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Hourly Mean Wind Speeds and Gust Factor Method for Wind Effects in Indian context

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Abstract- Refinements in design analysis, computation models, development of light weight high strength materials, advancement in construction techniques and confidence of structural engineers have resulted in more flexible and tall structures which are susceptible to dynamic wind loading. Present Indian Standard for wind loads IS 875 (Part 3) 1987 like its predecessor is also based on Static Method. However, Gust Factor Method has also been included for flexible structures to account for dynamic component of wind and structures. The code recommends that wind effects on flexible structures be computed by Static Method as well as Gust Factor Method and severe of the two is to be considered for design. Static Method is governed by 3-second peak winds referred as basic wind speed in the code. In Gust Factor Method hourly mean wind speeds are required which are recommended to be obtained from basic wind speeds by using conversion table given in the code which is not based on Indian Environment. Review of relevant literature shows that hourly mean wind speeds based on statistical analysis of hourly mean wind speeds data exists. These values were used in Gust Factor Method for computing wind loads. For the building chosen for case study wind loads, base shears and base moments were computed by using hourly mean wind speeds as obtained from the code and those based on statistical analysis of mean hourly wind speed data. The results show that the values obtained based on code are overestimated to the large extent in all the four terrain categories. This is because of higher values of hourly mean wind speeds obtained as per code in comparison to those based on statistical analysis of hourly mean wind speed data. From present study it is clearly established that hourly mean wind speeds to be used in Gust Factor Method for computing wind effects on flexible structures play an important role.

Keywords: Peak wind, Hourly winds, Gust Factor, Force Coefficient, Power Law Coefficient, Terrain Category, Terrain Surface, Gradient Height, Gradient wind.

1. INTRODUCTION

Refinements in design, analysis, computation models, development of light weight high strength materials, advancements in construction techniques and confidence of structural engineers have resulted in more flexible and tall structures which are susceptible to dynamic wind loading Present Indian codal provisions for wind loads IS 875(Part 3) 1987 includes Gust Factor Method for computing wind effects on flexible and tall structures which is for the first time. Basically the present code like its predecessor is based on static approach and basic wind speed map is based on statistical analysis of consecutive yearly maximum 3-second peak wind speeds at various meteorological stations in the country. The code recommends that wind loads on flexible and tall structures be computed by both the Static Method and Gust Factor Method and severe of the two should be considered. In Static Method basic wind speeds (3-seconds) are used whereas in Gust Factor Method hourly mean wind speeds are used.

Hourly Mean Wind Speeds Based on IS 875 (Part 3) 1987.

IS 875(Part 3) 1987 recommends that Table 33 be used for converting basic winds into hourly mean wind speeds in different terrain categories at various heights. By using this table hourly wind speeds at various heights in different terrain categories have been obtained and given in Table 1 for Delhi zone for which basic wind speed is 47 m/s.
Conversion table (Table 33) for obtaining hourly mean wind speeds from basic wind speeds is not based on Indian environment and it has been underlined that:
"*It must also be recognized that the ratio of hourly mean wind (HMV) to peak speed given in Table 33 may not be obtainable in India since extreme wind*

occurs. Mainly due to cyclones and thunderstorms unlike in U.K and Canada where the mechanism is fully developed pressure system. However, Table 33 may be followed at present for the estimation of the hourly mean wind speed till more reliable values became available"

Hourly Mean Wind Speeds Based on statistical Analysis of Hourly Mean Wind Speeds Data

Perusal of relevant literature shows that Indian Meteorological Department (IMD) maintains record of hourly mean wind speeds (10 minute average) in addition to 3 second peak wind speeds at different meteorological stations in the country.

Sharma (1993,1994) carried out statistical analysis of consecutive yearly maximum hourly mean wind speeds at various metereological stations and obtained hourly mean wind speeds for different return periods. For Delhi zone value of hourly mean wind speed at 10m height in Terrain Category 2 for 50 years return period has been worked out as 29.17 m/sec.

