Along wind load dynamic analysis of buildings with different geometries

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ABSTRACT

Wind induced structural responses, including pressure, are directional dependent. First win speed will not be uniform in all directions. Second the shape and structural properties of the structure will not be axi-symmetric. Consideration of the directionality effect will help to achieve an economical and safe design of structure The wind pressure acting on individual units of a structure can be determined using the pressure coefficient which depends on the overall dimensions of the structure as well as the openings present in the walls of the structure. The numerical example considered in this chapter illustrates the determination of static wind loads by both force coefficient and pressure coefficient methods.-Dynamic along-wind analysis procedures using Random Vibration Analysis and codal provisions explained in this paper. For the purpose of along-wind analysis of the structures by the analytical procedure based on random vibration analysis, a FORTAN program was developed. For this purpose, three structures have been considered, out of which, two are buildings and one is a chimney. The output of the program is the response of the structure in terms of mean response, peak factor, standard deviation of fluctuating response along the height of the structure.

Keyword: *Static Wind load analysis, distributed horizontal load.*

1. INTRODUCTION

Most wind damage to buildings occurs during strong winds. The wind loads specified here are applied to the design of buildings to prevent failure due to strong wind. The strong winds that occur in this country are mainly those that accompany a tropical or extra tropical cyclone, and down-bursts or tornados. The structural response of a building to wind refers to the pressure, force, deflection, acceleration, or based-moment due to wind blow. Owing to the shape of the building, the structural response will depend on the direction of wind blow. There is usually a critical direction in which the response is the maximum for a constant wind speed irrespective of direction. Wind forces are depending upon porosity, prevailing wind direction, surface roughness, turbulence, viscosity, windward face. High rises are sometimes defined as buildings above some 15 or 16 stories in height, but rather than define them in terms of the number of stories, the reporters prefer for purposes of this report to define them as buildings in which the height of the structure is such that prediction of its stability, internal stresses, reactions and movements are necessary and require rigorous analysis of both superimposed vertical and lateral loads and effects of shrinkage, creep, and temperature to assure adequate and safe performance for their intended purposes. Therefore, wind resistant design for components/cladding should be just as careful as that for structural frames.

2. LITERATURE REVIEW

Reference [2] shows the paper on the structure increases the distance of the wind shadow, and minimizes the air flow in leeward direction, i.e. behind the building at the street level, while increasing the depth till four times of its height does not affect the wind shadow 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.

3. PROBLEM DEFINITION

Here, three structures have been considered, out of which, two are buildings and one is a chimney. The first structure is a 200m high rise building taken from Simiu and Scanlan (1986). The second building is a 183m tall building which is commonly referred to as the CAARC Standard Tall Building taken from Melbourne (1976). The third structure is a 400m tall Chimney taken from the literature of Menon and Rao (1996). 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.

4. BUILDING DESCRIPTION

1. Structure 1: 200m Building:

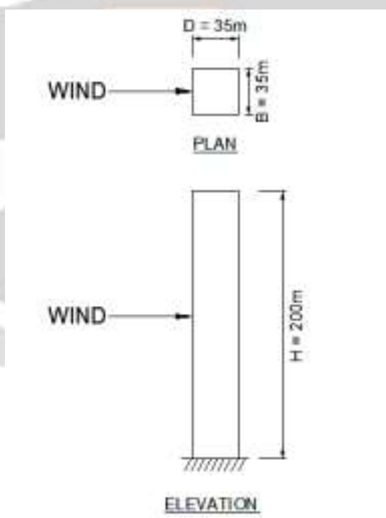

Fig.1 : Dimension details of 200m building

This example has been taken from Simiu and Scanlan (1986).

