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WIND ANALYSIS OF TALL BUILDING

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ABSTRACT
Tall building is an emerging construction practice in Indian metropolitan cities due to large urbanization. The design criteria for tall buildings are different than low and mid-rise buildings. In tall buildings usually, the wind is the critical load that needs to be considered for the safety and serviceability of the structure. Any tall building can vibrate and oscillate in both the directions due to along-wind and across-wind. These oscillations may even cause discomfort to the occupants even if it is not in a threatening position for the structural damage. So, an accurate assessment of building motion is an essential prerequisite for serviceability. National building code and other Indian standard codes are not sufficient to adequately address various issues related to tall buildings. Recently, IS 16700: 2017 "Criteria for Structural Safety of Tall Concrete Buildings" is released by BIS for tall concrete buildings.
This Work deals with the detailed wind analysis of 180m tall building as per IS 16700: 2017. In which wind tunnel studies will be carried out on a scaled-down model of a proposed tall building. This wind tunnel studies have also been compared with the responses computed analytically and also check and satisfy all the criteria as per this code.

KEYWORDS: Along-wind, Across-wind, tall buildings, wind tunnel studies, IS 16700: 2017.

1. INTRODUCTION
At every step that tall building design takes toward the sky, today's structural engineers and architects coming across new complications. As the height of tall buildings rises with developments in the field of structural system design and the use of high-strength materials, their strength to weight ratio, slenderness and flexibility increase, and their rigidity decrease and thus their susceptibility to wind loads increase. Wind loads, which cause large lateral deflection, play a key role in the design of tall buildings and can be even more critical than earthquake loads. As a result, the wind loads to which tall buildings are subject have become an important problem.

Since the weight of the structural system in the early tall buildings made vertical forces more critical than lateral forces, wind loads were not considered important. In time, with developments and innovations in structural systems and the increase in the strength to weight ratio of the structural elements, the weight of buildings decreased and wind loads began to be important. Consequently, because the tall buildings being constructed today are lighter, slenderer and more flexible than their predecessors, they are more prone to lateral drift with low damping, and wind-induced building sway has been transformed into one of the most important problems encountered by tall building designers, becoming a basic input to the design.

1.1 Dynamic effect of wind
As wind is a highly random varying dynamic phenomenon, it has significant dynamic effects on buildings and structures, especially on tall building structures. Codes and standards suggest the gust factor Method approach for estimating dynamic effect on high-rise structures. The concept of Gust factor method was first introduced by davenport in 1967. The last few years have been witnessed considerable progress in the understanding of the characteristics of wind, as well as the response to the various kinds of structures. "B. Dean Kumar and B.L.P. Swami et al.(2010) carried out a dynamic analysis of slender tall structures the found that the gust factor computed by the gust effectiveness factor method increase with the height of the building and they are more critical than static pressure."

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"Halder and Dutta et al. (2010) had compared the structural parameters based on IS 875 (part3) and ASCE 7-02. It was observed that base shear estimated for low to high rise buildings by Indian wind code is 1.30- 1.90 times the same estimated by ASCE 7-02". "I.Srikanth and b.Vamsi et al.(2014) focuses on Equivalent frames from 20 to 80 stories for D.L and L.L combination". "Zheng-wei Zhang and Michael et al.(2017) worked focus is on the calculation of cross-wind response of rectangular buildings, which is not covered by Eurocode 1 (part 1 to 4)."

1.2 Wind tunnel studies

Shorter and less flexible buildings are generally treated by building codes as static structures, and wind load can be calculated as a static load on the building. For taller and/or more flexible structures the static load approach is insufficient, and the wind load on the building is treated as a dynamic load. Boundary-layer wind tunnel tests can be used to accurately determine the dynamic response of tall buildings to wind loading and excitation."Dragoiescu.C , Garber.J and K.Suresh et al.(2006) carried out a detailed investigation aimed at quantifying the advantages and limitations of the HFFB and HFPI methods. They concluded that the HFFB method offers the advantage that the total loading on complex geometries will be reflected in the measured base loads". "P.Mendis, T.Ngo, N. Haritos et al.(2007) gives an summary of advanced levels of wind design, in the context of the Australian Wind Code, and also illustrates the exceptional benefits it offers over simplified approaches. Wind tunnel tests, which has the potential advantage of further refinement in deriving design wind loading and its effects on tall buildings, is also emphasized."