Table 1. Hourly Mean Wind Speeds in different Terrain Categories at various heights based on IS 875 (Part 3)-1987

Height (m)	Hourly Mean Wind Speed($\overline{V}_z$) in m/s			
	T.C 1	T.C 2	T.C. 3	T.C 4
Up to 10	36.66	31.49	23.5	11.28
15	38.54	33.84	25.85	11.28
20	39.95	35.25	27.73	11.28
30	41.36	37.13	30.08	15.98
50	43.71	39.95	32.9	21.15
100	46.53	43.24	37.13	26.79
150	48.41	45.12	39.48	30.08
200	49.82	47	41.36	31.96
250	50.76	47.94	42.77	33.84
300	51.23	48.88	43.71	34.78
350	52.17	49.82	44.65	36.19
400	52.64	50.29	45.59	37.13
450	53.11	50.76	46.06	38.07
500	53.58	51.23	46.53	38.54

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Sharma, Mayank (2018), "Reliability of Gust Factor Method for Wind Loading as per Indian Codal Provisions". Thesis submitted in partial fulfillment of the requirement for the award of the degree of Master of Technology in Structural Engineering Department of Civil Engineering, Indo Global College of Engineering & Technology, Abhipur, Mohali, I.K.Gujral Punjab Technical University, Jalandhar, 2018.

Power Law Coefficients and Gradient Heights for Mean Wind Speeds

Power Law coefficients and Gradient heights over different terrain surfaces for mean wind speeds are required for obtaining hourly mean wind speeds at various heights in different terrains.

Power law coefficients and gradient heights for different surfaces for mean wind speeds as per Davenport (2004) have been given in Table 2.

Table 2. Parameters of Mean Wind Speeds over different Terrain Surfaces.

Surface	Power Law Coefficient	Gradient Height (m)
Rough Sea (Terrain Category 1)	0.11	250
Farm Land (Terrain Category 2)	0.16	300
Forest, Subarbs (Terrain Category 3)	0.28	400
City Centres (Terrain Category 4)	0.40	500

The four types of surfaces mentioned are equivalent to Terrain Category 1, Terrain Category 2, Terrain Category 3 and Terrain Category 4 listed in IS 875 (Part 3) 1987. The values of hourly mean wind speed of 20.17 m/sec has been computed at

10m height in Terrain Category 2 for 50 years return period. The value of Power Law Coefficient varies with averaging time of wind speed. It is 0.09 for 3-sec wind, 0.16 for hourly mean wind speed and the value is 0.15 when averaging time is 10 minutes in Terrain Category 2. The values of hourly mean wind speeds (averaged over 10 minutes) available with IMD have been used for statistical analysis. By making use of Power Law the value of gradient wind speed at a height of 300 m has been obtained as 48.58 m/sec. Similarly wind speeds at different heights in Terrain Category 2 have been computed. As at gradient heights in different Terrain Categories gradient wind speed is constant which is 48.58 m/sec. From the gradient wind speeds magnitudes of hourly mean wind speeds at various levels in different terrain categories have been computed and listed in Table 3.

Table 3. Hourly Mean Wind Speeds in different Terrain Categories for various heights based on Hourly Mean Wind Speeds Data.

Height(m)	Hourly Mean Wind Speed(V_z) in m/s			
	T.C.1	T.C.2	T.C.3	T.C.4
Upto 10	35.20	29.17	17.29	10.15
15	36.66	30.999	19.37	11.94
20	37.73	32.36	20.99	13.405
30	39.29	34.39	23.522	15.465
50	41.35	37.134	27.13	19.34
100	44.32	41.20	32.95	25.51
150	46.16	43.78	36.91	30.012
200	47.50	45.718	40.01	33.672
250	48.58	47.27	42.58	36.81
300	48.58	48.58	44.82	39.60
350	48.58	48.58	46.797	42.12
400	48.58	48.58	48.58	44.43
450	48.58	48.58	48.58	46.57
500	48.58	48.58	48.58	48.58

Gust Factor (GF) or Gust Effectiveness Factor (GEF) Method.

a. Applications: Only the method of calculating load along wind or drag load by using Gust Factor Method is given in the code since method for calculating across-wind or other components are not fully matured for all types of structures. However, it is permissible for a designer to use Gust Factor Method to calculate all components of load on structure using any available theory. However, such a theory must take into account the random nature of atmospheric wind speed.

b. Hourly Mean Wind: Use of existing theories of Gust Factor Method require a knowledge of maximum wind speed averaged over one hour at a particular location. Hourly mean wind speeds at different heights in different terrains is obtained from basic wind speed by conversion factor. The conversion factor has been given at various heights for different terrains.

c. Along Wind Load: Along wind load on a structure on a strip area (Ae) at any height (z) is given by:

$F_z = C_f \, Ae \, p_z \, G$

where:

F_z= along wind load on the structure at any height z corresponding to strip area Ae.

