Computational Techniques in Wind Response of Tall Buildings

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Abstract: The demand for taller, lighter and more slender structure continues to increase in India, so it increases the importance of design for wind-induced building motion. Tall structures that meet the code for lateral drift requirement can still sway in strong winds. Some severe disasters in United States due to the hurricanes also prove that existing buildings are not fully wind resistant therefore it becomes necessary to review the computing techniques that are currently in use for the determination of along wind load. This paper discusses the methods for calculating along wind response by gust factor method by considering the effects of change in terrain category, as described by the present IS code [IS: 875 – (Part 3) – 1987] and as per the new code which reaffirmed in 2013 as well as other techniques by which we can predict wind response.

Keywords – Wind Response, computing techniques

1. INTRODUCTION [1], [2], [4]

The present Indian Standard for Wind Loads on Buildings and Structures (IS 875 (Part – 3) – 1987) recommends Gust Factor (GF) or Gust Effectiveness Factor (GEF) for calculating along wind load or drag load on flexible slender structure which includes tall buildings. The procedure makes use of hourly mean wind speed and cumbersome charts to arrive at the Gust Factor. This code is due for revision and Bureau of Indian Standards (BIS) has very recently circulated a revised draft for the code, which is under circulation and will become operative very soon. Many modifications have been made in this revised code and in particular the procedure to obtain along wind response of tall buildings has been simplified making use of formulae. It also includes the procedure to obtain across wind response for building.

Flexible slender structure and structural elements shall be investigated to ascertain the importance of wind induced oscillations or excitations along and across the direction of wind.

Following two sections discuss the steps to obtain along wind response as per IS 875 (Part 3) – 1987 and revised draft CED 37/7792.

2. IS 875 (PART 3) 1987 [1]

The code recommends that following guidelines may be used for examining the problems of wind induced oscillations:

a) Buildings and closed structures with height to minimum lateral dimension ratio of more than about 5.0
b) Buildings and closed structures whose natural frequency in the first mode is less than 1.0 Hz.

Any building or structure which does not satisfy either of the two criteria shall be examined for dynamic effects of wind.

2.1 Time Period (T)

The fundamental time period (T) may either be established by experimental observations on similar buildings or calculated by any rational method of analysis. In the absence of such data, T may be determined as follows for multi-storied buildings:

a) For Moment Resisting Frames without bracing or shear walls for resisting the lateral loads

$$T = 0.1\, n$$

Where, n – number of storeys including basement storeys

b) For all others

$$T = \frac{0.09H}{\sqrt{d}}$$

Where, H – Total height of the main structure of the building in meters, and
d – Maximum base dimension of building in meters in a direction parallel to the applied wind force.

2.2 Along Wind Load (Fz)

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

$F_z = C_f A_e \bar{p}_z G$

Where,

F_z - Along wind load on the structure at any height z corresponding to strip area A_e.

C_f - Force coefficient for the building (see Fig. 4, pg no.39 of the standard)

A_e - Effective frontal area considered for the structure at height z

$\bar{p}_z$ - design pressure at height z and obtained as $0.6\bar{V}_z^2$ (N/m2)

G - Gust Factor

2.3 Gust Factor

Gust factor is given as:

$$G = 1 + g_{fr}\sqrt{\left[B(1+\varnothing)^2 + \frac{SE}{\beta}\right]}$$

Where,

g_{fr} - Peak factor defined as the ratio of the expected peak value to the root mean value of a 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_{fr} is given in Fig. 8 of standard

B – Background factor indicating a measure of slowly varying component of fluctuating wind load and is obtained from Fig. 9 of standard,

$\frac{SE}{\beta}$ – Measure of the resonant component of the fluctuating wind load,

S – Size reduction factor (Fig. 10 of standard)

E – Measure of available energy in the wind stream at the natural frequency of the structure (Fig. 11 of standard)

β - damping coefficient of the structure (Table 34 of standard)

$\varnothing = \frac{g_{fr}\sqrt{B}}{4}$ and is to be accounted only for buildings less than 75 m high 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.

