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Wind Analysis of High Rise Buildings

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Abstract –*For the purpose of determination of structural response by RVA, a FORTRAN program was developed. In random vibration analysis procedure, the mean component and fluctuating component of deflection of the structure were determined individually and later combined in order to give the maximum response. Gust factor which is the ratio of maximum response of the structure to the mean response was also calculated in the RVA method. In case of codal analysis, Gust factor can be directly determined using formulae which is combined with the wind pressure, drag coefficient and the area on which it is acting, in order to calculate the along wind load acting on the structure. Only wind load, Shear force and Bending moment results can be determined using codal procedures.*

For both the buildings first vibrational mode with linear mode shape and constant lumped masses along the height was considered. In case of chimney, SAP2000 was used model it as a vertical cantilever beam and modal analysis was performed on the FEM model. The required data of the structures were given as input to the FORTRAN program and the along wind response of the structures were obtained. Responses from various PSDs discussed in Chapter 3 were obtained and the results have been compared with each other and also with results presented in the literature from which they have been taken. Also the results codal analyses have been presented.

Key Words: FORTRAN Program, SAP 2000, FEM Model

1. INTRODUCTION

With the increase in population, lack of open space, development of modern construction materials and techniques, demand for taller, lighter and slender structures continues to increase. This includes tall buildings, chimneys, transmission towers, masts, etc. The fundamental frequencies of such structures lie in the range of the average frequency of powerful gusts which might cause the structure to undergo large resonant motions under severe wind loads. Wind load acting on a structure depends on characteristics of wind velocity, terrain, geometry of the structure, etc. The dynamic forces act not only in the direction of wind flow (Drag forces), but also in the direction perpendicular to the flow (Lift forces). Thus, tall structures undergo across-wind vibration in addition to vibration in the along-wind direction. It is hence the task of an engineer to ensure adequate performance of the structure against wind loading during it anticipated life time based on the along-wind response or across-wind response of the structure or by the combination of the two responses.

Analysis methods are available for along-wind and across-wind responses of tall structures. These methods are based on random vibration approach wherein the random (or stochastic) nature of variation of wind velocity with time is considered. These methods have been well explained in textbooks [Simiu and Scanlan (1986), Nigam and Narayanan (1994)] and are also included in wind design codes [IS: 875 (Part 3) – 1987, IS: 4998 (Part 1) – 1992, ASCE 7-10, AS/NZS 1170.2:2011, EN 1991-1-4:2005, HK CoP-2004, etc.]. However codes of practices also include simplified approach for structures of moderate height.

LITERATURE REVIEW

Davenport (1961) proposed an empirical expression for determining the spectra of longitudinal wind fluctuations of gustiness based on the study made on about 70 such spectra of horizontal components causing gustiness in wind. Changes in the spectra due to change in mean wind velocity, terrain roughness and height above the ground surface were studied. Wind velocities were measured at three different stations and this recorded data was used in acquiring the spectra of wind velocity using a procedure called Tukey's method. The spectra at three different height, namely, 12m, 64m and 183m were studied and it was observed that the difference in ratio of total variance to square mean velocity was less than 10 percent and hence not very significant. By trial, a height-independent expression for the spectra was proposed by Davenport. Expressions for total variance and turbulence intensity have also been mentioned in the literature. Values of surface drag coefficient and power law exponent applicable for various terrain categories have also been tabulated.

Simiu (1974) discusses about the various spectra for longitudinal turbulence of wind velocity which were prevailing during the publication of this particular paper. The variation of these spectral curves in frequency domain, depending upon the variation in height and terrain category has been presented. In the later sections of the literature, improved expression for the spectra of longitudinal wind fluctuations had been proposed, which takes into account the variation in spectra with height that was neglected by Davenport's empirical expression. It has also been mentioned that Davenport's height-independent formula, which has been adopted by Canadian and American codes, overestimates the fluctuating deflections of tall and flexible structures.

Simiu (1976) mentions that the wind velocity profile given by logarithmic law is superior to the one given by power law and has suggested values of roughness length to be used for various terrain categories. Expressions for cross spectra of fluctuating pressures for wind acting at two different points and the correlation coefficients in along-wind and across-wind directions have also been provided. Along-wind response has been determined for a 400m tall building using the random vibration analysis procedure in the first mode, assuming the building to have a linear modeshape. It has also been shown that deviation of fundamental modal shape from a straight line has an insignificant effect on the dynamic response of the structure.

Muller and Nieser (1976) have measured wind velocity and wind acceleration at three different levels of a 180m RC chimney located in South Germany. A mechanical model of the chimney was built in order to obtain displacement from the measured acceleration data. Along wind response and across wind response of the chimney obtained from the model have been plotted for various wind velocities. These values have been compared with theoretical procedure by using Davenport‟s PSD and the results have been presented.

Melbourne (1980) has made a comparative study on the wind response measurement conducted on the CAARC standard tall building model which was conducted at five different centers and discussed during the 5th International Conference on Wind Effects on Building and Structures (1975). This literature was prepared so that the results presented in it can be used as a benchmark for an isolated tall rectangular building. Thus, this building has been considered for the along-wind analysis in the later sections of this dissertation and the results obtained have been discussed and compared with the results of this literature.

Kareem (1981) observed that, although contribution of higher modes of vibration to wind excited displacement response is negligible, their influence on the higher derivative of displacement, i.e., acceleration and jerk, is quite significant. Method for determination of the contribution of higher modes to crosswind response of a structure has beenpresented and it has been illustrated by considering contribution of first five modes of a 183m tall building.

