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STUDY ON CHARACTERIZATION OF WIND AND ITS EFFECT ON STRUCTURES

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ABSTRACT

Due to the complexity of wind, all the major code and standard related to wind load of various countries have considered it as Equivalent Static Wind Load (ESWL). For tall and slender structures the dynamic method i.e. Gust Factor Method is suggested originally proposed by Davenport (1967) which is based on the Displacement based Gust Loading Factor (DGLF).

Zhou and Kareem (2003) have highlighted that the Moment based Gust Loading Factor (MGLF) offers a more realistic way of distribution of the ESWL along the height of the building compared DGLF. The paper focuses on understanding the wind characterization methodology of DGLF and MGLF, in detail. It also aims towards comparing DGLF based existing Indian Code IS:875(Part-iii)-1987, the method proposed in IS:875 Draft code by Bhandari et al (2006) and the MGLF procedure proposed by Zhou and Kareem (2003).

A thirty storey, wind governed, Reinforced Concrete (R.C.) symmetric building is considered. Response quantities like Lateral Wind Force, Displacement, Moment, and Base Shear are calculated and compared using the above mentioned three approaches.

INTRODUCTION:

Wind, being random in both time and space, is a complex phenomena. Its complexity makes it difficult to understand and thus since many years all the code and standard related to wind load, the Equivalent Static Wind Load (ESWL) concept has been a popular method of estimating the wind forces on buildings and other structures.

There are two basic approaches for calculation of ESWL: (I) Static Method and (II) Dynamic Method. **Static Method** would generally suffice for stiff structures but for tall, slender and flexible structures, the dynamic response becomes dominant and hence the dynamic method needs to be employed. **Dynamic Method** consists of determination of along wind response of structure under buffeting action of wind and is commonly known as Gust Factor Method originally proposed by Davenport. The ESWL is mean wind force multiplied by the Gust Loading Factor (GLF).

BRIEF LITERATURE REVIEW:

Agrawal et.al [3] have presented a comparative study of different wind characteristics pertaining to dynamic wind load for three terrain categories namely: sub-urban, heavy sub-urban and urban as given in the different codes namely Japanese, Australia/New-Zealand, American, British/European, Canadian, Hong-Kong, Chinese and Indian [existing (1987) as well as proposed draft]. Explanation regarding the various wind characteristics including mean wind velocity, turbulent intensity profiles, integral length scale of turbulence and power spectral density as adopted by different codes and standards for the above parameters have been discussed with reasons.

Zhou and Kareem[1] presented the new method for distribution of ESWL along the height of the building wherein the gust factor is a moment based gust factor which has been used to calculate the ESWL

GUST FACTOR APPROACH - NEW MODEL

Zhou and Kareem (2003) have highlighted that the Moment based Gust Loading Factor (MGLF) offers a more realistic way of distribution of the ESWL along the height of the building as compared to DGLF. The MGLF is the ratio of peak base bending moment and mean base bending moment.

The gust factor in present code of IS:875(Part-III)-1987 is essentially the ratio of peak and mean displacement and hence it is known as Displacement Based Gust Loading factor. But since only the mean and fluctuating displacement responses in the first mode are included in the derivation, the DGLF comes out to be *constant* for a given structure. [ ] (Zhou and Kareem (2003)).

The DGLF has many advantages; simplicity in application, accurate estimation of displacement response etc. but it has been found that for relatively long, tall and flexible buildings, it falls short in accurate estimation of other response quantities like Base Shear and base Bending Moment. [ ] (Zhou et. al (2001)). Since the multiplication factor (Gust Factor) is a constant value, the distribution of the ESWL is same as the mean wind velocity profile. This contradicts the common perceptive that the distribution of ESWL should depend on the structural mass distribution and the mode shape of the structure (like the earthquake load are distributed). For relatively small and less flexible structures, the results would not be as much inaccurate as the background component of wind velocity governs in these cases. But for tall, slender, long and flexible structures the resonant response is the dominant one and hence the distribution of ESWL must take into account the structural properties i.e. mass distribution and mode shape.

