ESTIMATION OF GUST RESPONSE FACTOR FOR A TALL BUILDING MODEL WITH 1:1.5 PLAN RATIOS

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ABSTRACT: The purpose of structural analysis and design of structures as per the building codes and its corresponding standards is to ensure the safety of structure under maximum loads and remains functional under service load. The structure which is designed under consideration of codes should also satisfy the durability, economy and aesthetics. The primary purpose of this work is to understand and compare design wind loads according with the Gust Response Factor as per codes of practices. The paper is concerned with the calculation of design wind loads on a rectangular building model (1:300 geometric scale) of size 10cm x 15cm x 70cm with an aspect ratio of 1:1.5:7 at eight different levels over the height under sub-urban terrain category for 0° angle and 90° angle wind incidence. The experiment is conducted in an atmospheric boundary layer wind tunnel facility of CSIR-Structural engineering Research centre, Chennai. The measured pressures are integrated to evaluate mean and RMS (Root, Mean, Square). Further the variation of above mentioned loads and response factor along the heights of the building with respect to sub-urban terrain condition are discussed and summarized in addition, the codal values of various international standards [IS-875 part-3 1987, IS-875 part-3 draft, ASCE-07] have also considered for comparison.

Index Terms—wind load, Tall Building, 1:1.5, comparison of IS-875(part-3) 1987 & IS-875(part-3) draft, Gust response factor.

I. INTRODUCTION

This With the development of technology in the field of civil engineering and increase in construction technologies bringing into focus on the concept of vertical construction, mainly construction of tall buildings. Apart from usual...
loads like dead and live loads the designer has to focus on the wind induced loads also for better serviceability of tall structure. Wind is essentially the large scale horizontal movement of free air. Wind engineering analyses effects of wind in the natural and the built-in environment and studies the possible damage, inconvenience or benefits which may result from wind. In the field of structural engineering it includes strong winds, which may cause discomfort, as well as extreme winds, such as in a tornado, hurricane or heavy storm, which may cause widespread destruction. So it is the task of the engineers that the performance of structures subjected to the action of wind will be adequate during their anticipated life from the standpoint of both structural safety and serviceability. The codes of practices recommended values of pressure coefficient and force coefficient for various types of structures. The majority of data have been obtained from the wind tunnel experiment data, conducted in the past, under uniform velocity condition. However as a continuous research and development work in the field of wind engineering during the past years, the concept of turbulence and to stimulate correctly the atmospheric boundary layer in wind tunnel for determining the wind pressure distribution have been well established. Thus, in the recent code of practice of wind loads, IS 875 part-3 1987, the pressure coefficient given in different tables, corresponding to rectangular building have been obtained taking in to account the effect of terrain category, Risk coefficient, topography.

**NEED FOR STUDY:**
It has been proposed to obtain wind load, by using different codes of practices and wind tunnel testing for a rectangular building model of aspect ratio 1:1.5:7 (Width: Length: Height) for different angles of wind incidence from 0° to 90° for different intervals under uniform flow based on pressure measurement using boundary layer wind tunnel facility at Wind Engineering Laboratory, CSIR-SERC, Chennai. Most international Codes and Standards utilize the “gust response factor” (GRF) approach for estimating dynamic effect on high-rise structures. The concept of GRF was first introduced by Davenport in 1967. The wind generates pressure in windward wall and suction in leeward wall, lateral walls and part of the roof. Wind loading is a complex live load that varies both in time and space. The object of both analytical and physical modeling of wind loading is usually to derive an equivalent static load for design purposes. Such an equivalent load accounts for the variability in time and space of the true wind loads and for dynamic interactions which may occur between the structure and the wind. The detailed gust factor methods for tall slender buildings developed and established in codes and standards offer examples of such processes. Even without a significant resonant response of the structures, these methods illustrate that the size of the building leads to averaging of the smaller gust inputs and hence the net effective load is reduced.

