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COMPARISION OF WIND LOADS ON TALL BUILDINGS BY ANALYTICAL & EXPERIMENTAL METHODS

CHILVERI GHANASHYAM S
PG Scholar: Department of civil engineering, P.D.V.V.P, College of Engineering, Ahmednagar, India, chilverigs@gmail.com

PANKAJ.B. AUTADE
Assistant Professor: Department of civil engineering, P.D.V.V.P, College of Engineering, Ahmednagar, India

ABSTRACT:

The work presents comparative study of wind forces on high rise buildings for different analytical methods. As the height of the structure goes on increasing wind forces start predominating over earthquake forces which require proper assumption of force factors in order keep structure safe & serviceable. The reason for knowing exact wind force behavior and values is to identify and keep parameters such as the base shear, storey displacement, storey drift, overturning moment and story shear within permissible limits of serviceability. As Comparisons of the wind forces obtained by Indian codal provisions & wind tunnel are presented for some representative cases to gaze the relative level of protection attributed by Indian wind codes. This study includes wind forces obtained by force coefficient based static analysis and gust factor based dynamic analysis. Experimental comparative study of wind force conducted on two of the high rise buildings from Mumbai metro city for static and dynamic codal provisions & wind tunnel observations. The analysis performed on this building to identify above factors by using software package i.e. Etabs & wind tunnel laboratory tests.

KEYWORDS : High rise, earthquake forces, wind forces, Base shear, storey displacement, storey drift, overturning moment, story shear, static and dynamic codal provisions, wind tunnel.

I. INTRODUCTION:

In present study comparison of wind loads on a tall building by analytical and experimental methods is carried out. The buildings are residential Building having typical plan dimensions of 74.8m x 32.9m and number of floors considered is G+63. The floor height at typical floors is 3.9m and varying for parking and basement levels. The structure is subjected to self-weight, dead load, live load, wind load and seismic loads under the load case details of E-tab. Analysis of the structure is done for both wind and earthquake but as wind is governing in this tall buildings. Wind forces are calculated as per code IS: 875:1987-part-3 and basic parameters for the same were input in etabs. The software outputs for static and dynamic analysis are compared with wind tunnel observations in etab's.

II. SCOPE OF WORK:

The scope of the present work includes the study of the Wind loads by both analytical and experimental methods on tall buildings. Tall buildings are analyzed for both static and dynamic analysis and results from these methods are again compared to wind tunnel observations.

III. OBJECTIVES:

Following are the main objectives of the work..

1. To calculate static forces for tall building manually.
2. To calculated gust forces manually for inputting in etabs software.
3. To check the models behavior with all three methods- static, dynamic and wind tunnel load cases.
4. To compare base shear, displacements for tower by three methods

IV. LITERATURE REVIEW:

- **Authors Patruno, M. Ricci, S. de Miranda, F. Ubertini (2017)** presented study on - an efficient approach to the determination of Equivalent Static Wind Loads (ESWLs). The methodology is based on the use of Principal Static Wind Loads which are obtained by using the recently introduced Proper Skin Modes. Moreover, a new efficient envelope reconstruction procedure is proposed.
- **Authors Rahul M. Kachole1, Prof. Amey Khedikar2, Prof Sanjay Bhadke3 (2016)** study on along wind load dynamic analysis of buildings with different geometries was done. They present methods of along wind analysis of tall and slender structures. For this they have done rigorous method of Random Vibration Analysis (RVA) and methods available in Indian Standard for wind load calculation [IS: 875 (Part 3) – 1987 and IS: 875 (Part 3) – Draft 2015].
- **Authors S.Vijaya Bhaskar Reddy1 Yugandhar Sagar.A2, Srinivas vasam3, P, Srinivasa Rao (2015)** Experimental study was carried on Effect of wind forces on multistoried structures. In this study they have modelled structures of 5 and 10 storeys and applied lateral loads. From the above study it was concluded by the authors that the effective parameters for wind forces affecting any building are the area subjected to wind as well as the intensity of wind defined by the code according

to it's the location. The wind loads increases with height of structure.