METHODOLOGY TO ESTIMATE WIND LOAD

In the present paper, ESWL is calculated for a G + 30 storey RC building using moment based gust factor concept given by Zhou and Kareem [ ]. ESWL is calculate for the same building using present IS:875(Part-III)-1987 and the IS:875 Proposed Draft and Commentary by Bhandari et al. Response quantities like Displacement, Base Shear, Base Moment and Lateral wind force. They are compared among three approaches used.

Procedure to determine Gust Factor and ESWL used in IS:875(Part-III)-1987 and draft code IS:875(Part-III) is briefly narrated below with notable variation among themselves. Apart, MGLF procedure given by Zhou and Kareem [ ] is briefly provided in way it is implemented in the paper.

IS:875(Part-III) - 1987 Method (DGLF Method)	**IS:875(Part-III) Proposed Draft and Commentary**
The Equation of Gust Factor,	**The equation for Dynamic Response Factor C_{dyn} (Gust Factor),**
$G = 1 + g_f r\sqrt{B(1+\emptyset)^2 + \frac{SE}{\beta}}$	$C_{dyn} = \frac{1 + 2I_h\sqrt{g_v^2 B_s + \frac{H_s g_R^2 SE}{\beta}}}{1 + 2g_v I_h}$
G = constant	C_{dyn} (= GLF) varies with height
Other factors like B, S, E are constant	Factors S, E are constant but Background Factor B_s and Height factor H_s are variable
ESWL, $\acute{P} = G\dot{P}$; where; $\dot{P}$ = Mean Wind Load	ESWL $\acute{P} = C_{dyn}\dot{P}$ where; $\dot{P}$ = Mean Wind Load
MGLF Procedure suggested by Zhou and Kareem [ ]	
(1) Calculate the mean wind force at each floor using $\dot{P} = C_d\, p_z\, A_e$.	

(2) Calculate the mean Base Bending Moment (BBM) using $\dot{M} = \sum_{i=1}^{n} P_i z_i$, where N is the number of floors of the structure.

(3) Obtain B, S and E through equations of IS:875(Part-III) Draft Code and plots of IS:875(Part-III)-1987.

(4) Calculate Gust Factor by splitting C_{dyn} equation (code specific) into Background (G_{MB}) and Resonant (G_{MR}) component. These components, as per IS:875(Part-III) draft code, is as follows.

$$G_{MB} = \frac{2g_v I_h \sqrt{B}}{(1 + 2g_v I_h)}$$

$$G_{MR} = \frac{2g_R I_h \sqrt{\frac{SEH_s}{\beta}}}{(1 + 2g_v I_h)}$$

Combined equation for Gust Factor can be given by,

$$G_M = \frac{1}{(1 + 2g_v I_h)} + \sqrt{{G_{MB}}^2 + {G_{MR}}^2}$$

(4) Compute the resonant extreme BBM component.

$$\acute{M}_R = G_{MR}\dot{M}$$

(5) Compute the resonant component of extreme ESWL at each floor by distributing resonant extreme BBM to each floor according to

$P_{Ri} = \frac{m_i \emptyset_i}{\sum m_i \emptyset_i z_i} \acute{M}_R$,where; $m = m_o[1 - \lambda\left(\frac{z}{H}\right)]$ and first mode shape function $\emptyset_1(z) = (\frac{z}{H})^\beta$

here; λ = mass reduction parameter; β = mode shape coefficient; H = height of building

(6) Compute the background component of extreme ESWL at each floor by $P_{Bi} = G_{MB}\dot{P}_i$.

(7) Compute response quantities like Base Shear and Overturning Moment obtained by Square Root Sum Square (SRSS) combination rule as follows.

$$r = \dot{r} + \sqrt{{r_B}^2 + {r_R}^2}$$

where $\dot{r}$, r_B and r_R are the mean, background and resonant response components are obtained by static structural analysis by using individual components of ESWL.

PROBLEM FORMULATION

A thirty storey RC building with following details is considered for the computation of wind force using three different approach.