3. IS 875 (PART 3): 2013 [3], [4]

3.1 Design Wind Speed (Vz)

Vz at any height z, for the chosen structure calculated as

$V_z = V_b k_1 k_{2,i} k_3 k_4$

Where,

V_b – Basic wind speed in m/s

V_z - design wind speed at any height z in m/s

k_1 - Probability factor (risk coefficient)

$k_{2,i}$ - Mean Hourly wind speed coefficient and

k_3 - Topography factor and

k_4 - Importance factor for the cyclonic region

3.2 Turbulent Intensity

The turbulence intensity variations with height for different terrains can be obtained using the relations given below:

Terrain Category: 1

$$I_{z,1} = 0.3507 - 0.0535 log_{10}\left(\frac{z}{z_{0,1}}\right)$$

Terrain Category: 2

$$I_{z,2} = I_{z,1} + \frac{1}{7}(I_{z,4} - I_{z,1})$$

Terrain Category: 3

$$I_{z,3} = I_{z,1} + \frac{3}{7}(I_{z,4} - I_{z,1})$$

Terrain Category: 4

$$I_{z,4} = 0.466 - 0.1358 log_{10}\left(\frac{z}{z_{0,4}}\right)$$

3.3 Design Wind Pressure

The wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind speed:

$p_z = 0.6V_z^2$

Where,

P_z – wind pressure in N/m^2 at height z, and

V_z – design wind speed in m/s at height z.

4. COMPUTER PROGRAM [5]

Present existing Indian Code IS 875 (Part 3) – 1987 provides step by step procedure for Dynamic Analysis of Building. This includes number of Tables and Cumbersome Charts for calculating all respective parameters for the complete analysis of any tall structure. By using these charts and Tables it is very difficult to develop a Computer Program and the manual analysis is very time consuming as well as tiresome.

The Draft Indian Code under Circulation CED 37 (7792) is available for estimating along wind load. This code includes number of formulae instead of Tables and Cumbersome Charts which makes analysis much simpler and rapid. By using these formulae we can easily develop a Computer Program in any suitable computer programming language.

A FORTRAN based computer program has been prepared as per the procedure given in revised Draft under Circulation CED 37 (7792) for obtaining the along wind response and which can be used to generate data to be used for the ANN network.

The input and output details, followed by flow chart, are given below: -

Give input as H, B, D, TC, VB, DH, and CF.

Where,
H – Total Height of Building
B – Dimension of building taken normal to wind
D – Dimension of building taken parallel to wind
TC – Terrain Category
VB – Basic Wind Speed in m/s.
DH – distance between two consecutive parts in which building is to be divided
CF – Drag Force Coefficient

Take output (SF and BM) in tabular form.

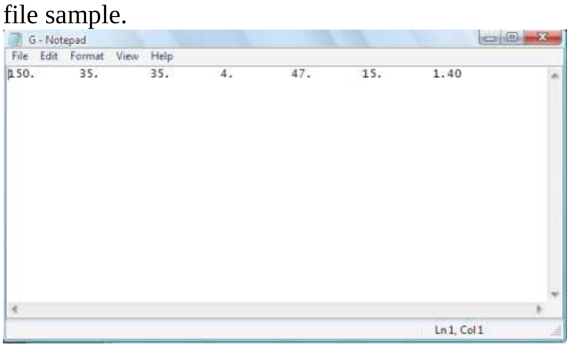
5. EXECUTION OF PROGRAM [6]

If we consider a building whose dimensions are as H = 150m , B = 35m, D = 35m coming under terrain category 4 with a wind speed of 47 m/s and drag force coefficient as Cf = 1.40.

Let us divide the building into 10 parts i.e. DH = 15 m.

5.1 Input File Preparation

Input file is prepared in file.dat format in notepad. Here file as G.DAT is prepared for the above mentioned building. In G.dat the values are entered for Height (H), width (B), length (D), terrain category (TC), wind speed (VB), distance between consecutive number of divisions (DH), and drag force coefficient (CF) as per the format (7F10.5), which means 10 places gap between first input variable (H) to (B) will be entered and so on. Following figure 1 shows input file sample.