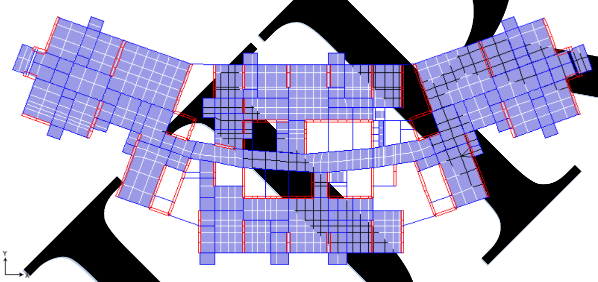
V. METHODOLOGY:

In this report our study is to find the wind loads by using analytical and experimental methods. Analytical methods are carried out as per the codal norms whereas experimental method involves wind tunnel experiment. Static and dynamic analysis is done as per the IS: 875:1987-part-3 and wind tunnel observations are done in experimental laboratory. Main aim is to find the loads variation by various methods and reliability in order to achieve sound serviceable at the same time economical design. For this purpose one structure is selected from Mumbai.

VI. BUILDING PARAMETERS:

Table 1 – Structural Data of Building

Building Details		
Max. Length X direction	74.8	m
Max. width Y direction	32.89	[illegible]
No. of Floors	2B+G+7POD+53	[illegible]
Floor height @ typical floors	3.9	[illegible]
Floor height @ typ. Podium	3	[illegible]
Floor height @ Ground level	3	m
Total height of the structure	211.60 from [illegible]	m



[illegible] Floor Plan [illegible]ding

VII. CALCULATIONS:

1. Analytical Method: Stati[illegible]ethod:

In this method, the force[illegible] acting in a specified direction of wind is given as:

$$F = C_f . A_e . P_d$$

Where,

A_e = the effective frontal area of the structure

C_f = Force Coefficient for the building and

P_d = Design wind pressure on the structure.

Table 2 – Structural Wind Data of Building

BUILDING DATA			
Length (a)	=	74.8	m
Width (b)	=	32.9	m
Height (h)	=	211.60	m
Parapet Ht.	=	1.2	m
WIND DATA			
Basic Wind Speed , V_b		44	m/s
Terrain Category		Category 3	
Structures Class		C	
DESIGN FACTORS			
Risk Coefficient k_1		1.00	
Terrain & Height F[illegible]to[illegible] k_2		1.18	Max.
Topograp[illegible]actor k_3		1.00	
DESIGN WIND PRESSURE			
Design [illegible] speed V_z		$V_b . k_1 . k_2 . k_3$	
[illegible]esig[illegible]Wind pressure p_z		$0.6 . V_z^2$	N/m²

Wind Parallel to "a"		Wind Parallel to "b"	
a / b	h / b	b / a	h / a
[illegible]7	6.43	0[illegible]4	2.83
Force coefficient C_f, a		Force coefficient C_f, b	
1.2		1.3	

[illegible]ind load along X [illegible] Y – direction:

Along X direction:

Design wind speed $V_z = V_b . k_1 . k_2 . k_3$

= 1 x 0.99 x 1 x 44

= 43.56m/s

De[illegible]gn Wind pressure $P_d = 0.6 . V_z^2$

= 0.6 x 43.56²

= 1138.48 N/m²

= 1139N/m²

By using force coefficient method:

Wind Force along X direction at 14th floor:

$$F = C_f . A_e . P_d$$

= 1.3 x 3.9 x 32.89 x 1139

= 189.41kN

Along Y direction:

Design wind speed

$$V_z = V_b . k_1 . k_2 . k_3$$

= 1 x 0.99 x 1 x 44

= 43.56m/s

Design Wind pressure

$$P_d = 0.6 . V_z^2$$

= 0.6 x 43.56²

= 1138.48 N/m²

= 1139N/m²

By using force coefficient method:

Wind Force along Y direction at 14th floor:

$$F = C_f . A_e . P_d$$

= 1.3 x 3.9 x 74.8 x 1139

= 431.95kN

Table No: 3 Manual wind force calculation in tabulated form (21st – Ground floor) in X direction

Story	Height	Elevation	V_b	V_z	P_d	FORCE in X direction				
						C_f	Width (B)	Height (h)	Frontal area	Force
	m	m	m/s	m/s	N/m²		m	m	m²	(kN)
21ST	3.9	68.6	44	46.19	1280.08	1.3	32.89	3.9	128.27	213.46
20TYP	3.9	64.7	44	45.91	1264.91	1.3	32.89	3.9	128.27	210.93
19TYP	3.9	60.8	44	45.64	1249.82	1.3	32.89	3.9	128.27	208.41
18REF	3.9	56.9	44	45.37	1234.83	1.3	32.89	3.9	128.27	205.91
17TYP	3.9	53	44	45.09	1219.93	1.3	32.89	3.9	128.27	203.43
16TYP	3.9	49.1	44	44.76	1202.14	1.3	32.89	3.9	128.27	200.46
15TYP	3.9	45.2	44	44.25	1174.65	1.3	32.89	3.9	128.27	195.87
14TYP	3.9	41.3	44	43.73	1147.47	1.3	32.89	3.9	128.27	191.34
13TYP	3.9	37.4	44	43.22	1120.62	1.3	32.89	3.9	128.27	186.87
12TYP	2	33.5	44	42.70	1094.08	1.3	32.89	2	65.78	93.56
11TH	5.1	31.5	44	42.57	1087.32	1.3	32.89	5.1	167.74	237.10
STILT	3.9	26.4	44	41.45	1030.76	1.3	32.89	3.9	128.27	171.88
7TH	3	22.5	44	40.59	988.53	1.3	32.89	3	98.67	126.80
6TH	3	19.5	44	39.86	953.48	1.3	32.89	3	98.67	122.30
5TH	3	16.5	44	38.28	879.22	1.3	32.89	3	98.67	112.78
4TH	3	13.5	44	37.62	849.16	1.3	32.89	3	98.67	108.92
3RD	3	10.5	44	36.08	781.06	1.3	32.89	3	98.67	100.19
2ND	3	7.5	44	36.08	781.06	1.3	32.89	3	98.67	100.19
1ST	3	4.5	44	36.08	781.06	1.3	32.89	3	98.67	100.19
GF	0	1.5	44	36.08	781.06	1.3	32.89	1.5	49.34	50.09

- **ANALYSIS RESULTS:**

➢ Displacements:

Table [illegible]o:4: Rectangular [illegible]ing –Static W[illegible] Load Displacem[illegible]

RECTANGULAR BUILDING - STATIC WIND DISPLACEMENTS								
Story	U_X (mm)	U_Y (mm)	Story	U_X (mm)	U_Y (mm)	Story	U_X (mm)	U_Y (mm)
TRRC	123	446	[illegible]R	85	274	20TYP	33	94
59TYP	123	437	39[illegible]	82	264	19TYP	31	86
58TYP	122	429	3[illegible]YP	80	254	18REF	28	78
57REF	120	420	37TYP	77	244	17TYP	26	70
56TYP	118	412	36TYP	75	235	16TYP	23	63
55TYP	116	403	35TYP	72	225	15TYP	21	56
54TYP	114	394	34REF	69	215	14TYP	18	49
53TYP	112	386	33TYP	67	205	13TYP	16	43
52TYP	110	377	32TYP	64	195	12TYP	14	37
51TYP	108	368	31TYP	61	186	11TH	13	34
50REF	106	359	30TYP	58	176	STILT	11	27
49TYP	104	349	29TYP	55	166	7TH	9	22
48TYP	101	340	28TYP	52	157	6TH	7	18
47TYP	99	331	27REF	50	147	5TH	6	15
46TYP	97	321	26TYP	47	138	4TH	5	12
45TYP	95	312	25TYP	44	129	3RD	4	9
44TYP	92	302	24TYP	41	120	2ND	3	7
43REF	90	293	23TYP	39	111	1ST	2	4
42TYP	87	283	22ND	[illegible]7	107	GF	1	3
41FC	86	278	21S[illegible]	36	102	BASE 1	1	1
						BASE 2	0	0

