Analysis and Design of Twisted Skyscraper Building Using ETABS

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***Abstract* - The objectives of this paper is to study the behavior of a Twisted Skyscraper Building subjected to earth quake load and wind load by adopting Response spectrum analysis .The analysis is carried out with the help of FEM software's ETABS 2018. The building model in the study has G+50 (52) storeys with constant storey height of 3.5m.According to the Indian Standard Code Analysis and Design are carried out for this study. The stiffness of the bearing structure is a superior criterion in the shaping of such buildings and its value lies in the size of permissible vertical deflection. Limitation of the vertical deflection of a high-rise building is not only aimed at preventing and minimizing the adverse P-delta effects on the structure of the building. The stiffness of a tall building can also be considered as an indirect indicator of its susceptibility to dynamic influences. This impact depends on the strength of the wind and on the aerodynamic properties of the building. The value of the wind load increases with the height of the building. High spatial rigidity reduces the amount of acceleration associated with the horizontal displacements of a structure and also increases the natural vibration frequency, which for low values can be dangerous for construction. The structure can fall into resonance at critical wind speeds, which generates both high stresses and vertical deflection. The aerodynamic twisted shape has the advantage of disturbing the form of the impact of wind around the building to effectively reduce wind excitation**

***keywords* - Twisted Skyscraper, Wind Effect, Response spectrum analysis, Storey Drifts, ETABS V18.**

I. INTRODUCTION

1.1 GENERAL

One of the biggest challenges for engineers when designing modern high buildings is the impact of wind. It has a dynamic character and its strength depends on the aerodynamic properties of the building and strength of the wind. Analysis of the aerodynamic system of buildings concerns variable phenomena, which are dependent on many unpredictable factors. The structure of air swirling around a building, as a result of air mass collision with the building's form, is very complex and not fully explained theoretically. Therefore, traditional calculation methods that are, sufficient for static load testing are not an effective tool in this regard. Experimental and advanced computer simulations are required. For buildings with complex shapes, and because there are no standard procedures for this type of construction, research is performed in an aerodynamic tunnel. Rigid reinforced concrete cores are constructed for the transfer of horizontal loads and to prevent buildings from swaying.
The 82,000-square-meter office tower has 52 levels, with each level rotated three degrees from the previous and the overall twist reaching 156 degrees clockwise. With the world's largest cold-bent glazing, the tower façade provides a seamless floating reflection that rotates the panoramas of the Moscow skyline vertically. The reflected clouds moving up the surface enhance the dynamic visual impact of the twisted tower, an unprecedented optical effect on this scale. The tower's crown, with a supporting steel structure made of two twisted arches, provides a helipad at the very top, as well as an open observation roof deck at level 52 featuring the best panoramas of the Moscow riverside, with views towards the historic city center.

1.2 EFFECT OF WIND FORCE ON DIFFERENT SHAPES OF BUILDING

This study is based on the research paper publish by

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For this Research 4 different shaped of 12 Models are used for Analysis

1) Basic models:The Square, Rectangular, Triangular, Circular, and Elliptic plan models are classified as Basic Models. The side ratio of the Rectangular and Elliptic Models is 1:2.
2) Corner modification models: Although there are several methods for corner modification, i.e., corner chamfered, corner cut, corner rounding, fin, and so on, the examination of corner modification focuses on a Corner Cut Model, a Corner Chamfered Model and a Tri-Corner Cut Model.