**EXPERIMENTAL SETUP**
The present study was conducted in the boundary layer wind tunnel facility available at CSIR-Structural Engineering Research Centre, Chennai. The original dimension of the tall building for which the study was being conducted is 30m x 45m x 210m. The prototype was modeled to a scale of 1:300 for the pressure measurement study. Hence the dimension of the model is 10cm x 15cm x 70cm with an aspect ratio of 1:1.5:7. The rigid model has been fabricated using acrylic sheets of 10mm and 6mm thickness. Pressure ports were drilled along the circumference of the building model at 8 different levels viz., 7cm, 14cm, 21cm, 35cm, 49cm, 56cm, 63cm and 66.5cm. A total of 192 pressure taps have been provided along the periphery of the building model at the eight levels (24 on each level). Fig. 1 shows the schematic diagram of the model with locations of pressure taps. The instrumented levels are z/H = 0.1, 0.2, 0.3, 0.5, 0.7, 0.8, 0.9, 0.95

![Fig. 1 schematic diagram of model with pressure tap locations](image)
The pressure taps on the model are connected to pressure transducers through PVC tubes with restrictors for the measurement of fluctuating pressures without distortion to the pressure trace. The model has been instrumented with three numbers of Scani-Valve pressure transducers.

**CODE SPECIFICATION:**

**Basic Wind Speed \( V_b \)**

Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 seconds and corresponds to mean heights above ground level in an open terrain. We can get \( V_b \) from IS: 875(Part 3)-1987 and IS 875 finalized draft for 10m height above mean ground level for different zones of the country.

**Design Wind Speed \( V_z \)**

The basic wind speed \( V_b \) for any site shall be obtained from Fig. 1 of IS: 875 (Part 3) and shall be modified to include the following effects to get design wind velocity at any height \( V_z \) for the chosen structure.

1. **Risk level**
2. **Terrain roughness, height and size of structure**
3. **Local topography.**

The design wind speed is given as,

\[
V_z = V_b K_1 K_2 K_3
\]

Where,

- \( V_b \) = Design wind speed at any height \( z \) in m/s
- \( K_1 \) = Risk coefficient
- \( K_2 \) = Terrain, height and structure size factor
- \( K_3 \) = Topography factor

Addition to the above factors IS-875 finalized draft has introduced **importance factor \( k_4 \)** for cyclonic region.

The east coast of India is relatively more vulnerable for occurrences of severe cyclones. On the west coast, Gujarat is vulnerable for severe cyclones. Studies of wind speed and damage to buildings and structures point to the fact that the speeds given in the basic wind speed map are often exceeded during the cyclones. The effect of cyclonic storms is largely felt in a belt of approximately 60 km width at the coast. In order to ensure better safety of structures in this region (60 km wide on the east coast as well as on the Gujarat Coast), the following values of (as recommended in IS 15498) are stipulated as applicable according to the importance of the structure:

| Structures of post-cyclone importance for emergency services (such as cyclone shelters, hospitals, schools, communication towers, etc) | 1.3 |
|---------------------------------------------------------------|-----|
| **Industrial structures**                                    | 1.15 |
| **All other structures**                                     | 1   |

And risk co-efficient according to the IS-875 (part-3) 1987 is given the hourly mean wind speed at heights \( Z \) for different terrains is given below.
Hourly Mean Wind Speed Factor $K_2$ in Different Terrains For Different Heights

| Height (m) | category-1 | category-2 | category-3 | category-4 |
|-----------|-------------|-------------|-------------|-------------|
| Up to 10  | 0.78        | 0.67        | 0.50        | 0.24        |
| 15.00     | 0.82        | 0.72        | 0.55        | 0.24        |
| 20.00     | 0.85        | 0.75        | 0.59        | 0.24        |
| 30.00     | 0.88        | 0.79        | 0.64        | 0.34        |
| 50.00     | 0.93        | 0.85        | 0.70        | 0.45        |
| 100.00    | 0.99        | 0.92        | 0.79        | 0.57        |
| 150.00    | 1.03        | 0.96        | 0.84        | 0.64        |
| 200.00    | 1.06        | 1.00        | 0.88        | 0.68        |
| 250.00    | 1.08        | 1.02        | 0.91        | 0.72        |
| 300.00    | 1.09        | 1.04        | 0.93        | 0.74        |
| 350.00    | 1.11        | 1.06        | 0.95        | 0.77        |
| 400.00    | 1.12        | 1.07        | 0.97        | 0.79        |
| 450.00    | 1.13        | 1.08        | 0.98        | 0.81        |
| 500.00    | 1.14        | 1.09        | 0.99        | 0.82        |