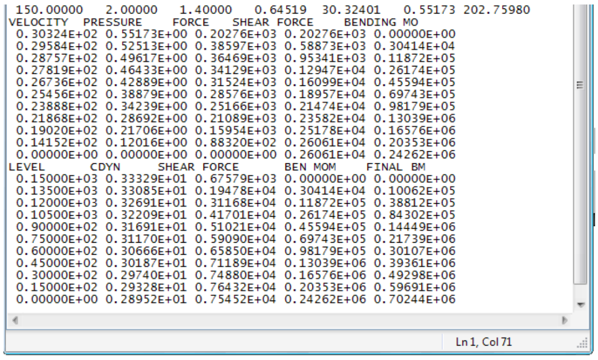


```
150.      35.      35.      4.      47.      15.      1.40
```

Fig 1: Input File

5.2 Output File Format

After execution of program, the program results the output data in M.OUT which is a note pad file which gives us Gust Factor, Wind Pressure, Wind load, shear force and bending moment at each mentioned level. Output file format is shown in figure 2.



```
 150.00000   2.00000   1.40000   0.64519  30.32401   0.55173 202.75980
VELOCITY  PRESSURE    FORCE    SHEAR FORCE    BENDING MO
 0.30324E+02 0.55173E+00 0.20276E+03 0.20276E+03 0.00000E+00
 0.29584E+02 0.52513E+00 0.38597E+03 0.58873E+03 0.30414E+04
 0.28757E+02 0.49617E+00 0.36469E+03 0.95341E+03 0.11872E+05
 0.27819E+02 0.46433E+00 0.34129E+03 0.12947E+04 0.26174E+05
 0.26736E+02 0.42889E+00 0.31524E+03 0.16099E+04 0.45594E+05
 0.25456E+02 0.38879E+00 0.28576E+03 0.18957E+04 0.69743E+05
 0.23888E+02 0.34239E+00 0.25166E+03 0.21474E+04 0.98179E+05
 0.21868E+02 0.28692E+00 0.21089E+03 0.23582E+04 0.13039E+06
 0.19020E+02 0.21706E+00 0.15954E+03 0.25178E+04 0.16576E+06
 0.14152E+02 0.12016E+00 0.88320E+02 0.26061E+04 0.20353E+06
 0.00000E+00 0.00000E+00 0.00000E+00 0.26061E+04 0.24262E+06
LEVEL      CDYN      SHEAR FORCE      BEN MOM     FINAL  BM
 0.15000E+03 0.33329E+01 0.67579E+03 0.00000E+00 0.00000E+00
 0.13500E+03 0.33085E+01 0.19478E+04 0.30414E+04 0.10062E+05
 0.12000E+03 0.32691E+01 0.31168E+04 0.11872E+05 0.38812E+05
 0.10500E+03 0.32209E+01 0.41701E+04 0.26174E+05 0.84302E+05
 0.90000E+02 0.31691E+01 0.51021E+04 0.45594E+05 0.14449E+06
 0.75000E+02 0.31170E+01 0.59090E+04 0.69743E+05 0.21739E+06
 0.60000E+02 0.30666E+01 0.65850E+04 0.98179E+05 0.30107E+06
 0.45000E+02 0.30187E+01 0.71189E+04 0.13039E+06 0.39361E+06
 0.30000E+02 0.29740E+01 0.74880E+04 0.16576E+06 0.49298E+06
 0.15000E+02 0.29328E+01 0.76432E+04 0.20353E+06 0.59691E+06
 0.00000E+00 0.28952E+01 0.75452E+04 0.24262E+06 0.70244E+06
```

Fig: 2 Output File Format

6. EXAMPLE [5], [6]

Six multistoried buildings with different terrain categories have been taken for Dynamic Analysis as per IS 875 (Part 3) – 1987 and CED 37 (7792) both. Validation of computer program is also done.

6.1 Validation of Program

Table 1 gives details of buildings which are used for validation of program.

Parameters	Building 1
Height (m)	200
Breadth (m)	33
Length (m)	33
Basic Wind Speed (m/s)	47
Terrain Category	1
Drag Force Coefficient (Cf)	1.50

Note: Breadth considered normal to the wind direction and k1, k3 and k4 taken as 1.0.

TABLE 1 Building Particulars

Building 1 was used for the validation purpose. Bending Moment and Shear Force in the building due to wind load under category 1 were calculated manually using graphs and charts of existing code along the height of the building. These were also calculated using the program based on new code CED 37 (7792). Following Figures show the comparison which validates the program.