➢ Static Support [illegible]eactions:

Table No: 5 Re[illegible]tangular bu[illegible] –Static Wind Base Reactions

Story	Load	Fx (kN)	Fy (kN)	Fz (kN)
Base Reaction	WLX	-12266.7	0.0[illegible]	0
[illegible]se [illegible]ion	WLY	0.[illegible]9	-28003.4	0

[illegible]alytical [illegible]od: Dyna[illegible]c (Gust Factor) Method

[illegible]le No: 6 -Dy[illegible]ic W[illegible]d parameters

TIME PERIOD			
T_x		2.336	(From ETABS)
T_y		3.56	(From ETABS)
[illegible] = lateral correlation constant (Page 52)			10
[illegible]udinal correlation constant (Page 52)			12
PEAK FACTOR AND ROUGHNESS FACTOR :-			
L (h)	=	2100	(Fro Fig. 8, Page 50)
$g_f . r.$	=	2.1	(From Fig. 8, Page 50)
BACKGROUND FACTOR (B) :-			
C_z (h)/ L (h)	=	1.209	
λ_x (C_yb / C_zh)	=	0.130	(clause 8.3, Page 52)
λ_y (C_ya / C_zh)	=	0.295	
Along X-dir, (B_x)	=	0.6	(From Fig. 9, Page 50)
Along Y-dir, (B_y)	=	0.5	
f_{ox} =(1 / T_x)		f_{oy} =(1 / T_y)	
0.428		0.281	
SIZE REDUCTION FACTOR (S) :			
Along X-dir, Fo_x	=	1087 / V_z	
Along Y-dir, Fo_y	=	713 / V_z	
Ø	=	0	
GUST ENERGY FACTOR (E) :			
Along X-dir, Ex	=	899 / V_z	
Along Y-dir, Ey	=	590 / V_z	
β - DAMPING COEFFICIENT			
- damping coefficient (as a fraction of critical damping) of the structure For R.C.C.		0.016	(Page 52- Table 34)
GUST FACTOR			
G = gust factor = (peak load) / (mean load), and is given by			

$$G = 1 + g_f . r. \sqrt{\left[B\,(1+\emptyset)^2 + \frac{SE}{\beta}\right]},$$

- **ANALYSIS RESULTS**:

➢ Displacements:

Table No:7: Dynamic - Story Displacements

RECTANGULAR BUILDING - DYNAMIC WIND DISPLACEMENTS										
Story	**U_X (mm)**	**U_Y (mm)**		**Story**	**U_X (mm)**	**U_Y (mm)**		**Story**	**U_X (mm)**	**U_Y (mm)**
TRRC	185	682		40 SR	126	416		20TYP	49	140
59TYP	185	670		39TYP	122	401		19TYP	45	128
58TYP	182	656		38TYP	118	386		18REF	41	116
57REF	180	643		37TYP	114	371		17TYP	37	105
56TYP	177	630		36TYP	110	356		16TYP	34	93
55TYP	174	617		35TYP	106	341		15TYP	30	83
54TYP	171	603		34REF	102	326		14TYP	27	73
53TYP	168	589		33TYP	98	311		13TYP	23	63
52TYP	165	576		32TYP	94	295		12TYP	20	54
51TYP	161	562		31TYP	90	280		11TH	19	50
50REF	158	548		30TYP	85	265		STILT	15	40
49TYP	155	533		29TYP	81	251		7TH	12	32
48TYP	151	519		28TYP	77	236		6TH	10	27
47TYP	148	505		27REF	73	221		5TH	9	22
46TYP	144	490		26TYP	69	207		4TH	7	[illegible]
45TYP	141	475		25TYP	64	193		3RD	[illegible]	13
44TYP	137	461		24TYP	60	180		2N[illegible]	[illegible]	10
43REF	133	446		23TYP	56	166		1ST	3	7
42TYP	130	431		22ND	54	160		GF	2	[illegible]
41FC	128	424		21ST	52	15[illegible]		[illegible]SE1	1	2
								[illegible]	0	0