1.3 Tall building codes

Recently, BIS released the Code IS 16700: 2017 "Criteria for Structural Safety of Tall Concrete Buildings" which covers the following design aspects of reinforced concrete building of height greater than 50 m but less than or equal to 250 m. It also suggests the criteria to adopt wind tunnel analysis. "Gangisetty, Venkata, Krishna, Ratnesh Kumar et al.(2018) gives a brief detail about various clauses of the code. Overall, this code will assist designers for considering various design limits for tall buildings and will channelize the design procedure".

2. MATERIALS AND METHODS

Tall buildings which are 'wind sensitive' shall be designed for dynamic wind loads. Hourly mean wind speed is used as a reference wind speed to be used in dynamic wind analysis. For calculation of along wind loads and response (bending moments, shear forces, or tip deflections) the Gust Factor (GF) method is used as specified in Cl 10.2 of IS 875 part 3. The across wind design peak base overturning moment & tip deflection shall be calculated using Cl 10.3 of IS 875 part 3. After analytical calculation the wind tunnel tests was conducted using the High Frequency Force Balance (HFFB) technique. A 1:400 scale model of the proposed development was constructed using the architectural. The model was tested in the presence of all surroundings within a minimum full-scale radius of 480 m, in RWDI's 2.4 m X 1.8 m boundary layer wind tunnel facility in Trivandrum, Kerala, India.

2.1 Description of Building

The building studied is named as colo rise tower going to be built at dadar, India by Epicons Company. The prototype is considered to be situated in an open terrain with well obstructions, defined in terrain category 4 in IS 875: part3. Base dimension of building: 33.95 m X 27.95 m and total height of building (Above ground) is 180.1m

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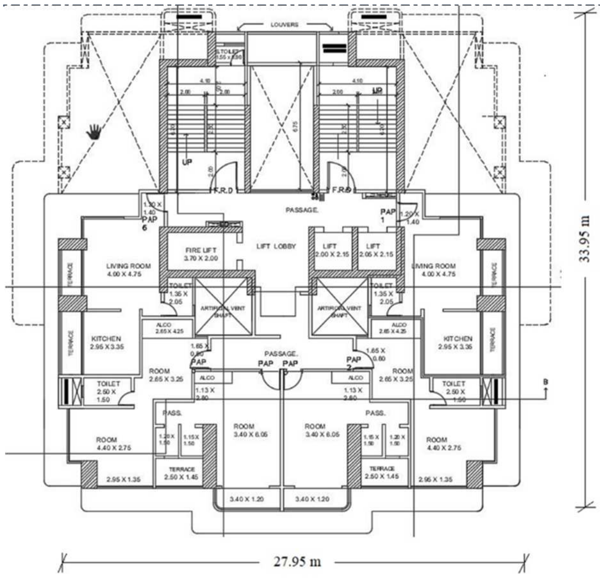

Figure 1. Plan of The Building

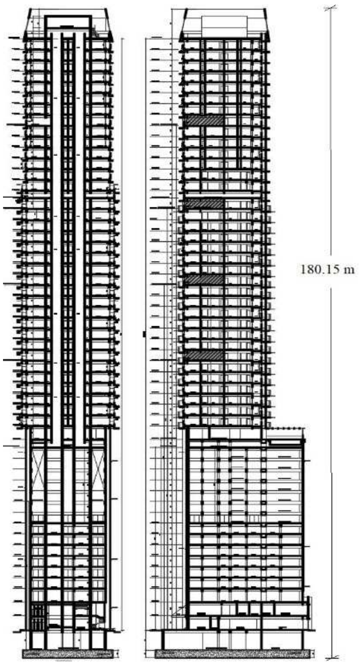

Figure 2. Elevation of The Building

2.2 Along Wind and Across Wind Loads Calculated by Gust Factor Method

The design peak along wind base bending moment, (Ma) shall be obtained by summing the moments resulting from design peak along wind loads acting at different heights, z, along the height of the building/structure and can be obtained from,