C_f=force coefficient for the building.

Ae= effective frontal area considered for the structure at a height z.

$\overline{P}_z$= design wind pressure at height z due to hourly mean wind obtained as 0.6 V_z^2 (N/m^2). where

V_z is hourly mean wind.

G= Gust Factor [=(peak load) /(mean load)] and is given by

$G= 1+ g_f r \sqrt{[B(1+\phi)^2+(SE/\beta)]}$

where:

g_f = peak factor, defined as the ratio of the expected peak value to the root mean value of the fluctuating load, and

r= roughness factor which is dependent on the size of the structure in relation to the ground roughness.

The value of "$g_f r$" has been given in the code in graphical manner.

B= background factor indicating a measure of slowly varying component of fluctuating wind load and has been given in the code in graphical form.

SE/β= measure of resonant component of fluctuating wind load.

S= size reduction factor, given in graphical form in code.

E= measure of available energy in wind stream at the natural frequency of the structure, given in graphical form in code.

β= damping coefficient (as a fraction of critical damping) of the structure and is given in code in tabular form.

$\phi= g_f r\sqrt{(B/4)}$ and is to be accounted only for buildings less than 75 m in terrain category 4 and for buildings less than 25 m high in terrain category 3, and is to be taken as zero in all other cases.

Impact of Hourly Mean Wind Speeds on Gust Factor Method

Hourly Mean Wind Speeds play an important role in Gust Factor Method for computing wind loads on flexible structures. The magnitudes of hourly mean wind speeds as computed from the code at various heights in different Terrain Categories have been listed in Table 1 whereas those obtained from statistical analysis of hourly mean wind speeds data have been given in Table 3. The comparison of values of hourly mean wind speeds as given in Table 1 and Table 3 shows that generally the values obtained as per IS 875 (Part 3) 1987 are more than those based on statistical analysis of hourly mean wind speeds data and taken from literature at various heights in different Terrain Categories.

With the objective of studying impact of hourly mean wind speeds on wind loads a building has been chosen as a case study. The wind loads on the building have been computed by using hourly mean wind speeds as obtained from the code and those obtained from the literature in Gust Factor Method. It has been found that the wind loads obtained based on codal values are consistently more than those based on values taken from literature.

Case Study

The building chosen for case study is 20 storeyed framed steel building with height of 82 m. each storey is of 4m height except the first storey which is of 6m height. The Parapet height is one metre. The building is square in plan with dimensions as 40m*40m with 5 bays in each direction. Each bay is of 8m span. Natural frequency of the building is 0.857 hertz and damping coefficient is 0.02. the building has been taken in Delhi zone for which the basic wind speed is 47 m/sec. plan and elevation of the building have been shown in Figure 1 and Figure 2 respectively. The wind loads on the building have been computed in Terrain Category 1, Terrain Category 2, Terrain Category 3 and Terrain Category 4 for 50 years return period and plane topography.