Table-1:Model data of 200m tall building

Height of building (H)	200m
Across wind plan dimension of building (B)	35m

Along wind plan dimension of building (D)	35m
Natural frequency in the first mode (n_1)	0.175 Hz
Damping ratio in the first mode (η_1)	0.01
Bulk density of the building (ρ_b)	200 kg/m^3
Total mass of the building (M)	16,333,300 kg
Mass of the building per unit height (Mz)	245,000 kg
Windward Pressure Coefficient (C_w)	0.8
Leeward Pressure Coefficient (C_l)	0.5
Density of air (ρ_a)	1.25 kg/m^3
Roughness length (z_0)	1 m
Mean wind velocity at 10m height (U_{10})	17.154 m/s
Shear velocity (u_0)	2.98 m/s
Modeshape (ϕ_z)	(z/H)
Averaging Period (T)	3600 sec
Exponential Decay parameter in Horizontal direction (C_y)	16
Exponential Decay parameter in Vertical direction (C_Z)	10

2 Structure 2: 183m Building:

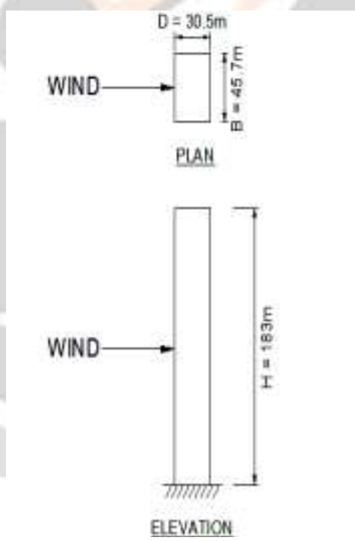

Fig.2: Geometric details of CAARC Standard Tall Building

This building has been taken for along wind analysis from Melbourne (1976) and Holmes (2014)

Table-2: Model data of 183m tall building

Height of building (H)	183m
Across wind plan dimension of building (B)	45.7m
Along wind plan dimension of building (D)	35m
Natural frequency in the first mode (n_1)	0.2 Hz
Damping ratio in the first mode (η_1)	0.01
Bulk density of the building (ρ_b)	160 kg/m^3

Total mass of the building (M)	40,811,928 kg
Mass of the building per unit height (Mz)	223016 kg
Windward Pressure Coefficient (C_w)	0.95
Leeward Pressure Coefficient (C_l)	0.5
Density of air (ρ_a)	1.23 kg/m^3
Power law coefficient (α)	0.28
Terrain roughness coefficient (k)	0.015
Modeshape (ϕ_z)	(z/H)
Averaging Period (T)	3600 sec
Exponential Decay parameter in Vertical direction (C_Z)	10

2. Structure 3: 400m Chimney:

(a) Elevation *(b) C/S Details at A* *(c) C/S Details at B*

Fig.3: Structural Details of Chimney

This structure has been taken from Menon and Rao (1996).

Table-3: Model data of 400m tall chimney

Height of building (H)	400m
Outer diameter of chimney at base (D_b)	33.33m
Outer diameter of chimney at top (D_t)	20m
Wall thickness at base (t_b)	0.95m
Wall thickness at top (t_t)	0.45m
Grade of Concrete (*fck*)	25MPa
Drag Coefficient (C_d)	0.65 for $z < (h-1.5D_t)$
Density of air (ρ_a)	1.23 kg/m^3
Power law coefficient (α)	0.14
Terrain Category	Open Terrain
Averaging Period (T)	3600 sec
Power Spectral Density function	Simiu"s PSD
Surface drag coefficient (k)	0.005
Exponential Decay Coefficient in Vertical direction (C_z)	10
Mean wind velocity at 10m	25 m/s

5. ANALYSIS

The details of the structures provided have been given as input to the FORTRAN program. The output of the program is the along-wind response of the structures in terms of mean response, peak factor, standard deviation of fluctuating response, gust factor, peak response of the structure, Bending moment and Shear force along the height of the structure.