Equation,

$$F_z = C_{f,z} A_z \; P_d \, G \qquad (1)$$

where, G = Gust Factor and is given by

$$G = 1 + r\sqrt{g_v^2 B_s (1+\phi)^2 + \frac{H_s g_R^2 SE}{\beta}}$$

F_z = design peak along wind load on the building/ structure at any height z
A_z = the effective frontal area of the building/ structure at any height z, in m2
P_d = design hourly mean wind pressure corresponding to $V_{z,d}$ and obtained as $0.6(V_{z,d})^2$(N/m2)
$V_{z,d}$ = design hourly mean wind speed at height z, in m/s

The across wind design peak base bending moment Mc for enclosed buildings and towers shall be determined as follows:

$$M_c = 0.5 g_h p_h b h^2 (1.06 - 0.06\, k)\sqrt{\frac{\pi C_{fs}}{\beta}} \quad (3)$$

The across wind load distribution on the building/ structure can be obtained from Mc using linear distribution of loads as given below:

$$F_{z,c} = \left(\frac{3M_c}{h^2}\right)\left(\frac{z}{h}\right) \quad (4)$$

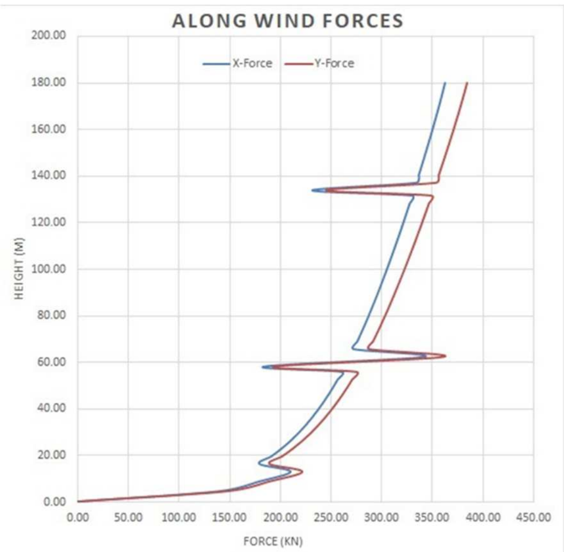

Figure 3. Along wind forces vs height graph

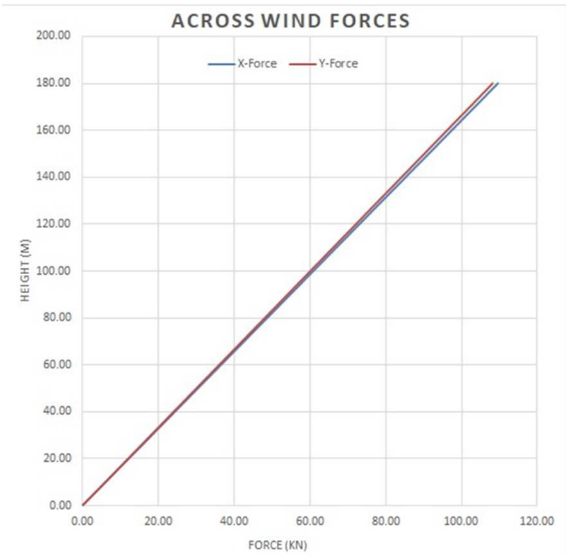

Figure 4. Across wind forces vs height graph

The along wind forces and across wind forces are calculated with excel spread sheets and the graphical representation of wind forces with respect to height are plotted. The fluctuation in the along wind force graph is due to the variation in floor to floor height and since the formula contain the effective frontal area of building the variation in forces are noticeable where as the across wind forces is quite linear because the formula to calculate across wind force does not vary much by the effect of height.