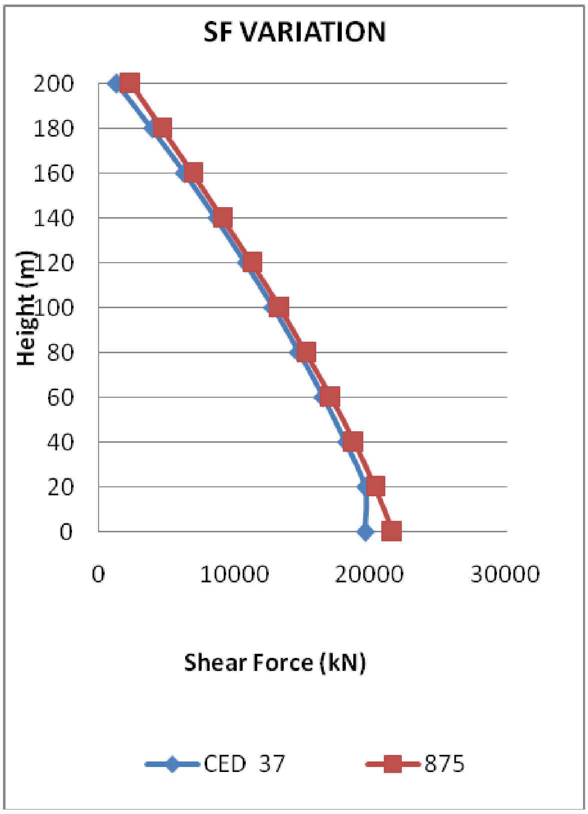


Fig 3: SF Variation for Terrain Category 1

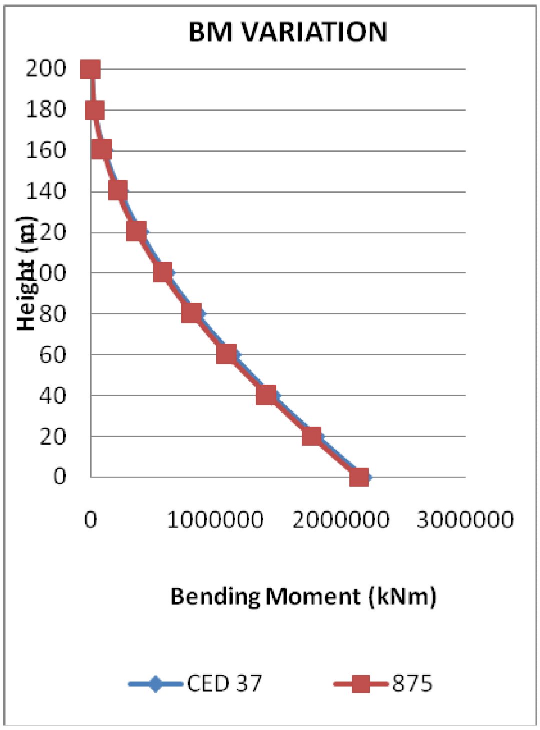


Fig. 4: BM Variation for Terrain Category 1

7. Neural Networks

Application of ANN in wind engineering started rather late (James, 1994) [7], (Flood and Kartam, 1994) [8], (Rafiq and Bugmann, 2001), (Rao and Datta, 2006) [9] have demonstrated use of ANN in complex civil engineering structural analysis and also in seismic analysis of structure. Application suggested by (Khanduri et. Al., 1995) [10], in which the use of Neural Network approach for assessment of wind induced interference effects on design load for building has been discussed. (Girma and Godbole, 1999) [11] had developed two ANN programs, first based on Back Propagation Learning Network (BPLN) and the other based on Cascade Co-relation Learning Network (CCLN) and demonstrated its use to determine pressure distribution for large multistoried office building for which limited wind tunnel test data was available. (Kwatra et. Al., 2002) [12] in his detailed studies carried out experimental studies on wind induced pressure on gable roof. He further utilized this limited test data and developed an ANN model for predicting wind induced pressures in various zones of gable buildings in a standalone situation as well as for interference with another similar building etc. are not included in the code at present. Limited studies on application of ANN for along and across wind load on building have been carried out by Hazra (2007), Patil (2008) and Nikose (2010) [13].

8. DISCUSSIONS

(a) The analysis of number of buildings using revised Code and present Code indicates that for Terrain Category 1, 2 and 3 the results for bending moment and shear force are very close while for category 4 the revised gives higher value for Shear Force and Bending Moment as compared to present Code.

(b) From the parametric study it is observed that for smaller width to length ratio gives higher values of shear force and overturning moment, while larger width to length ratio gives the higher value of Gust factor which further gives higher SF and BM values.

(c) Many papers reviewed for the use of artificial neural networks in civil engineering structural analysis and it is found that the use of ANN is most useful tool for predicting the wind response.

(d) The use of ANN in calculation of wind response of tall buildings plays an important role in the analysis where the complete data is not available.

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