➢ Dynamic Support Reactions:

Table No:8 Dynamic Wind [illegible] R[illegible]

Story	Load	Fx (kN)	Fy (kN)	Fz (kN)
Base Reaction	Gx	[illegible]118.9	0.0[illegible]	0
Base Reaction	Gy	0[illegible]	-4004[illegible]	0

3. EXPERI[illegible]TAL METHOD: W[illegible] TUNNEL M[illegible]THOD:

A 1:400 [illegible] model of the pro[illegible]ed development was constructed u[illegible] the architectural [illegible]awings. The model was tested in the [illegible]ence of all [illegible]ndings within a full-scale radius of 500[illegible] Windtech's 2.6m X 14m boundary layer wind tunnel.

- **WIND TUNNEL ANALYSIS RESULTS:**

➢ Displacements:

Table.No.9 Wind Tunnel Displacements

Story	Load	U_x (mm)	U_y (mm)
TERRACE	WT1	101.3362	-266.807
TERRACE	WT2	-115.732	131.3021
TERRACE	WT3	25.2835	-477.928
TERRACE	WT4	28.1257	412.366
TERRACE	WT5	61.7132	-396.788
TERRACE	WT6	-49.3396	-400.894
TERRACE	WT7	-76.9072	250.547
TERRACE	WT8	63.4132	287.8563
TERRACE	WT9	124.0534	-267.415
TERRACE	WT10	-92.2363	130.673
TERRACE	WT11	46.0818	-478.485
TERRACE	WT12	51.4738	411.7409
TERRACE	WT13	82.5115	-397.345
TERRACE	WT14	-28.5414	-401.451
TERRACE	WT15	-56.5828	250.0029
TERRACE	WT16	86.7614	287.2312
TERRACE	WT17	-77.9504	153.7533
TERRACE	WT18	-77.9504	153.7533
TERRACE	WT19	53.4867	-270.189
TERRACE	WT20	53.4867	-270.189

➢ Support Reactions:

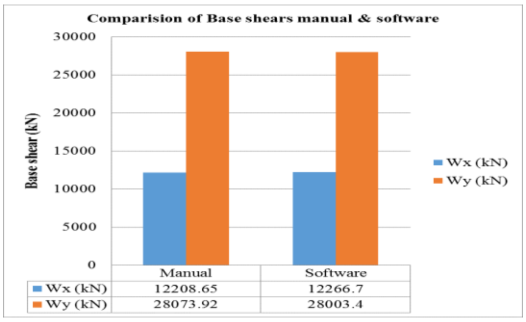
The summary of the support r[illegible]ctions for the 20 wind load cases is shown below:

Table.No10. Rectan[illegible]ar building - Tunnel Support [illegible]ctions

Load	F_x (kN)	F_y (kN)
W[illegible]	-8940.35	15398
WT2	8780.21	[illegible]0.01
WT3	-3572.86	2[illegible]99
WT4	[illegible]2669.81	[illegible]18755
WT5	-6209.62	21258
[illegible]	2198.65	21257.99
W[illegible]	5595.48	-12114
WT8	-5530[illegible]	-13078
WT9	[illegible]40.17	15398.01
WT10	8780.39	-7550
WT11	-3572.69	24861
WT12	-2669.62	-18755
WT13	-6209.45	21258.01
WT14	2198.82	21258
WT15	5595.64	-12114
WT16	-5530.4	-13078
WT17	5739.46	-8940.01
WT18	5739.46	-8940.01
WT19	-3402.63	15398.01
WT20	-3402.63	15398.01