Risk co-efficient $K_{2,z}$ according to the IS-875 (finalized draft) the hourly mean wind speed at heights $Z$ is given by following formula.

$$K_{2,z} = 0.1423 \left( \ln \left( \frac{Z}{Z_{0.1}} \right) \right) \times (z_{0.1})^{0.0706}$$

**Gust Response Factor:**

Gust response is the ratio peak load to the mean load

$$G = \frac{\text{peak load}}{\text{mean load}}$$

Gust response factor is applied if and only if

1. If Building height to least lateral dimension is more than 5.
2. If the building frequency is less than 1 Hz.

| Gust response factor | As per IS-875 (part-3) 1987 | As pr IS-875 Draft |
|---------------------|-----------------------------|------------------|
| $G$                 | 1                           | 1                |
| $+ r \sqrt{B(1 + 0)^2 + S \epsilon + \beta}$ | $+ r \sqrt{g_0^2 B_0(1 + 0)^2 + (H_s g_0^2 SE)}$ |
| Where               |                             | Where             |
| $g_0$ = peak factor |                             | $g_0$ = peak factor |
| $r$ = roughness factor (Fig-8) |                             | $r$ = roughness factor (clause 5.5) |
| $B_0$ = back ground factor (Fig-9) |                             | $B_0$ = back ground factor = |
| $S$ = size reduction factor (Fig-10) |                             | $S$ = size reduction factor = |
| $\epsilon$ = available energy in wind stream (Fig-11) |                             | $1$ |
| $\beta$ = damping coefficient (Table-34) |                             | $1$ |
| $\theta = g_0 r \sqrt{B}$ |                             | $1$ |
| $n$                  |                             | $1$ |
| $\sigma$ = damping coefficient (table-36) |                             | $1$ |

$$\sigma = \frac{1}{(1+70.8 \beta^2)}$$
Pressure measurements were conducted on the instrumented rectangular building model under sub urban terrain condition for different angles of wind incidence (0°, 5°, 10°, 15°, 25°, 33.5°, 45°, 56.5°, 60°, 75°, 87.5° and 90°). The data has been collected for wind speed of about 16m/s. The measured pressure data has been processed to evaluate Gust Response Factor, force/moment coefficients and loads at each level have been calculated and reported in this chapter.

A. Evaluation of Gust Response Factor

Fig. 6.1 shows the different faces of angles considered for the pressure measurement study. The chord length for each face is given as follows: Face A: 0-10cm, Face B: 10-25cm, Face C: 25-35cm, Face D: 35-50cm

![Diagram of different faces of model](image)

B. Gust Response Factor as per IS: 875 (Part-3)

Figure 6.2 to 6.5 are reproduced from the Code of Practice for reference. Based on these graphs the values of Gust Response Factor (GRF) are derived. The distribution of Gust Response Factor values for 0° angle of incidence is shown in Fig. 6.6. It shows that on windward face (Face A), the distributions for levels 1 to level 8 are very well comparable, which indicates that the edge effects are less on the windward face. The Gust Response Factor (GRF) values at level 8 on the side faces (Face B & D) are observed to be significantly more than those for other levels as well as than the leeward face (Face C) and this may be due to vortex shedding phenomenon occurring on the transverse sides and these values are increased at higher levels. The values of Gust Response Factor (GRF) on the windward and leeward faces for all the levels are calculated with the help of graphs as shown below and shown in the Tables 6.1 and 6.2 respectively. Table 6.3 gives the comparison of the windward and leeward Gust Response Factor (GRF) values.