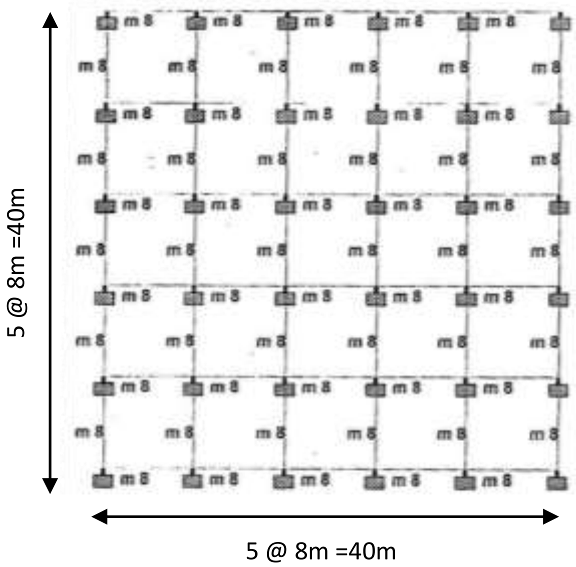

Fig. 1 Plan of the Building

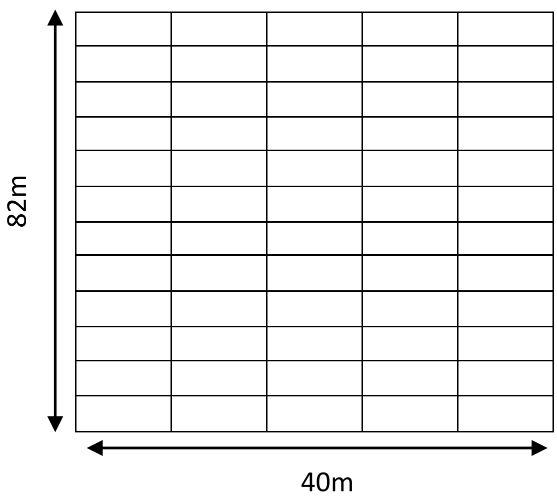

Fig. 2 Elevation of the Building

RESULTS

Wind loads at various floor levels of the building in all the four Terrain Categories have been computed as per IS 875 (Part 3) 1987 by:

a. Gust Factor Method (GFM)
   wherein hourly mean wind speeds used have been obtained from Table 33 of IS 875 (Part 3) 1987 which is used for converting basic wind speed (3-second wind) into hourly mean wind speed as given in Table 1.
b. Gust Factor Method* (GFM*)
   wherein hourly mean wind speeds used are based on statistical analysis of hourly mean wind speeds data and taken from literature. The values computed have been given in

Table 3 for various heights and in different Terrain Categories.

Gust Factor Method (GFM)

The values of Gust Factor, G, as per Gust Factor Method (GFM) for Category 1, Terrain Category 2, Terrain Category 3 and Terrain Category 4 have been obtained as 1.6962055, 1.7997660, 2.010027 and 2.7275 respectively. The value of the Force Coefficient, Cf, for the building has been computed as 1.28.

The values of wind forces at various floor levels along the height in Category 1, Terrain Category 2, Terrain Category 3 and Terrain Category 4 have been computed and have been shown in Table 4, Table 5, Table 6 and Table 7 respectively.

The variation of wind forces along the height in Category 1, Terrain Category 2, Terrain Category 3 and Terrain Category 4 has also been shown graphically and given in Figure 3, Figure 4, Figure 5 and Figure 6 respectively.

The magnitudes of base shears and overturning moments for the building in all the four Terrain Categories have also been computed and given in Table 8 and Table 9 respectively.

Gust Factor Method* (GFM*)

The values of Gust Factor, G, as per Gust Factor Method* (GFM*) for Category 1, Terrain Category 2, Terrain Category 3 and Terrain Category 4 have been obtained as 1.669796, 1.7934, 2.00689 and 2.72119 respectively. The value of the Force Coefficient, Cf, for the building has been computed as 1.28.

The values of wind forces at various floor levels along the height in Category 1, Terrain Category 2, Terrain Category 3 and Terrain Category 4 have been computed as per Gust Factor Method* (GFM*) and has been shown in Table 4, Table 5, Table 6 and Table 7 respectively..

The variation of wind forces along the height in Terrain Category 1, Terrain Category 2, Terrain Category 3 and Terrain Category 4 has also been shown graphically and given in Figure 7, Figure 8, Figure 9 and Figure 10 respectively.

The magnitudes of base shears and overturning moments for the building in all the four Terrain Categories have also been computed and given in Table 8 and Table 9 respectively.

The values obtained as per Gust Factor Method* (GFM*) have been taken as datum and equal to unity and the corresponding values obtained as per Gust Factor Method (GFM) have also been given in Table 8 and Table 9 respectively.

Table 4. Wind Force (kN) Variation with height as per GFM and GFM* in Terrain Category 1

Storey	Height m	GFM	GFM*
1	6	330.3320081	304.385738
2	10	264.2656065	243.508591
3	14	286.3937246	259.936817
4	18	305.0278379	273.459614
5	22	318.2723922	284.41706
6	26	327.2584653	293.824126
7	30	336.3696345	303.384241
8	34	344.0578351	309.780253
9	38	351.832908	316.242985
10	42	359.6948533	322.772436
11	46	367.6436708	329.368607
12	50	375.6793607	336.031498
13	54	379.5673489	339.904314
14	58	383.4753525	343.79932
15	62	387.4033714	347.716515
16	66	391.3514057	351.6559
17	70	395.3194555	355.617475
18	74	399.3075206	359.60124
19	78	403.3156011	363.607194
20	82	407.3436969	367.635338