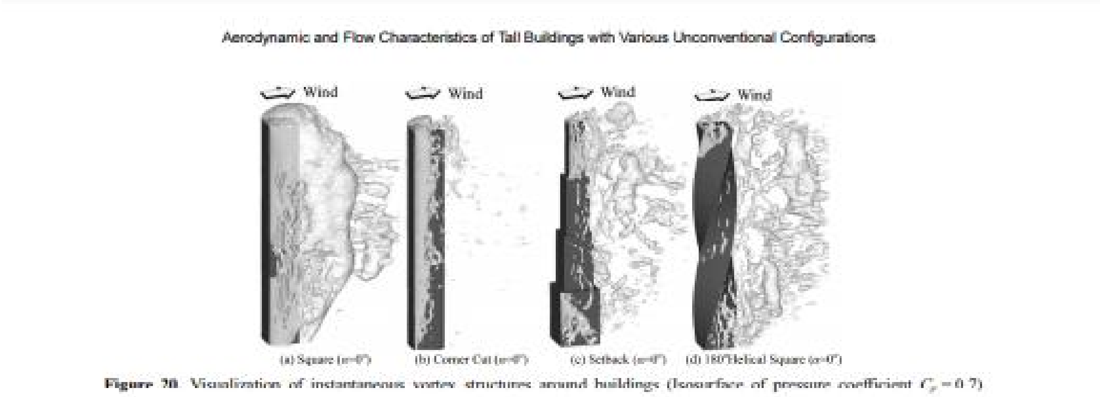

Fig 1: Visualization of instantaneous vortex structures around building (Isosurface of pressure coefficient $C_p = 0.7$).

3) Tapered models:The tapered models include the following five types: a 2- Tapered Model which has only two tapered surfaces, a 4-Tapered Model which has four tapered surfaces, an Inversely 4-Tapered Model which has the inverse building shape of the 4-Tapered Model, and a Bulged Model whose sectional area at mid-height is expanded.
4) Helical models:The sectional shapes of the helical models are square, rectangular and triangular, and the twist angle θ between the roof floor and the base floor is set at 60º, 90º, 180º, 270º and 360º

Results of Wind-induced Responses Analysis:
The wind pressure measurements were carried out on 12 models, including 8 single-modification models and 4 composite-modification models. The single-modification models include: Square Model, Corner Chamfered Model, Corner Cut Model, 4-Tapered Model, Setback Model, two Helical Models (θ = 90º and 180º), and Cross Opening Model (h/H = 5 /24). The composite-modification models include: 180ºHelical & Corner Cut Model, 4-Tapered & 180ºHelical Model, and two 4-Tapered & Helical (θ = 180º and 360º) & Corner Cut Models. Response analyses were conducted for these 12 models.

II. METHODOLOGY

2.1 METHOD FOR ANALYSIS OF THE STRUCTURE

The seismic analysis should be carried out for the buildings that have lack of resistance to earthquake forces. Seismic analysis will consider dynamic effects hence the exact analysis sometimes become complex. However for simple regular structures equivalent linear static analysis is sufficient one. This type of analysis will be carried out for regular and low rise buildings and this method will give good results for this type of buildings. Dynamic analysis will be carried out for the building as specified by code IS 1893-2016 (part1). Dynamic analysis will be carried out either by Response spectrum method or site specific Time history method. Following methods are adopted to carry out the analysis procedure.

2.2 RESPONSE SPECTRUM ANANLYSIS

- **Response-spectrum analysis** (RSA) is a linear-dynamic statistical analysis method which measures the contribution from each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure. Response-spectrum analysis provides insight into dynamic behavior by measuring pseudo-spectral acceleration, velocity, or displacement as a function of structural period for a given time history and level of damping. It is practical to envelope response spectra such that a smooth curve represents the peak response for each realization of structural period.
- Response-spectrum analysis is useful for design decision-making because it relates structural type-selection to dynamic performance. Structures of shorter period experience greater acceleration, whereas those of longer period experience greater displacement. Structural performance objectives should be taken into account during preliminary design and response-spectrum analysis.
- The representation of maximum response of idealized single degree freedom system having certain period and Damping, during earthquake ground motions. This analysis is carried out according to the code IS 1893-2016 (part1). Here type of soil, seismic zone factor should be entered from IS 1893-2016 (part1). The standard response spectra for type of soil considered is applied to building for the analysis in ETABS 2018 software. Following diagram shows the standard response spectrum for medium soil type and that can be given in the form of time period versus spectral acceleration coefficient (Sa/g).