6. RESULTS AND OBSERVATION

6.1 Structure 1: 200m Building:

The PSD that was actually used Simiu and Scanlan (1986) was the PSD proposed by Simiu. The output of the FORTRAN program using PSDs suggested by Davenport (1961), Harris (1968), Kaimal (1972) and Simiu (1974) have been presented in Table 5.1 along with the numerical results given in the literature from which this example has been taken from Simiu and Scanlan (1986) at the top of the building.

Table-4: RVA results of 200m building

	X_{mean} (m)	K_x	σ_x (m)	G	X_{peak} (m)
Simiu and Scanlan (1986)	**0.184**	**3.63**	**0.074**	**2.46**	**0.452**
Simiu's PSD	0.186	3.64	0.083	2.62	0.488
Kaimal's PSD	0.186	3.66	0.077	2.51	0.467
Harris's PSD	0.186	3.67	0.092	2.82	0.524
Davenport's PSD	0.186	3.70	0.094	2.88	0.535

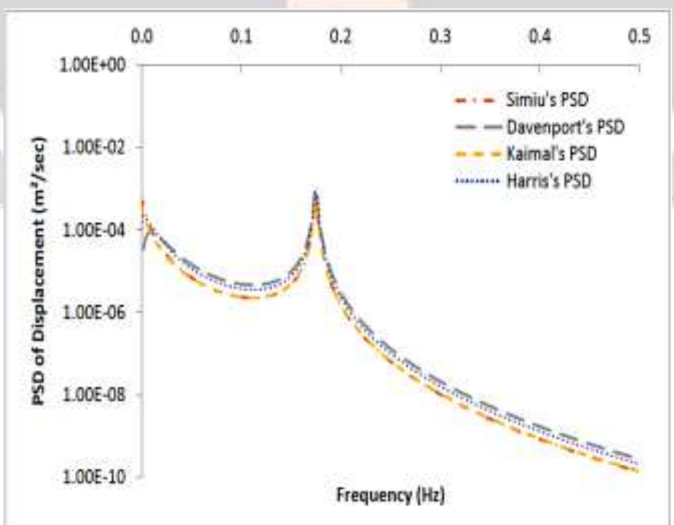

Fig 4: PSD of Displacement at height 200m

6.2 Structure 2: 183m Building:

The PSD used in the literature Melbourne (1980) is as described. This has been given as the input PSD of velocity to the FORTRAN program. The results obtained from the FORTRAN program using following equation. $nS_u (z.u) / u^2 =$

$4x^2/(2+x^2)^{5/6}$ Other PSD discussed earlier have been compared with the results available in Melbourne (1980). Also, the Bending moment results obtained from the program have been compared wind tunnel results given by Holmes (2014).

Table-5: RVA results of 183m building

	Xmean (m)	Kx	σ_x (m)	G	Xpeak (m)
Simiu and Scanlan (1986)	0.217	3.73	0.086	2.48	0.537
Simiu's PSD	0.217	3.7	0.079	2.34	0.508
Kaimal's PSD	0.217	3.72	0.074	2.27	0.492
Harris's PSD	0.217	3.72	0.089	2.53	0.547
Davenport's PSD	0.217	3.75	0.093	2.6	0.565