![Graphs of GRF values](image)

Table 6.3 gives the comparison of the windward and leeward Gust Response Factor (GRF) values.
Calculation of Gust Response Factor as per IS-875(part-3) 1987 Provisions

| LEVELS | Z/H | HEIGHTS in cm | \( G_X \) 1987(0°) | \( G_Y \) 1987 (90°) |
|--------|-----|---------------|----------------|------------------|
| 1      | 0.1 | 7             | 1.839          | 1.773            |
| 2      | 0.2 | 14            | 1.929          | 1.829            |
| 3      | 0.3 | 21            | 1.957          | 1.839            |
| 4      | 0.5 | 35            | 1.978          | 1.855            |
| 5      | 0.7 | 49            | 1.991          | 1.860            |
| 6      | 0.8 | 56            | 2.026          | 1.890            |
| 7      | 0.9 | 63            | 2.141          | 1.963            |
| 8      | 0.95| 66.5          | 2.230          | 2.125            |
| 9      | 1   | 70            | 2.403          | 2.224            |
C. Gust Response Factor as per Revised IS: 875 Draft

The distribution of Gust Response Factor (GRF) values for 0° angle of incidence is shown in Fig. 6.7. It shows that on windward face, face A, the distributions for levels 1 to level 8 are very well comparable, which indicates that the edge effects are less on the windward face. The Gust Response Factor (GRF) values at level 8 on the side faces (Face B & D) are observed to be significantly more than those for other levels as well as than the leeward face (Face C) and this may be due to vortex shedding phenomenon occurring on the transverse sides. The values on the leeward face for all the levels are calculated with the help of formula as shown below in Table 6.4. Table 6.5 and 6.6 gives the calculation steps for computing Gust Response Factor (GRF) as per revised IS: 875 draft code for windward and leeward respectively. Table 6.7 gives the summary of Gust Response Factor (GRF) values.

PNG file: Microsoft Word, Microsoft PowerPoint, or Microsoft Excel. Though it is not required, it is recommended that these files be saved in PDF format rather than DOC, XLS, or PPT. Doing so will protect your figures from common font and arrow stroke issues that occur when working on the files across multiple platforms. When submitting your final paper, your graphics should all be submitted individually in one of these formats along with the manuscript.

Formula for calculation of Gust Response Factor value as per revised IS: 875 draft

\[ G = 1 + r \sqrt{\left[ g^2 B_s (1 + \theta)^2 + (H_s g) E + \beta \right]} \]

Where
- \( g \) = peak factor
- \( r \) = roughness factor (clause 5.5)
- \( B_s \) = back ground factor
- \( S \) = size reduction factor
- \( E \) = spectrum of turbulence
- \( \beta \) = damping coefficient (table-36)
LEVELS | Z/H | HEIGHTS in cm | Gx Revised code (0°) | Gy Revised code (90°) 
--- | --- | --- | --- | --- 
1 | 0.1 | 7 | 2.058 | 2.053 
2 | 0.2 | 14 | 2.081 | 2.075 
3 | 0.3 | 21 | 2.107 | 2.099 
4 | 0.5 | 35 | 2.164 | 2.153 
5 | 0.7 | 49 | 2.228 | 2.210 
6 | 0.8 | 56 | 2.261 | 2.237 
7 | 0.9 | 63 | 2.289 | 2.260 
8 | 0.95 | 66.5 | 2.300 | 2.268 
9 | 1 | 70 | 2.306 | 2.274