This approach permits the multiple modes of response of a building to be taken in to account (in the frequency domain). This is required in many building codes for all except very simple or very complex structures. The response of a structure can be defined as a combination of many special shapes (modes) that in a vibrating string correspond to the "harmonic" computer analysis can be used to determine these modes for a structure. For each mode, a response is read from the design spectrum, based on the modal frequency and the modal mass, and they are then combined to provide an estimate of the total response of the structure. In this we have to calculate the magnitude of forces in all directions i.e. X, Y & Z and then see the effects on the building. Combination methods include the following:

- absolute - peak values are added together

- square root of the sum of the squares (SRSS)
- complete quadratic combination (CQC)

2.3 BUILDING DESIGN CONSIDERATIONS

2.3.1 Model Details:

Plan Dimensions	40m X 40m
Building Heights	Total height of building above G.L is 182.3m and floor to floor height is 3.5m
Grade of concrete	M50 for columns, shear walls and beams M40 For slab
Grade of Rebar	Fe-500(HYSD500) for columns, beams, Slabs and Shear walls
Thickness of slab	220 mm
Beam size(mm)	B600×830M50 SB700×850M50
Column size(mm)	SC1200×1200M50
Shear Wall Thickness	For inner and outer Core 400mm For lift Core 300mm
Dead load and live load	Floor finish=1KN/m^2 Live load=4KN/m^2 (living room, staircase)
Seismic load	Seismic Zone=3, Response Reduction Factor=5, Importance Factor=1.2, Soil type=2, Damping=5%
Wind Load	V_b=44m/s, Category=3, Class=C, Gust factor as per clause 8 of IS 875 part 3
Site Location	India(Mumbai)
Analysis Software	ETABs v18