Location of building: Mumbai, Plan dimensions of building: 24 × 24 m, Wind zone: III, Basic wind speed: 44 m/s, Average storey height: 3m, Frame spacing in X- and Y-Direction: 8 m, Number of storeys: 30, Aspect ratio: 3.75:1:1. Typical storey height: 3 m,

Positioning of building: One face of the building is facing the sea and hence assumed to be in Category 1 while all the other faces are assumed to be in Category 4 (in order to consider the extreme effect of terrain category)

Building Parameters: Size of beam: 300 × 600 mm, Size of columns: 800 × 800 mm, Slab thickness: 125mm, Thickness of shear wall: 300 mm, Partition wall thickness: 150 mm, Material characteristics: Characteristic strength of concrete f_{ck} = 30 MPa, Characteristic strength of reinforcing steel f_y = 415 MPa, Density of concrete = 25 kN/m^3, Density of brick wall: 20 kN/m^3.

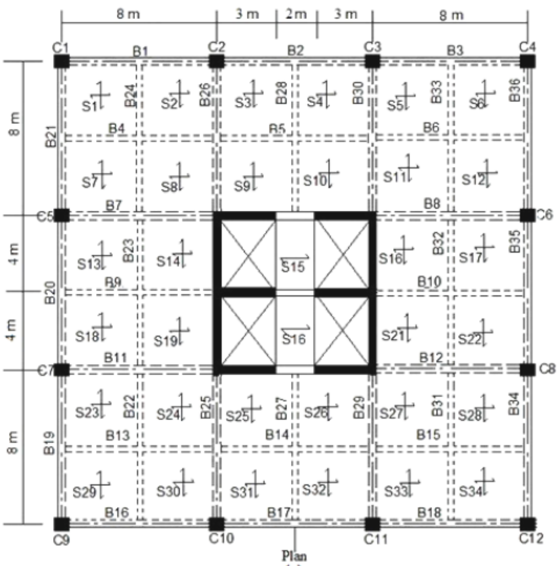

Fig. 1 Building Plan

RESULTS AND DISCUSSION:

ESWL for RC building with above mentioned details was calculated using EXCEL sheet. ESWL obtained are processed to determine Base shear and Overturning moment through ETABS. The results are compared among excel based calculation and ETABS result. Comparison among results obtained for ESWL are made in two parts.

Part I: Comparison of IS:875 (Part-III) - 1987 and the Proposed Draft Code

ESWL determined using three different approach is plotted against height of the building in Fig. 2 & Fig. 3.

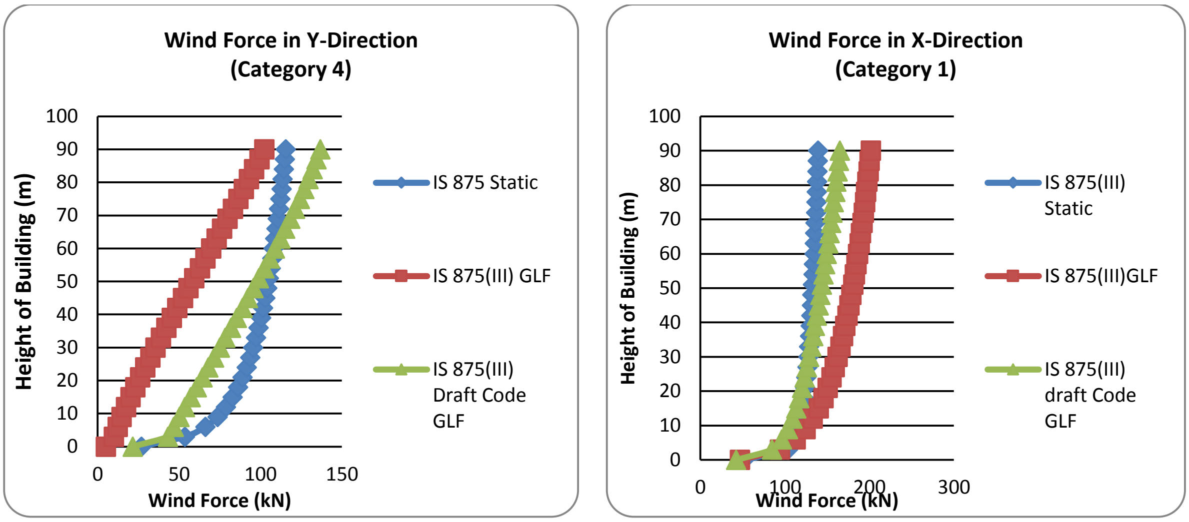

Fig. 2: Variation of Wind Force along the height of the building in X and Y-Direction.