Table 5. Wind Force (kN) Variation with height as per GFM and GFM* in Terrain Category 2

Storey	Height m	GFM	GFM*
1	6	267.1491186	229.1938
2	10	213.7192949	183.3551
3	14	239.9997696	202.8293
4	18	259.3025878	218.7042
5	22	273.5473668	232.2816

6	26	285.2174211	244.1453
7	30	297.1312362	254.8499
8	34	306.2265657	264.6804
9	38	315.4590107	273.6669
10	42	324.8285713	282.0078
11	46	334.3352473	289.7623
12	50	343.9790389	297.1416
13	54	348.526399	304.0955
14	58	353.1036197	310.6714
15	62	357.7107012	319.9028
16	66	362.3476434	322.8988
17	70	367.0144463	328.7137
18	74	371.7111099	334.241
19	78	376.4376342	339.5064
20	82	381.1940192	344.606

Table 6. Wind Force (kN) Variation with height as per GFM and GFM* in Terrain Category 3

Storey	Height m	GFM	GFM*
1	6	162.580138	87.86771
2	10	130.06411	70.29417
3	14	151.706778	84.47555
4	18	171.412011	97.30084
5	22	187.292319	108.6578
6	26	199.986576	119.1378
7	30	213.097038	130.1001
8	34	221.163094	138.2095
9	38	229.378984	146.564
10	42	237.744708	155.1636
11	46	246.260265	164.0084
12	50	254.925656	173.0728
13	54	260.196811	179.0643
14	58	265.521907	185.1577
15	62	270.900942	191.3531
16	66	276.333918	197.6504
17	70	281.820833	204.0496
18	74	287.361689	210.5508
19	78	292.956485	217.154
20	82	298.605222	223.8591

Table 7. Wind Force (kN) Variation with height as per GFM and GFM* in Terrain Category 4

Storey	Height m	GFM	GFM*
1	6	44.847731	36.30190646
2	10	35.878185	29.04152516
3	14	35.878185	37.81415996
4	18	35.878185	46.32288835
5	22	42.107036	53.81642582
6	26	56.059664	60.42669161
7	30	72.005524	67.41975726
8	34	81.625362	74.34630442
9	38	91.848153	81.61147793
10	42	102.6739	83.29886602
11	46	114.10259	97.15770396
12	50	126.13424	105.4387565
13	54	131.57338	110.8895028
14	58	137.12732	116.4776115
15	62	142.79607	122.2030825
16	66	148.57964	128.0611091
17	70	154.47801	134.0661114
18	74	160.49119	140.2036694
19	78	166.61919	146.4785896
20	82	172.86199	152.8908723

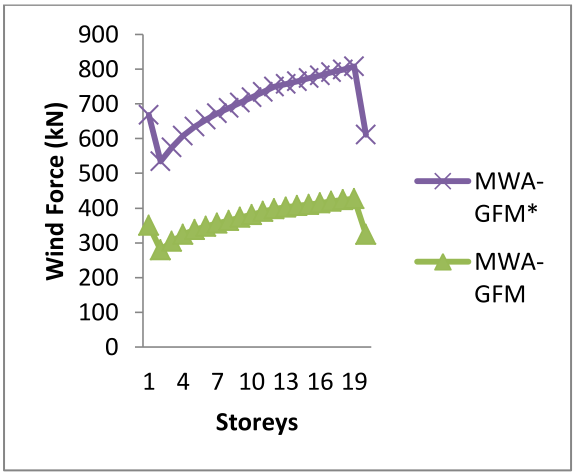

Figure 3 Graphical representation of Wind Force variation along storeys for 20 storey building as per GFM and GFM* in Terrain Category 1.