Table1: Details of the Structure

2.3.2 Plan View in Etabs

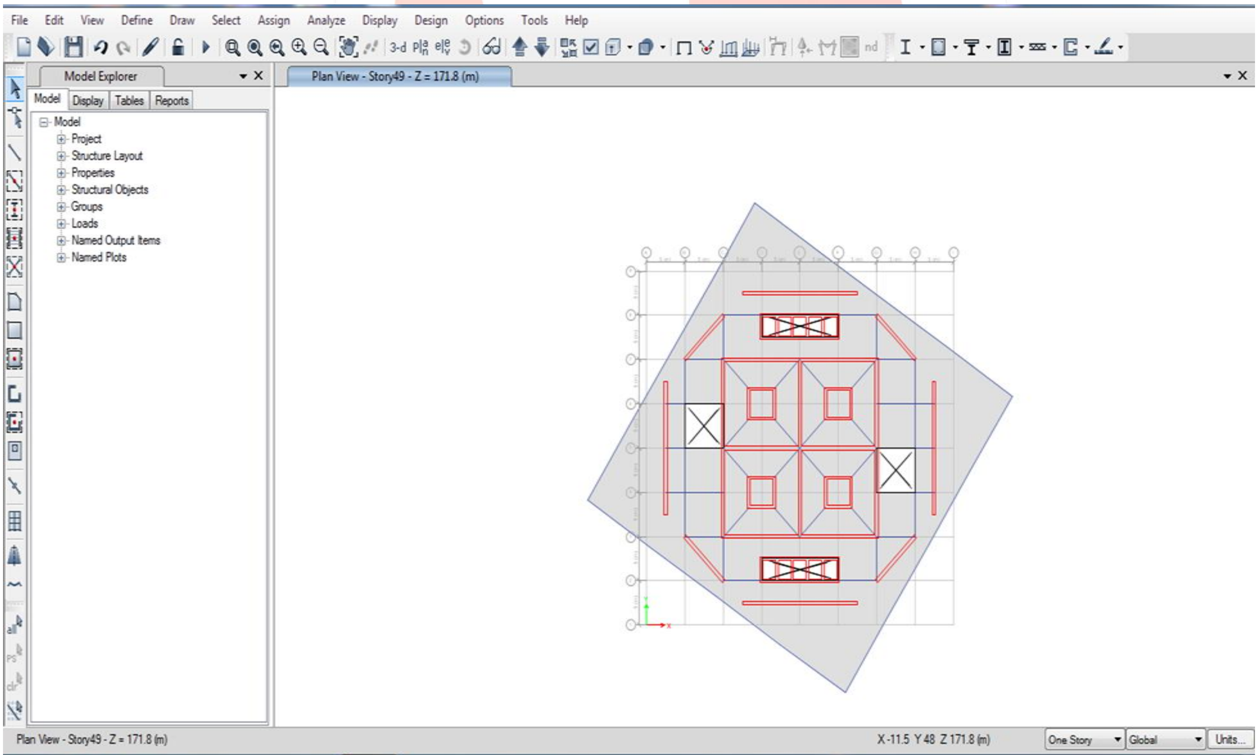

Fig2: Plan of structure in ETABS

III. RESULTS

3.1 STOREY DRIFT

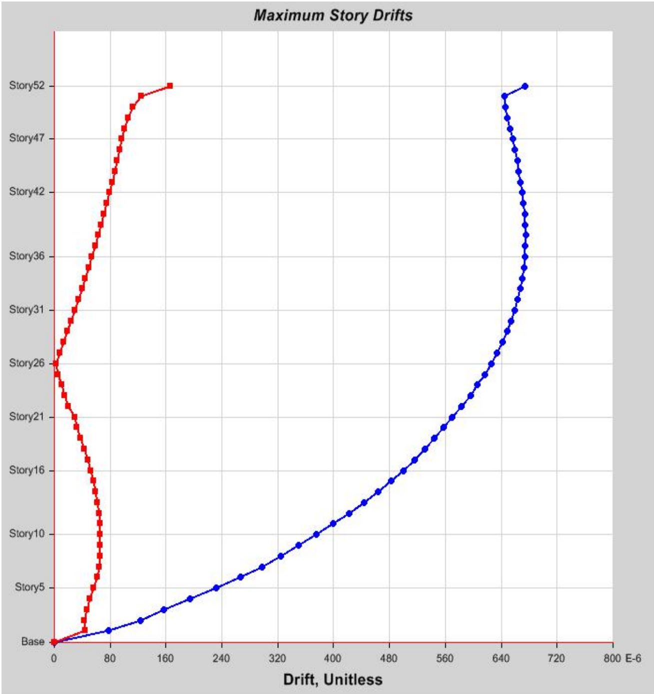

Fig 3: Graph for Storey Drift in EQ-X direction

Story	Elevation(m)	Location	X-Dir	Y-Dir
Story52	182.3	Top	0.000675	0.000166
Story51	178.8	Top	0.000645	0.000124
Story50	175.3	Top	0.000646	0.000112
Story47	164.8	Top	0.000656	0.000096
Story46	161.3	Top	0.00066	0.000093
Story35	122.8	Top	0.000672	0.000049
Story30	105.3	Top	0.000654	0.000025
Story29	101.8	Top	0.000648	0.000019
Story28	98.3	Top	0.000641	0.000014
Story27	94.8	Top	0.000634	0.000009
Story26	91.3	Top	0.000626	0.000003
Story25	87.8	Top	0.000616	0.000006
Story15	52.8	Top	0.000482	0.000057
Story14	49.3	Top	0.000463	0.000059
Story13	45.8	Top	0.000443	0.000062
Story12	42.3	Top	0.000421	0.000064
Story11	38.8	Top	0.000399	0.000065
Story5	17.8	Top	0.000232	0.000057
Story4	14.3	Top	0.000195	0.000052
Story3	10.8	Top	0.000157	0.000047
Story2	7.3	Top	0.000123	0.000043
Story1	3.8	Top	0.000077	0.000045
Base	0	Top	0	0

Table2: Storey Drift Values

Story	Elevation(m)	Location	X-Dir	Y-Dir
Story52	182.3	Top	0.00017	0.000574
Story51	178.8	Top	0.000134	0.000547
Story50	175.3	Top	0.000124	0.000548
Story47	164.8	Top	0.000111	0.00056
Story46	161.3	Top	0.000108	0.000564
Story35	122.8	Top	0.000068	0.000592
Story30	105.3	Top	0.000044	0.000584
Story29	101.8	Top	0.000039	0.00058