2.2 Wind tunnel analysis

The study was conducted using the High Frequency Force Balance (HFFB) technique. A 1:400 scale model of the proposed development was build using the architectural drawings. The model was tested in the presence of all surroundings within a minimum full-scale radius of 480 m, in RWDI's 2.4 m X 1.8 m boundary layer wind tunnel facility in Trivandrum, Kerala, India. Photographs of the wind tunnel study model are shown in Figure 5. An orientation plan showing the study site and immediate surroundings is given in Figure 6. Wind direction is defined as the direction from which the wind blows, measured clockwise from true north.

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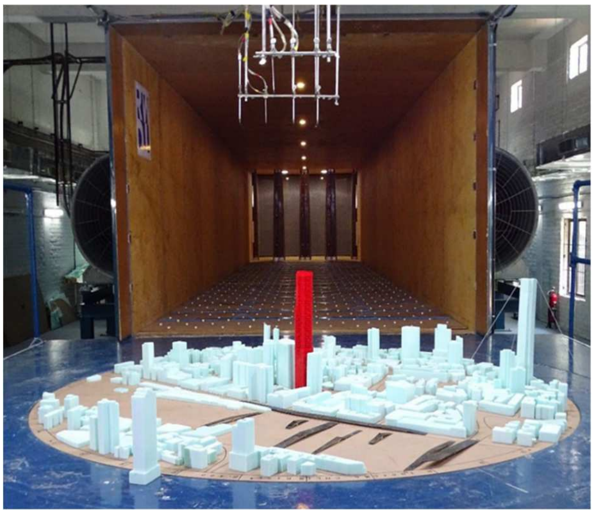

Figure 5. Wind Tunnel Study Model

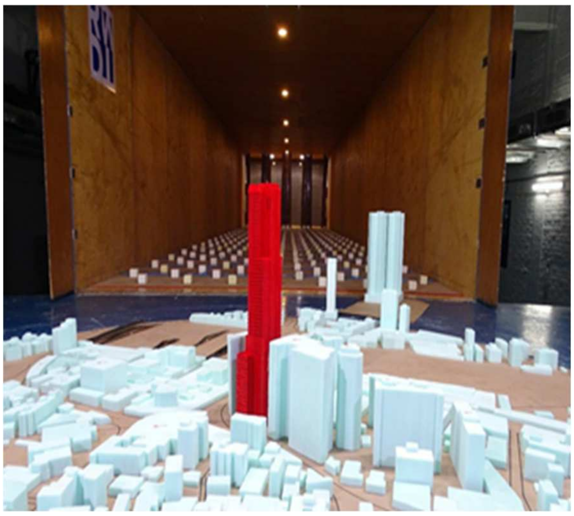

Figure 6. An orientation plan showing the study site

Table 1. Effective Wind Loads for 50-Year Return Period

Floor Level	Ht. (m)	Fx (N)	Fy (N)	M z (Nm)	Floor Level	Ht. (m)	Fx (N)	Fy (N)	M z (Nm)
G.F	0	41500	18700	104000	21	94.95	201400	162700	451000
1	4.2	78000	37800	193000	22	98.25	208200	169900	466000
2	8.1	74000	33000	177000	23	101.55	214900	177000	480000
3	11.4	74100	29900	182000	24	104.85	220000	182800	490000
4	14.7	79300	31100	203000	25	108.15	228500	191500	507000
5	18	85100	36200	225000	26	111.45	235300	198700	521000
6	21.3	90800	41400	246000	27	114.75	241900	205800	533000
7	24.6	97200	47000	268000	28	118.05	248500	213000	545000
8	27.9	103600	52800	291000	29	121.35	255200	220200	557000
9.1	31.2	147700	85500	528000	30	124.65	261800	227500	569000
9.2	34.5	64500	29600	116000	31	127.95	267400	233800	578000
9.3	37.8	91100	50000	215000	32	131.25	293300	257400	644000
9.4	41.1	81600	44700	179000	33	134.55	228100	201500	393000
9.5	44.4	67300	35700	121000	34	137.85	233200	205400	396000
9.6	47.7	68600	37700	123000	F.C.F	141.15	241300	217500	415000
9.7	51	69700	39800	124000	35	143.85	237400	210900	396000
S.F	54.3	176300	124600	694000	36	147.15	249900	223900	411000
10	55.95	123500	89900	270000	37	150.45	257600	231500	427000
11	59.25	129100	88700	278000	38	153.75	260100	234900	428000
12	62.55	137800	96400	302000	39	157.05	267500	242700	437000
13	65.85	143800	102600	317000	40	160.35	272300	248300	442000
F.C.F	69.15	150600	111600	335000	41	163.65	277100	253800	447000
14	71.85	148300	110700	330000	42	166.95	281700	259300	451000
15	75.15	161400	121000	360000	43	170.25	286300	264700	456000
16	78.45	167900	127800	375000	44	173.55	290800	270100	460000
17	81.75	173300	133700	388000	45	176.85	295200	275500	464000
18	85.05	181200	141600	406000	T.F	180.15	535000	524700	957000
19	88.35	188000	148600	421000	Total		1.05E+07	8.51E+06	2.15E+07
20	91.65	194800	155700	436000					