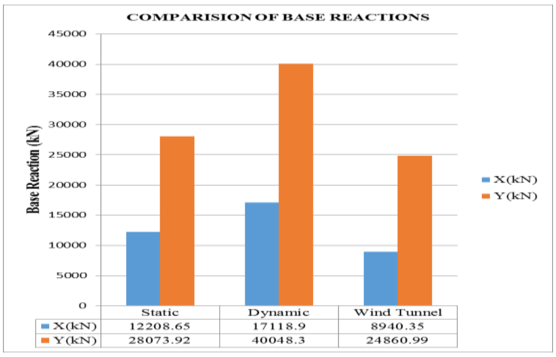
- **COMPARISON RESULTS FROM THREE METHODS:**

➢ **BASE REACTIONS:**



Graph.No.1 Comparison of Base Shear values with manual & Software

From the above graph it is observed that difference of values between manual & software is very less and accuracy is more than 99% which indicates reliability of the software to be used for analysis and design of the structure under consideration.

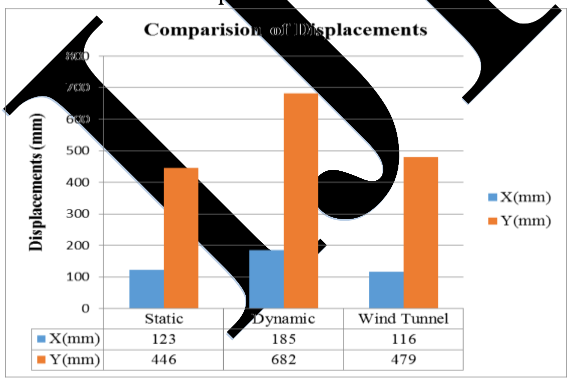


Graph.No.2- Comparison of Base reactions for all three methods

The above graph shows that the base reaction values of wind tunnel method are much lesser than other two methods. The governing direction is Y in all the three methods which is accepted as the length of the building perpendicular to Y direction is more than the X direction.

➢ **Displacements:**

From the below displacement values it is clear that structure is more exposed in Y direction than X direction which shows perfect behaviour as per the geometry of the structure. Now when values of displacements from three methods compared in Y direction as static and wind tunnel values are almost same but very much less than dynamic gust factor values. Dynamic gust factor displacements values in Y direction are more than 4[illegible] than that of the static & wind tunnel displacements values.



The Graph.No.3 lists the maximum displacements in the X direction and Y direction for the different analysis methods.

VIII. CONCLUSION:

Wind load analysis with analytical and experimental methods conducted on building from which we can fairly conclude that to capture the true dynamic effects of wind, one should conduct the experimental test.

1. The Gust analysis does not effectively capture the dynamic load distribution along the structure height. The displacement values reported by the Tunnel methods clearly indicate that the Gust factor methods clearly under estimate the true dynamic behavior of the structures.
2. For the 60 storied structure building, Tunnel tests report about 40% decrease in the Y displacement values than the Gust factor method. It also reports a decrease in the X-direction as well. Incidentally it reports an increase in the displacement values in the X direction than the Gust factor method. That is because the Gust factor method only takes into consideration of the along wind response of the wind dynamics. It never considers the across wind response and torsional components. It cannot consider the effect of geometry of the structure and also the effects of the surrounding structures. That is the reason, the code method is in the conservative side in the stiff direction of the structure and in the slender axis, and it reports heavily underestimated forces.
3. It is obvious from the values reported by the code method, as the Displacements & Base shear values are quite heavy for the tower. For Strength & serviceability checking, so we have to rely on the experimental method only. But to get a fair indication of the wind forces, this code method can be used and also for the concept design of the structures. But for the actual evaluation of the forces and for member design of tall buildings, one should always look into the experimental method. It is high time the authorities and the practicing structural Engineers should understand this issue and proceed in this direction.

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