Story	Elevation(m)	Location	X-Dir	Y-Dir
Story28	98.3	Top	0.000034	0.000576
Story27	94.8	Top	0.000029	0.00057
Story26	91.3	Top	0.000024	0.000564
Story25	87.8	Top	0.000019	0.000557
Story15	52.8	Top	0.000036	0.000448
Story14	49.3	Top	0.000039	0.000432
Story13	45.8	Top	0.000042	0.000414
Story12	42.3	Top	0.000045	0.000395
Story11	38.8	Top	0.000047	0.000375
Story5	17.8	Top	0.000045	0.000223
Story4	14.3	Top	0.000041	0.00019
Story3	10.8	Top	0.000038	0.000156
Story2	7.3	Top	0.000036	0.000119
Story1	3.8	Top	0.000034	0.000072
Base	0	Top	0	0

Table3: Storey Drift Values

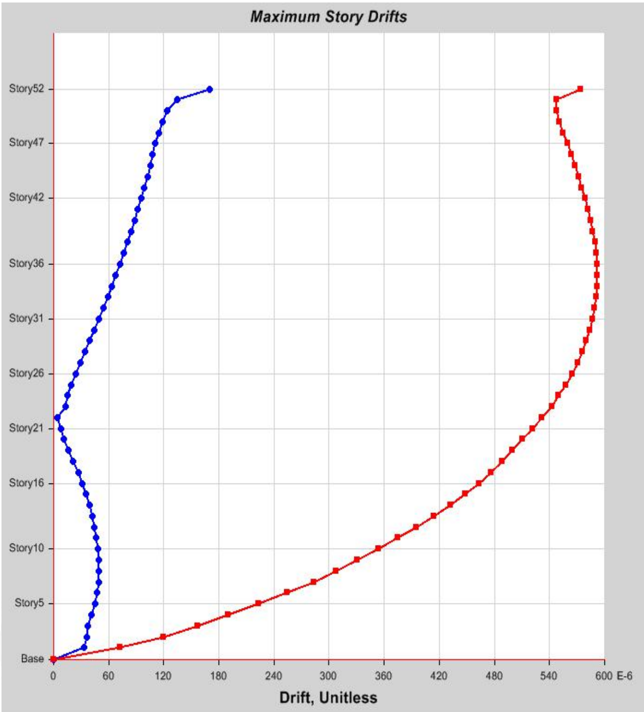

Fig 4: Graph for Storey Drift in EQ-Y direction

Story	Elevation(m)	Location	X-Dir(mm)	Y-Dir(mm)
Story52	182.3	Top	97.802	2.392
Story51	178.8	Top	95.493	1.842
Story45	157.8	Top	81.838	0.468
Story44	154.3	Top	79.519	0.776
Story43	150.8	Top	77.194	1.072
Story35	122.8	Top	58.395	2.948
Story34	119.3	Top	56.046	3.114
Story33	115.8	Top	53.705	3.264
Story24	84.3	Top	33.434	3.81
Story23	80.8	Top	31.317	3.785
Story21	73.8	Top	27.202	3.676
Story15	52.8	Top	15.973	2.882
Story12	42.3	Top	11.133	2.284
Story11	38.8	Top	9.669	2.068
Story5	17.8	Top	2.715	0.778
Story4	14.3	Top	1.917	0.597
Story3	10.8	Top	1.246	0.436

Story	Elevation(m)	Location	X-Dir(mm)	Y-Dir(mm)
Story2	7.3	Top	0.704	0.295
Story1	3.8	Top	0.294	0.17
Base	0	Top	0	0