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The floor wise wind forces acting on a building are obtained from both dynamic analysis and wind tunnel analysis which will be input as wind loads in Etabs model for further analysis.

2.3 Modelling of the Building

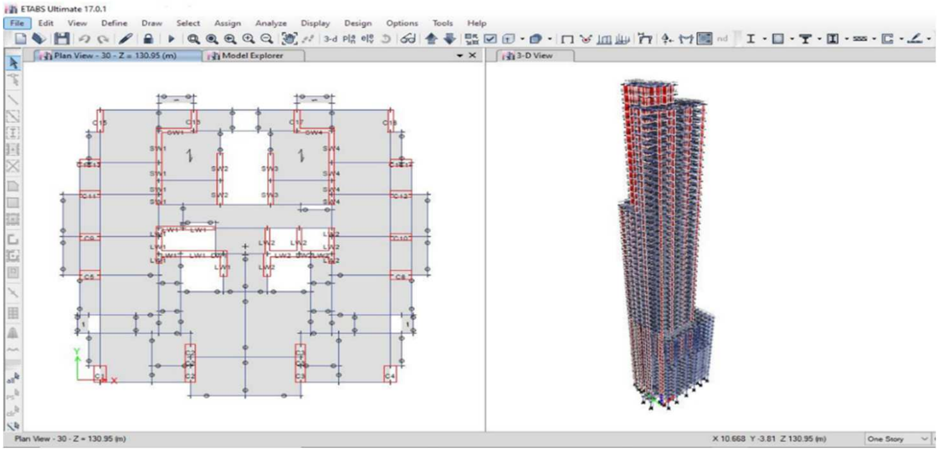

Figure 7. Model of the Building in ETABS 2017

Structure has been analysed using ETABS 17 version. ETABS is developed by CSI and is completely tested by various institutes and is highly recommended for building structures. After modelling, two separate models are created in which loads obtain from dynamic analysis and loads obtain from wind tunnel analysis are applied to their respective model. Both models are run in ETABS 2017 and the results obtained from them are compared.

3. RESULTS AND DISCUSSION

The Result are obtained from analysis of both the Etabs models in which one has dynamic wind analysis loads and other has wind tunnel analysis load and the parameters like base shear, Deflection and Drift are compared.

3.1 Base Shear Results

Base shear is an estimate of the maximum expected lateral force that will occur due to wind or seismic ground motion at the base of a structure.

Base shear in X – direction by dynamic wind analysis model is found out to be 13295.5 kN
Base shear in X – direction by wind tunnel analysis model is found out to be 10480 kN
Base shear in Y – direction by dynamic wind analysis model is found out to be 14318 kN
Base shear in Y – direction by wind tunnel analysis model is found out to be 8508.8 kN