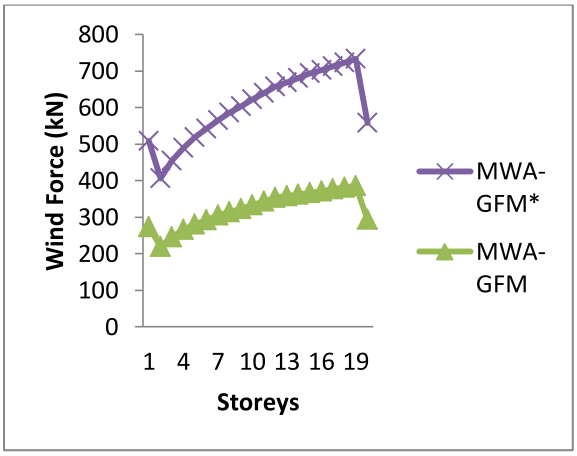

Figure 4 Graphical representation of Wind Force variation along storeys for 20 storey building as per GFM and GFM* in Terrain Category 2.

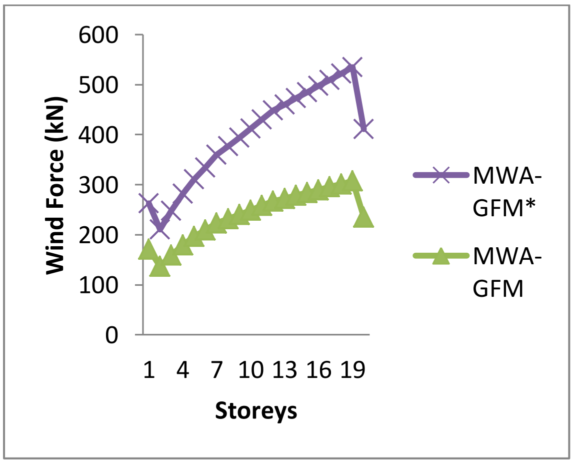

Figure 5 Graphical representation of Wind Force variation along storeys for 20 storey building as per GFM and GFM* in Terrain Category 3.

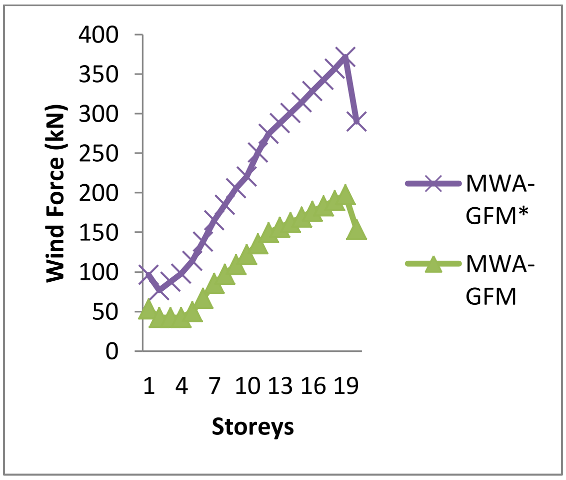

Figure 6 Graphical representation of Wind Force variation along storeys for 20 storey building as per GFM and GFM* in Terrain Category 4.

Table 8. Base shears for buildings chosen for case studies as per GFM and GFM* in different Terrain Categories.

Terrain Categories	Base Shear	20 Stories
TC1	GFM	7432.8
	Ratio with respect to GFM * Value	1.127404
	GFM*	6592.8
	Ratio w.r.t. GFM* value	1
TC2	GFM	6447.8
	Ratio with respect to GFM* Value	1.1482
	GFM*	5615.6
	Ratio w.r.t. GFM* value	1
TC3	GFM	4787.1
	Ratio with respect to GFM* Value	1.50757
	GFM *	3175.4
	Ratio w.r.t. GFM* value	1
TC4	GFM	2385.3

	Ratio with respect to GFM* Value	1.1259
	GFM*	2118.6
	Ratio w.r.t. GFM* value	1

Table 9 Base Moments for buildings chosen for case studies as per GFM and GFM* in different Terrain Categories.

Terrain Categories	Base moment	20 Stories
TC1	GFM	341228
	Ratio with respect to GFM* Value	1.129288
	GFM *	302162.1
	Ratio w.r.t. GFM* value	1
TC2	GFM	301815.3
	Ratio with respect to GFM* Value	1.137182
	GFM*	265406.4
	Ratio w.r.t. GFM* Value	1
TC3	GFM	230914.2
	Ratio with respect to GFM* Value	1.5076
	GFM *	63507
	Ratio w.r.t. GFM* Value	1
TC4	MWA - GFM	128724.1
	Ratio with respect to GFM * Value	1.143777
	GFM *	112543
	Ratio w.r.t. GFM* Value	1

Discussion of Results

With the objective of understanding impact of hourly mean wind speeds a 20 storey building has been analysed for wind loads by Gust Factor Method by using hourly mean wind speeds as obtained from conversion table given in the code and those taken from literature. Wide variations in the values of wind forces, base shears and base moments in all the four terrain categories have been observed in the two cases and these are discussed below:

Variation of Hourly Mean Wind Speeds at various heights in different Terrain Categories.