Table 4: Story Displacement Values

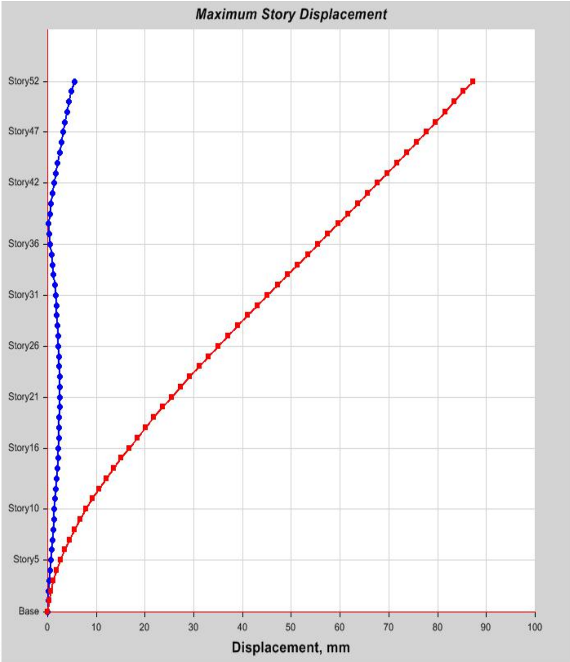

Fig 5: Graph for Storey displacement in EQ-X direction

3.2 STOREY DISPLACEMENT

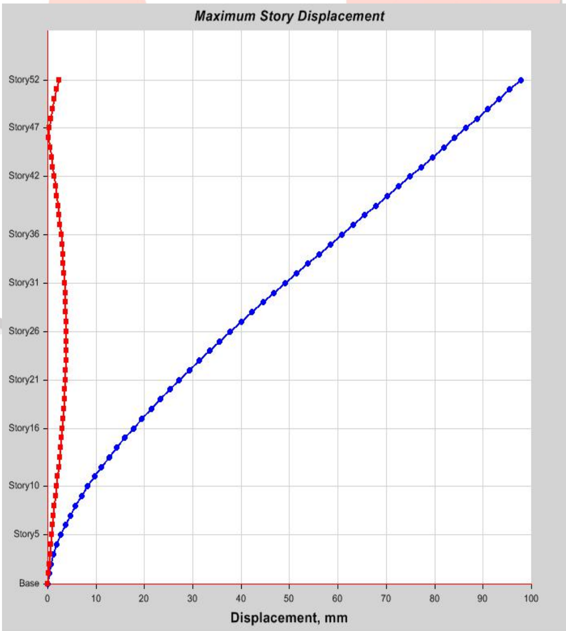

Fig 6: Graph for Storey displacement in EQ-Y

Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Story52	182.3	Top	5.448	87.279
Story51	178.8	Top	4.883	85.329
Story45	157.8	Top	2.437	73.719
Story44	154.3	Top	2.071	71.735
Story43	150.8	Top	1.718	69.737
Story35	122.8	Top	0.795	53.386
Story34	119.3	Top	1.024	51.318

Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Story33	115.8	Top	1.237	49.251
Story24	84.3	Top	2.382	31.109
Story23	80.8	Top	2.429	29.189
Story22	77.3	Top	2.457	27.298
Story21	73.8	Top	2.467	25.441
Story15	52.8	Top	2.111	15.107
Story12	42.3	Top	1.726	10.599
Story11	38.8	Top	1.577	9.222
Story5	17.8	Top	0.618	2.628
Story4	14.3	Top	0.478	1.852
Story3	10.8	Top	0.349	1.187
Story2	7.3	Top	0.234	0.651
Story1	3.8	Top	0.128	0.275
Base	0	Top	0	0