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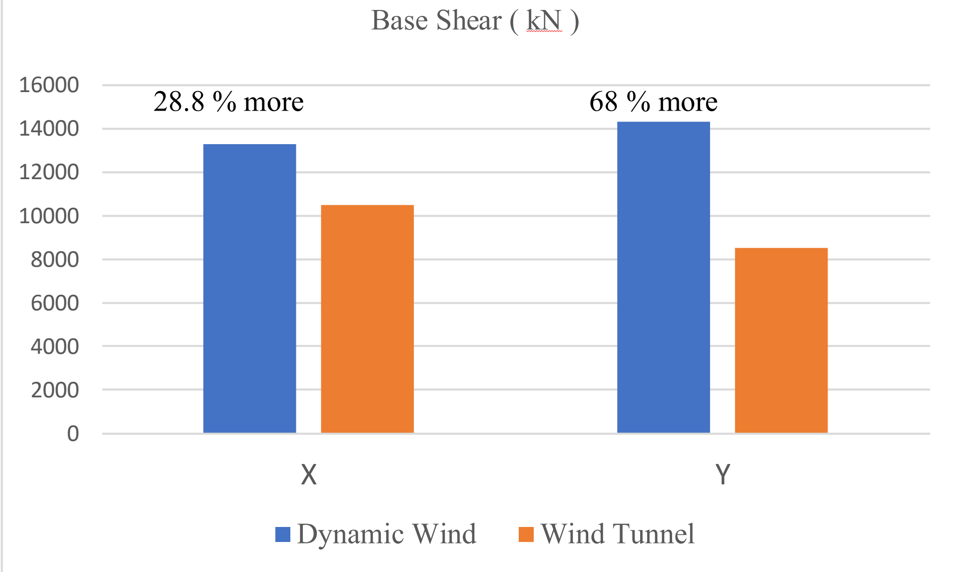

Figure 8. Base Shear Comparison of dynamic wind analysis and wind tunnel analysis

3.2 Deflection Results

Deflection is the absolute value of displacement of the storey under action of the lateral forces.

Deflection in X – direction by dynamic wind analysis model is found out to be 284.81 mm
Deflection in X – direction by wind tunnel analysis model is found out to be 272.5 mm
Deflection in Y – direction by dynamic wind analysis model is found out to be 341.3 mm
Deflection in Y – direction by wind tunnel analysis model is found out to be 306.9 mm

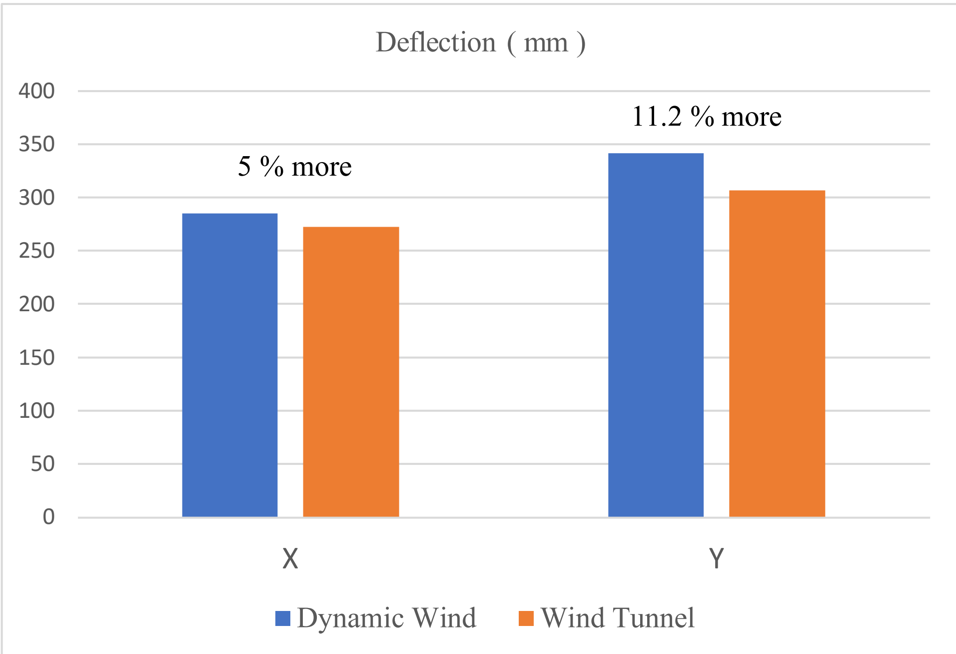

Figure 9. Deflection Comparison of dynamic wind analysis and wind tunnel analysis

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3.3 Drift Results

Drift defined as the lateral frame deflection at the top of the most occupied floor divided by the height of the building to that level, Δ/H.