Hourly Mean Wind Speeds play an important role in Gust Factor Method (GFM) of analysis for wind loads on structures. IS 875(Part 3) includes GFM wherein hourly mean wind speeds have been recommended to be obtained from basic wind speeds by using conversion factor (Table 33). The values of hourly mean wind speeds by using Table 33, have been given in Table 5.11.

In the present study hourly mean wind speeds based on statistical analysis of hourly mean wind speeds data available with I.M.D. for Delhi zone have been used in GFM* for determining wind forces on buildings chosen for case studies. The variation of hourly mean wind speeds at various heights in different terrain categories have been given in Table 5.5.

Perusal of hourly mean wind speeds given in two tables (Tables 5.5 and 5.11) reveals that the values of hourly mean wind speeds as obtained from IS 875 (Part 3) are consistently more than those obtained from statistical analysis of IMD data in Terrain Category 1 and Terrain Category 2 for all the heights. The same trend has been observed upto 250 m in terrain Category 3 however the trend gets reversed beyond height of 250m the difference is only marginal.

For Terrain Category 4 the values of hourly mean wind speeds as obtained from IS 875(Part 3) 1987 are more than those based on statistical analysis of hourly mean wind speed data upto height of 150m. however beyond 150m height the trend gets reversed. The values obtained from statistical analysis of hourly mean wind speed data are more than those obtained from IS 875 (Part 3) 1987.

Wind Forces

Wind forces on the building as obtained from Gust Factor Method (GFM) are consistently more in comparison to those obtained by Gust Factor Method* (GFM*) in all the four terrain categories.

Base Shears

The values of base shears as obtained by Gust Factor Method (GFM) are 1.13 times, 1.15 times, 1.15 times and 1.13 times the values obtained as per Gust Factor Method* (GFM*) in Terrain Category 1, Terrain Category 2, Terrain Category 3 and Terrain Category 4 respectively.

Base Moments

Like wind forces and base shears the values of base moments as obtained from Gust Factor Method (GFM) are consistently more in comparison to those obtained by Gust Factor Method* (GFM*) in all the four terrain categories.

The values of base moments as obtained by Gust Factor Method (GFM) are 1.13 times, 1.14 times, 1.51 times and 1.14 times the values obtained as per Gust Factor Method* (GFM*) in Terrain Category 1, Terrain Category 2, Terrain Category 3 and Terrain Category 4 respectively.

CONCLUSIONS

Based on the study following conclusions have been drawn:

1. Hourly mean wind speeds at various heights in different terrain categories obtained from IS 875 (Part 3) 1987 are generally more than those based on statistical analysis of hourly mean wind speed data. Hourly mean wind speeds affect the values of forces, base shear and base moments considerably.
2. The values of wind forces at various floor levels along the height for the building as obtained from Gust Factor Method (GFM) are consistently more than those obtained from Gust Factor Method* (GFM*) in all the four terrain categories.
3. The values of base shears as obtained from Gust Factor Method (GFM) are 12.74%, 14.82%, 50.76% and 12.59% more than the corresponding values obtained as per Gust Factor Method* (GFM*) in Terrain Category 1, Terrain Category 2, Terrain Category 3 and Terrain Category 4 respectively.
4. The values of overturning moments computed for the building as per Gust Factor Method (GFM) are 12.93%, 13.72%, 50.76% and 12.95% more than the corresponding values obtained as per Gust Factor Method* (GFM*) in Terrain Category 1, Terrain Category 2, Terrain Category 3 and Terrain Category 4 respectively.

The present study clearly establishes that hourly mean wind speeds play an importaun role in Gust Factor Method for computing wind effects on flexible structures. The values of wind forces, base shears and overturning moments have been found more as per Gust Factor Method (GFM) as compared to the corresponding values computed as per Gust Factor Method* (GFM*) as hourly mean wind speeds in the former case are consistently more than the corresponding values of hourly mean wind speeds in the later case.

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