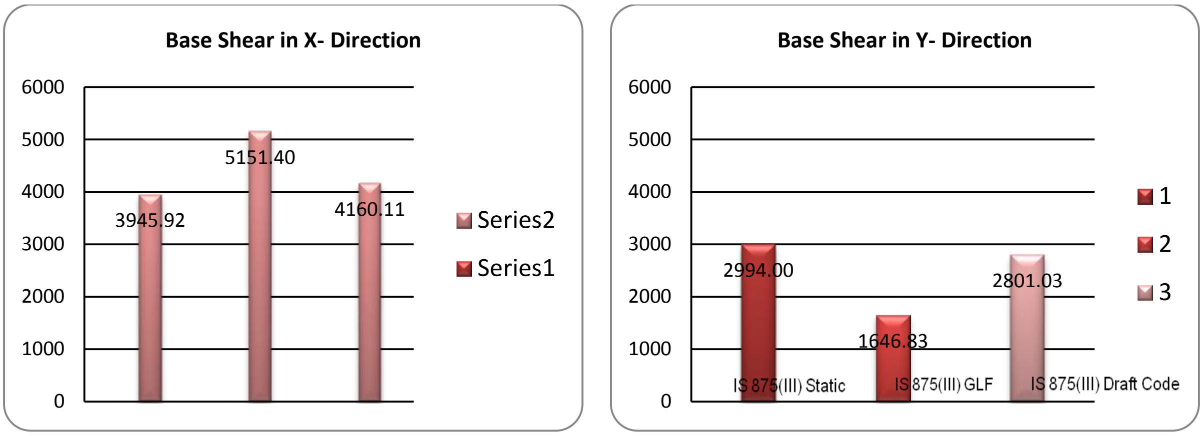

Fig.3: Comparison of Base Shear Force

Major observations related to Fig. 2 & Fig. 3 are discussed herein. As the height of the building increases, the dynamic response becomes more predominant and hence the static method cannot be relied upon. The static method of IS:875(Part-III)-1987 gives higher value of wind loads in the lower region of the building as it does not account for the effect of turbulence intensity on the pressure. In the dynamic method, the turbulence intensity function takes care of the turbulence generated by friction on the ground and drag on surface obstacles hence the value of forces is lower in the lower height region. In line with this, the static method would give higher value of storey shear in lower storeys and lesser value of storey shear in higher storeys. As a result the estimation of the storey drift would be affected and the value of top storey drift obtained in case of static method would be less than the actual. The variation of force in case of static method and dynamic method of present code is dependent on the wind velocity profile only as a result the variation is parabolic. The wind force in Terrain Category 1 is observed to be highly overestimated in case of gust loading factor method whereas the same in Terrain Category 4 is highly underestimated compared to draft code results. The Base shear obtained from the static method is nearly equal to that obtained through the draft code method, but the distribution of the shear along the storey is different.

PART II: Comparison DGLF and MGLF

Four different cases are considered for the study, wherein Case 1:β = 1.0 and λ = 0.0; Case 2: β = 1.6 and λ = 0.0; Case 3: β = 1.0 and λ = 0.2; and in Case 4: β= 1.6 and λ = 0.