Table 5: Story Displacement Values

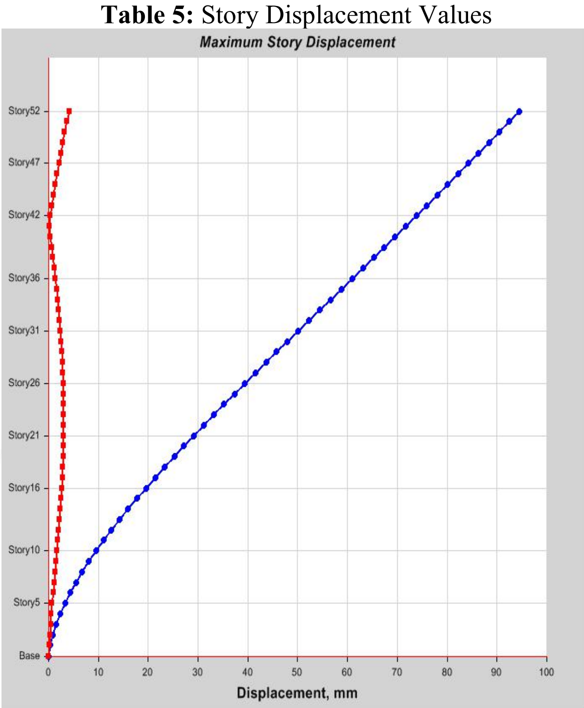

Fig 7: Graph for Storey displacement due to wind

Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Story52	182.3	Top	94.549	4.239
Story51	178.8	Top	92.444	3.706
Story50	175.3	Top	90.426	3.265
Story47	164.8	Top	84.283	2.113
Story46	161.3	Top	82.207	1.753
Story45	157.8	Top	80.121	1.403
Story43	150.8	Top	75.917	0.731
Story42	147.3	Top	73.798	0.411
Story41	143.8	Top	71.671	0.104
Story40	140.3	Top	69.535	0.371
Story37	129.8	Top	63.095	1.171
Story36	126.3	Top	60.928	1.41
Story35	122.8	Top	58.759	1.634
Story34	119.3	Top	56.59	1.843
Story32	112.3	Top	52.247	2.219
Story31	108.8	Top	50.086	2.383
Story30	105.3	Top	47.933	2.529
Story27	94.8	Top	41.53	2.863

Story	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Story26	91.3	Top	39.422	2.937
Story25	87.8	Top	37.331	2.994
Story24	84.3	Top	35.255	3.03
Story23	80.8	Top	33.198	3.057
Story21	73.8	Top	29.137	3.052
Story20	70.3	Top	27.167	3.019
Story17	59.8	Top	21.414	2.792
Story16	56.3	Top	19.567	2.677
Story15	52.8	Top	17.758	2.544
Story14	49.3	Top	15.994	2.397
Story13	45.8	Top	14.285	2.236
Story12	42.3	Top	12.636	2.063
Story10	35.3	Top	9.532	1.692
Story9	31.8	Top	8.112	1.498
Story8	28.3	Top	6.767	1.303
Story7	24.8	Top	5.5	1.108
Story6	21.3	Top	4.33	0.922
Story5	17.8	Top	3.273	0.745
Story4	14.3	Top	2.342	0.58
Story3	10.8	Top	1.546	0.431
Story2	7.3	Top	0.887	0.299
Story1	3.8	Top	0.371	0.177
Base	0	Top	0	0

Table 6: Story Displacement Values

IV. CONCLUSION

From the above study following conclusions are made

1. The values of storey drifts decrease from top storey to bottom storey and the maximum value is obtained for storey 50 (i.e. 0.00065 and 0.000574 in X-Direction and Y-Direction resp) and according to IS 1893-2016 part 1 this values are within the limit(i.e. maximum drift allowed is 0.004 of storey height).
2. Top storeys are more susceptible to the drifts, building torque, forces and moments and these values decrease as we move on to the bottom storeys.
3. As the height of the building increases, lateral forces plays a dominant role. Therefore, certain provisions shall be made in order to resist these lateral forces so that building performance under the effect of lateral loads can be improved.
4. Skyscraper Building subjected to earth quake load has been analyzed by adopting Response spectrum analysis by using ETABS V18.
5. It has become clear that super tall buildings require more efficient design than normal high-rise buildings and that it is not possible to simply use a scaled up structural system of a 100 meter high building for a 800 meter high building . Super tall buildings require a different and more structurally efficient design. The changes in the design are necessary for the following reasons.
    - Larger consequence of negative effects due to differential settlements.
    - Increasing lateral Wind Load.
    - Susceptibility to dynamic behavior.
    - Daylight entry problem.
    - Vertical transportation large influence of the erection process and construction time on the projects feasibility.

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