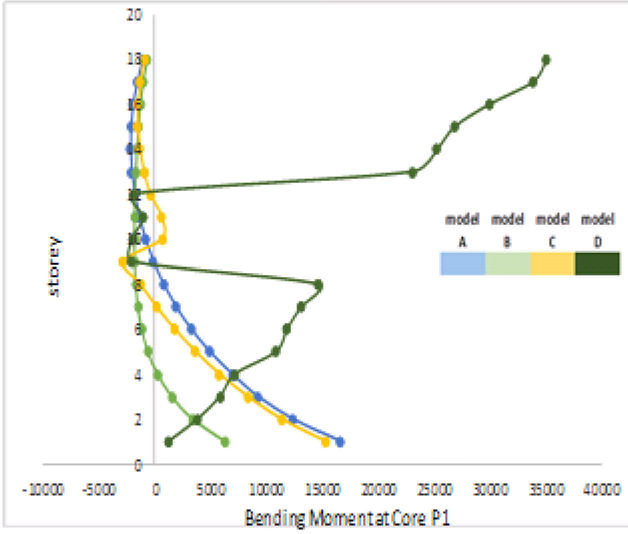
Graph 3: Storey drift variation for all building model under wind load in X direction



Graph 4: Storey drift variation for all building model under wind load in X direction



Graph 5: Modal response for all models under wind load



Graph 6: Bending moment variation for all model at core

7. CONCLUSIONS

Summary

The present study discusses the behavior of buildings with and without shear wall and effect of outrigger at 0.5H and 0.67H under wind load conditions. All the models are geometrically modeled and analyzed with a finite element code incorporating response spectrum method. The results expected in the analyses will be in terms of seismic parameters such as storey drift, model time period (FTP), storey displacement, bending moment variation at core.

The performance of building with shear wall and addition of outrigger significantly unlike when compared to each other for bending moment variation.

Based on dynamic analysis of various building model following conclusions have been drawn.

Storey Drift

Based on storey drift observation following conclusions are drawn.

1. Storey drift values of x and y direction for all models are within permissible limit as per IS 1893:2016 Cl.no.7.11.1 which is 0.4% of storey height.
2. Model-A and B shows highest value at 8th in x and y direction which is well within permissible limit as per codal provision.
3. All model has shown its maximum value of storey drift between 6th to 8th storey level in x and Y direction from which it can be concluded that outriggers are effective to reduce above story drift towards the top.

4. storey drift values observed very less in model C and D at all storey which may due to higher stiffness enhance due to provision of shear wall and outriggers.

Storey Displacement

1. Model A having highest value of displacement which proves less stiffness as compared to other model in x direction.
2. Performance of model B and C nearly same from displacement in x direction reduction point of view which shows provision of outrigger at multilevel can be effective as good as provision of shear wall.
3. Model D perform well and proved that provision of shear wall and outrigger together can enhance stiffness considerably i.e. 40%.
4. Model A having highest value of displacement which proves less stiffness as compared to other model in Y direction.
5. Performance of model B and C nearly same i.e. 20% variation from displacement in Y direction reduction point of view which shows provision of outrigger at multilevel can be effective as good as provision of shear wall.
6. Model D perform well and proved that provision of shear wall and outrigger together can enhance stiffness considerably even if (i.e. 33%) even on shorter direction (i.e. Y direction).

Modal Behavior

Based on above graph and table it has been observed that time period and modes are inversely proportional to each other for all building models.

1. Model A has highest time period as compared other models it may due to lesser stiffness available.
2. Model C and D has near about equal value of time period due to addition of outrigger from this it can be prove that inclusion of outrigger enhances the lateral stiffness of building i.e. reduction in lateral displacement.
3. Model D has lowest value of time period which shows lesser stiffness of building model.4. first three modes of all models shows reduction and fourth mode shows sudden drop of time period which shows highest mass participation covered in first three modes.

Bending moment at Core

1. Model A shows maximum bending moment value at bottom storey than other models. it may due to less moment of inertia. whereas Model B shows average bending moment from bottom to top due to uniform moment of inertial available from bottom to top.
2. Model C shows similar bending moment variation as model A but curve has pinched in between storey 9 to storey 12. This pinch of curve shows reduction of bending moment due to provision of outrigger.
3. Model D indicates maximum values of bending moment variation from 6th floor to 9th floor and sudden reduction of bending moment between 9th to 12th floor which is due to provision of outrigger.
4. Model D shows higher values of bending moment than other model above 6th floor which may due to increase of seismic weight because of shear wall and outrigger and reduction of response reduction factor.
5. Model D bending moment variation for pier-3 it is due to uniform tie of outrigger in both X and Y direction.

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