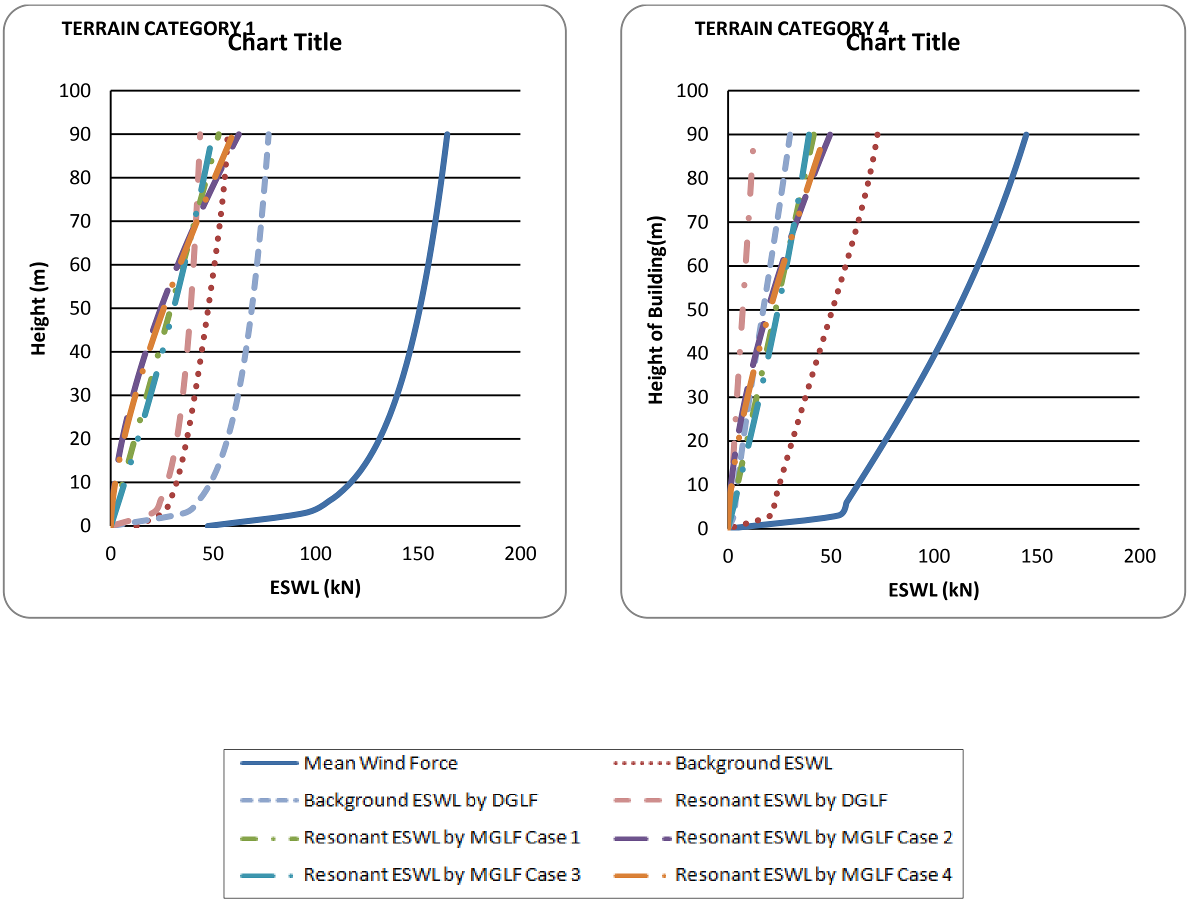

Fig. 4 Variation of components of ESWL along the height of the building

The following observations can be made from the plots in Fig. 4. The DGLF method used in IS 875(III)-1987 does not differentiate the cases that have nonlinear mode shapes or non-uniform mass, or both, from the case that has a linear mode shape and uniform mass, or case 1 considered here. Hence the DGLF method would give the same result for all 4 cases. The effect of the non-uniform mass is insignificant and the effect of a nonlinear mode shape is 2.1% on the resonant forces which are negligible as the plots are nearly overlapping each other.