Drift in X – direction by dynamic wind analysis model is found out to be 0.001912
Drift in X – direction by wind tunnel analysis model is found out to be 0.001874
Drift in Y – direction by dynamic wind analysis model is found out to be 0.001984
Drift in Y – direction by wind tunnel analysis model is found out to be 0.001669

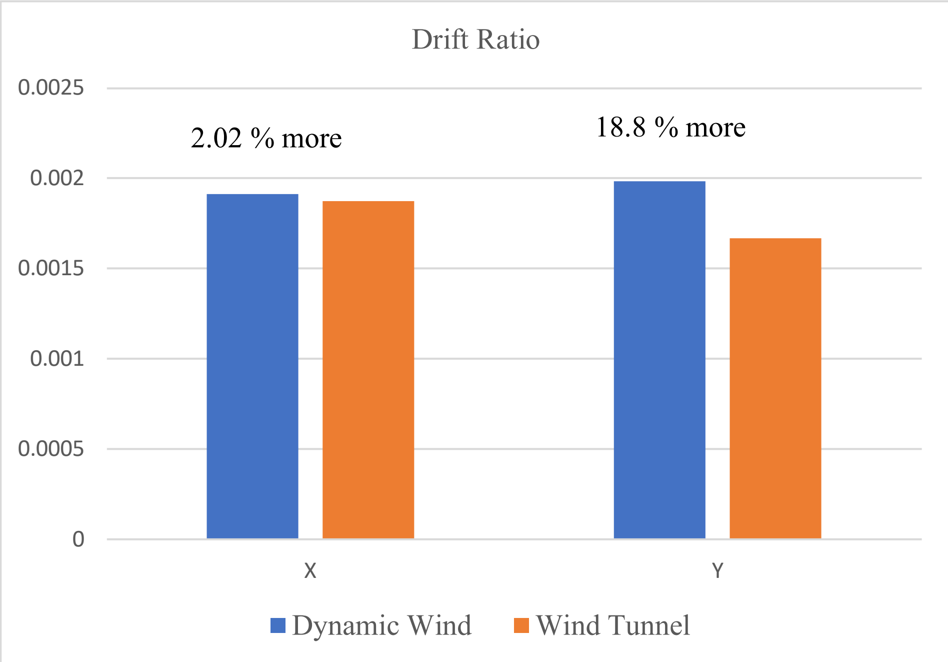

Figure 10. Drift ratio Comparison of dynamic wind analysis and wind tunnel analysis

4. CONCLUSION

In this study, wind analysis is carried out for a tall building by using two different methods. The two methods are dynamic analysis (Gust factor method) by using is 875-2015 and wind-tunnel analysis. The loads obtain from the above methods are applied to the respective etabs model and the results (base shear, deflection and storey drift) are compared.

Following conclusions are drawn from this study:

- The base shear of building obtained from dynamic-wind analysis is 28.8% more than the base shear obtained by wind-tunnel analysis in the X direction. The base shear obtained from dynamic-wind analysis is 68% more than the base shear obtained by wind tunnel analysis in the Y direction.
- The deflection of building obtained from dynamic-wind analysis is 5% more than the deflection obtained by wind tunnel analysis in the X direction. The deflection obtain from dynamic-wind analysis is 11.2% more than the deflection obtained by wind tunnel analysis in the Y direction.
- The Storey Drift of building obtained from dynamic-wind analysis is 2.02% more than the Storey Drift obtained by wind tunnel analysis in the X direction. The Storey Drift obtain from dynamic-wind analysis is 18.8% more than the Storey Drift obtained by wind tunnel analysis in the Y direction.
- As we compare, the dynamic wind analysis results are higher than wind tunnel analysis results so it can say that dynamic wind analysis by IS code 875 2015 provide more factor of safety. On the other hand wind tunnel analysis of building gives more accurate wind forces based on actual site condition.

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