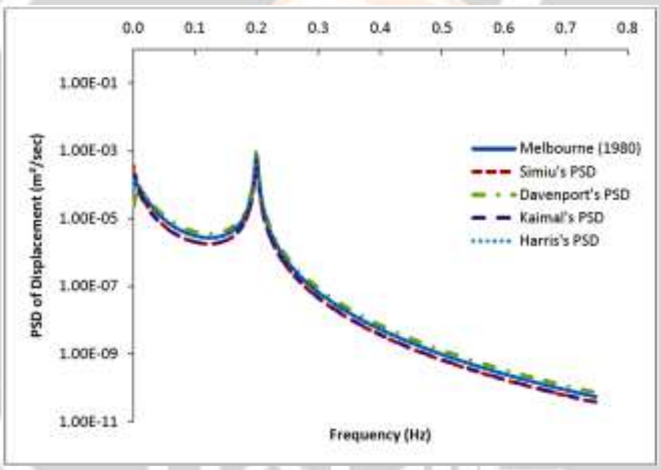

Fig 5: Response of CAARC building atUh =40m/s

The 400m chimney was modeled using SAP2000, as a cantilever beam having tapered section with geometric. FEM model of the two-noded single-element beam was developed by discretizing it into 36 elements, as considered in the literature [Menon and Rao (1996)]. The discretized model of the chimney is shown in Figure. Modal analysis was performed on the FEM model in order to obtain the natural frequency of chimney, lumped mass and normalized mode shape details. It has been mentioned in the literature that only the first three vibrational modes of the chimney were considered. Same has been followed for the present study also. The first three mode shapes of the chimney are shown in Figure 6.

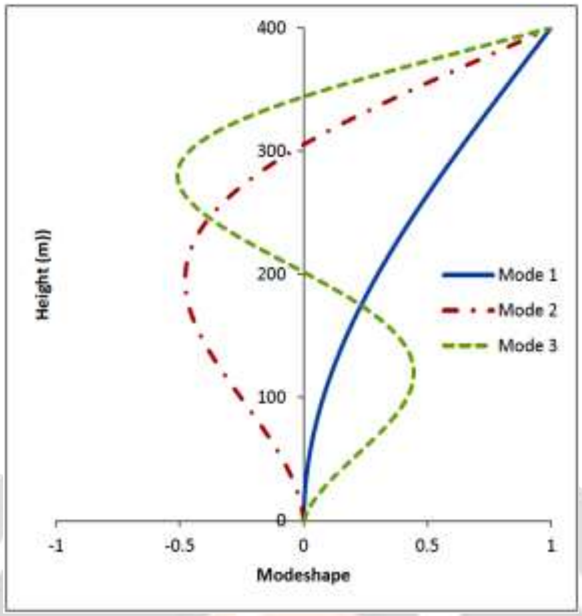

Fig 6: Modeshapes of 400m Chimney

Table-5: RVA results of 400m chimney

	Xman (m)	Kx	σ_x (m)	G	Xpeak (m)
Simiu's PSD	0.334	3.585	0.079	1.858	0.620
Kaimal's PSD	0.334	3.614	0.073	1.793	0.598
Harris's PSD	0.334	3.678	0.099	2.094	0.699
Davenport's PSD	0.334	3.701	0.104	2.152	0.718

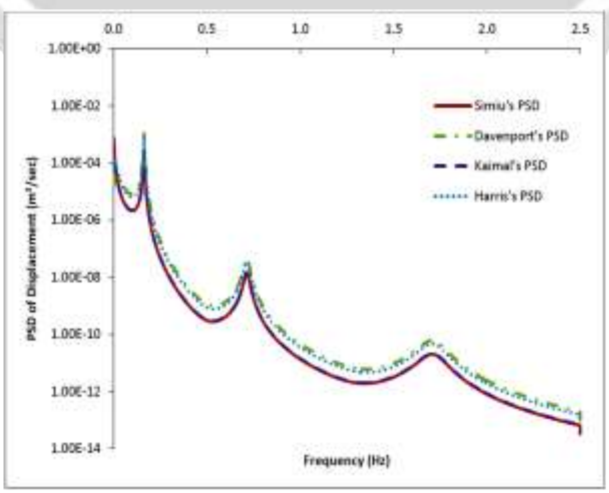

Fig 7: Response of 400m Chimney

5. CONCLUDING REMARKS

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. Only wind load, Shear force and Bending moment results can be determined using codal procedures.

Two tall buildings and a chimney have been taken and their along wind responses have been calculated using the above mentioned procedures. The effect of various PSDs on the response has also been studied and discussed with the help ao appropriate tables and graphs.

6. REFERENCES

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