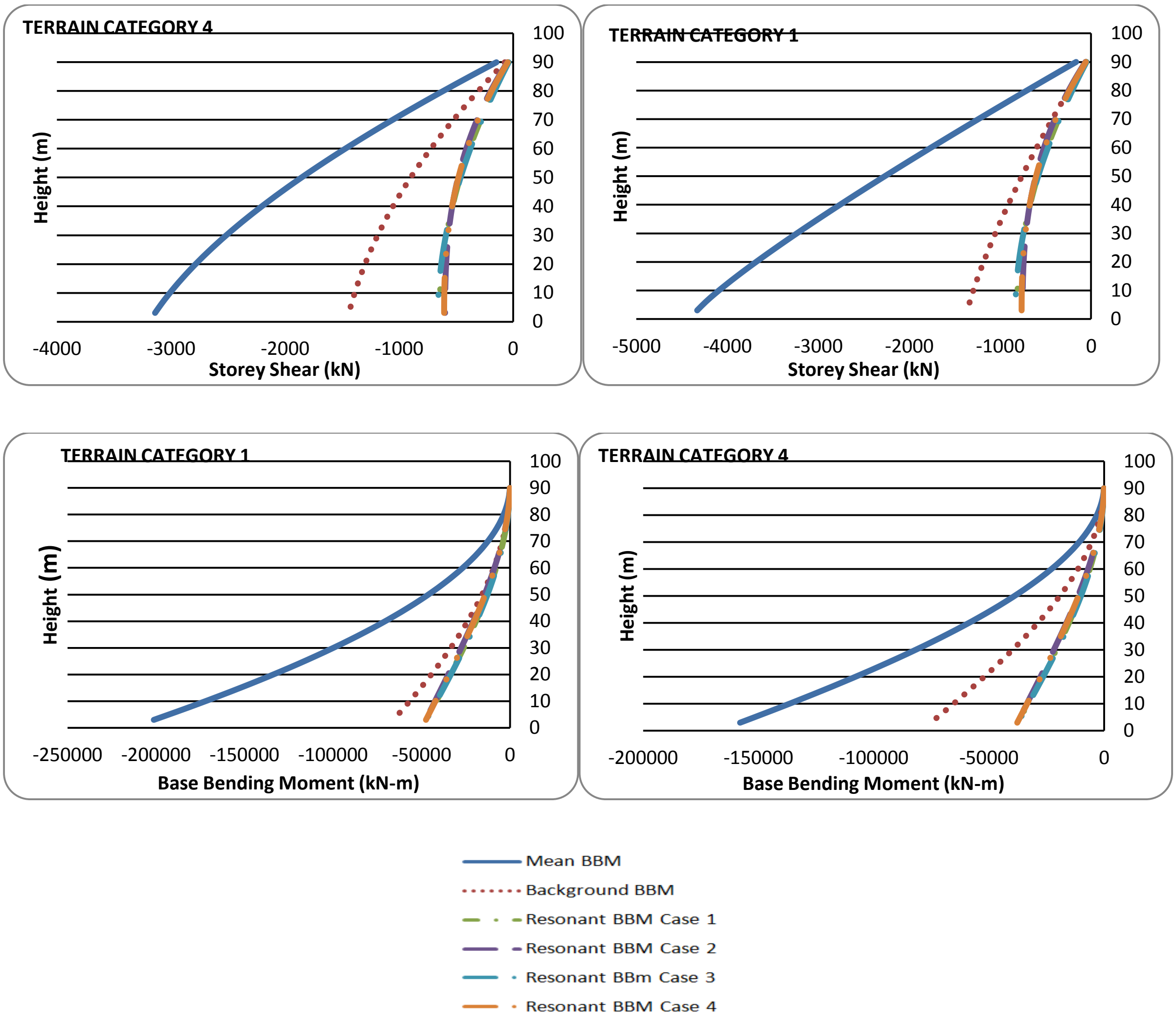

Fig. 5 Variation of Shear Force and Bending Moment along the height of building

Fig. 5 shows the variation of base shear and bending moment along the height of the building. The mean background and the resonant components are plotted against height of building.

CONCLUSIONS:

In this paper a brief characterization of wind forces in the form of DGLF and MGLF approach is studied. The comparison of three different methods is carried out i.e. IS 875(Part III)-1987, IS 875(Part III)-Draft Code and the MGLF Procedure suggested by Zhou and Kareem. A thirty storey RC building is considered for the computation of wind forces using three different approaches. It is found that MGLF is more realistic in application than the

DGLF approach. The existing information of the codes is used in the MGLF approach which makes it easy to apply on different problems and it estimates the ESWL more correctly. Also its application range is extended to consider the effect of nonlinear mode shapes and non-uniform mass distributions.

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