Solari (1983) observed that distinguishing flexible structures from rigid structures is very important so that dynamic analysis can be performed on flexible structures. The principles which were available to classify the structures based on their rigidity did not include all required parameters. So he proposed a general relationship for structural classification and the modified relationships for point-like structures and three-dimensional structures separately. These expressions took care of all necessary parameters like mean wind speed, fundamental frequency, height and terrain roughness. A simple expression of gust factor for rigid structures has also been proposed in the paper.

RESULT AND DISCUSSION

Wind load on the building as a whole

Force coefficient Method has to be used for this purpose as Force Coefficients (or thesum of corresponding Pressure Coefficients) help in determining the overall force acting on a structure in order to design the framework or to compute stability of a structure.

Wind load is determined using Force coefficient method described in section 3.2.2.1 and it is calculated at each story level separately for each wind direction as the wind velocity is not constant throughout the height of the building. The structure is assumed to consist of RC column-beam frame at 5m c/c horizontal spacing and 3m c/c vertical spacing. Thus the wind load acting on the intermediate frames and end frames are calculated from their respective surface areas as shown in Table 4.1.

Table 4.1: Wind Load calculated using Force coefficient method

Wind Load in the direction perpendicular to the longer face of the building							
Floor Level	Height (m)	Force Coefficient (Cf)	Ae (sq.m)		Pz (kN/sq.m)	Wind Load (kN)	
			Intermediate Frames	End Frames		Intermediate Frames	End Frames
1	3	1.18	7.5	3.75	1.273	11.266	5.633
2	6	1.18	15	7.5	1.273	22.532	11.266
3	9	1.18	15	7.5	1.273	22.532	11.266
4	12	1.18	15	7.5	1.273	22.532	11.266
5	15	1.18	15	7.5	1.38	24.426	12.213
6	18	1.18	7.5	3.75	1.428	12.638	6.319
Wind Load in the direction perpendicular to the shorter face of the building							
Floor Level	Height (m)	Force Coefficient (Cf)	Ae (sq.m)		Pz (kN/sq.m)	Wind Load (kN)	
			Intermediate Frames	End Frames		Intermediate Frames	End Frames
1	3	1.00	7.5	3.75	1.273	9.548	4.774
2	6	1.00	15	7.5	1.273	19.095	9.548
3	9	1.00	15	7.5	1.273	19.095	9.548
4	12	1.00	15	7.5	1.273	19.095	9.548
5	15	1.00	15	7.5	1.38	20.700	10.350
6	18	1.00	7.5	3.75	1.428	10.710	5.355

Wind Load acting on the Walls and Cladding units

Wind load acting in individual structural elements of the building such as walls and cladding units are determined using the Pressure Coefficient method. Wind Load, F, acting in a direction normal to the individual structural element or cladding unit is,

$$F = \left(C_{pe} - C_{pi}\right) A p_d$$

where, Cpe = External Pressure Coefficient

Cpi = Internal Pressure Coefficient

A = surface area of structural element or cladding unit

pd = design wind pressure.

Percentage area of openings in the walls = 4.167 < 5%

Therefore, as per Cl 6.2.3.1, Internal Pressure coefficient, Cpi = ± 0.2

Table 4.2:Calculation of Net Pressure Coefficients on the walls

External Pressure Coefficients (Cpe)		
Wall	Cpefor Wind angle (θ) = 0°	Cpefor Wind angle (θ) = 90°
A	0.7	-0.5
B	- 0.48 (= - 0.4 - 0.08)	0.5
C	-0.7	0.8
D	0.7	-0.1
Net Pressure Coefficients (Cpnet= Cpe-Cpi)		
Wall	Net Pressure Coefficients (Cpnet)	
A, B	+ 0.7 – (-0.2) = +0.9 (Pressure)	
	- 0.5 – (+ 0.2) = - 0.7 (Suction)	
C, D	+ 0.8 – (-0.2) = + 1.0 (Pressure)	
	- 0.7 – (+ 0.2) = - 0.9 (Suction)	

Table 4.3: Design wind pressure acting on individual structural units

Wall	Height (m)	Cpnet	Pz	Design Wind Pressure (kN/m2)	Nature of Load
A, B	Upto 10m	0.9	1.273	1.146	Pressure
		-0.7	1.273	-0.891	Suction
	15	0.9	1.38	1.242	Pressure
		-0.7	1.38	-0.966	Suction
	18	0.9	1.43	1.287	Pressure
		-0.7	1.43	-1.001	Suction
C, D	Upto 10m	1.0	1.273	1.273	Pressure
		-0.9	1.273	-1.146	Suction
	15	1.0	1.38	1.380	Pressure
		-0.9	1.38	-1.242	Suction
	18	1.0	1.43	1.430	Pressure
		-0.9	1.43	-1.287	Suction

The individual structural elements like walls, and individual cladding units like glazing and their fixings are designed for the load obtained by multiplying the design wind pressure from Table 4.3 at the required height above the ground surface with their respective surface areas.

CONCLUSION

In the present work, methods of along wind analysis of tall and slender structures have been discussed in detail. This includes the 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]. The RVA procedure considers the modal properties and geometric properties of the structure, and the wind characteristics in the terrain in which the structure is located in order to give the response of the structure in terms of mean and fluctuating displacement, Gust factor, Shear force and Bending Moment. Only wind load, Shear force and Bending moment results can be determined using codal procedures.

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