D. Gust Response Factor (GRF) as per Experiment

Gust Response Factor (GRF) derived from the experiment are shown in the Fig. 6.8. The distribution of Gust Response Factor values for 0°and 90° angles of wind incidence are shown in Fig. 6.9 and 6.10 respectively. It shows that on windward face (Face A), the distributions for levels 1 to level 8 are very well comparable, which indicates that the edge effects are less on the windward face. The Gust Response Factor (GRF) values at level 1 on the side faces, face B & D are observed to be significantly more than those for other levels as well as than the leeward face, face C and this may be due to vortex shedding phenomenon occurring on the transverse sides. The values on the leeward face for all the levels are calculate with the help of Boundary Layer Wind Tunnel as shown below in Table.
| LEVELS | Z/H | HEIGHTS in cm | $G_X$ EXP ($0^\circ$) | $G_Y$ EXP ($90^\circ$) |
|--------|-----|---------------|----------------------|----------------------|
| 1      | 0.1 | 7             | 2.218                | 2.565                |
| 2      | 0.2 | 14            | 2.299                | 2.247                |
| 3      | 0.3 | 21            | 2.053                | 1.983                |
| 4      | 0.5 | 35            | 2.276                | 1.498                |
| 5      | 0.7 | 49            | 2.392                | 1.600                |
| 6      | 0.8 | 56            | 2.106                | 2.074                |
| 7      | 0.9 | 63            | 2.127                | 1.796                |
| 8      | 0.95| 66.5          | 2.110                | 1.590                |
| 9      | 1   | 70            | 2.110                | 1.590                |
CONCLUSIONS

Wind tunnel experiments were conducted on a rectangular building model with plan dimensions 10 cm × 15 cm with a height of 70 cm in the sub urban terrain condition corresponding to a scale of 1:300 for 12 different angles of wind incidence: 0°, 5°, 10°, 15°, 25°, 33.5°, 45°, 56.5°, 60°, 75°, 87.5° and 90° at mean wind speed of about 16m/s. The acrylic model used in this experiment was instrumented with pressure ports on the surface of model distributed in eight levels along the height of model. The levels were denoted as Level 1, Level 2, Level 3, Level 4, Level 5, Level 6, Level 7 and Level 8 corresponding to the heights of z/H= 0.1, 0.2, 0.3, 0.5, 0.7, 0.8, 0.9 and 0.95 respectively. The data has been acquired at a sampling frequency of 800 samples/sec/channel for a sampling duration of 15sec. Static pressure data had been collected by a Pitot tube at height of 70 cm. Corresponding to the height of the model the measured pressure data has been processed to obtain Mean and Standard Deviation (SD) of pressure coefficients and Mean and Standard Deviation (SD) of aerodynamic coefficients using MATLAB program.

Based on the study the following conclusions have been obtained:

- The Gust Response Factor values on the windward side are almost comparable at all levels, while on the leeward face the values are less for Level 8 than other levels. This may be due to the vortex shedding phenomenon and terrain roughness factor.

- The Gust Response Factor values on the leeward side for 0° are less when compared to that of the draft code value on the leeward side for 90°. This difference may be due to the ratio of width parallel to flow to width perpendicular to flow being greater for 0°.

- Mean force value for 0° for Level 5 is always higher than all the other levels due to greater area of projection and edge effect at the ground level. For all other levels, values are almost same with draft code and IS: 875 (part-3) 1987 which indicates that these values are mostly governed by buffeting characteristics of approaching wind flow.

- Mean force value for 0° for Level 5 is always higher than all the other levels due to greater area of projection and edge effect at the ground level. For all other levels, values are greater than with draft code.
and IS: 875 (part-3) 1987 of 0.5 ratio which indicates that these values are not governed by buffeting characteristics of approaching wind flow.

- Standard deviation of force coefficients shows decrease in value with height which shows that these parameters depend on the decrease in turbulence intensity with height.

**REFERENCES**

1) IS : 875 (Part 3) – 1987, “Code of practice for design loads (Other than Earthquake) for Buildings and Structures – Part 3: Wind Loads”, BIS, New Delhi.

2) IS : 875 Revised draft, “Code of practice for design loads (Other than Earthquake) for Buildings and Structures – Part 3: Wind Loads”, BIS, New Delhi.

3) J. Katagiri, T. Ohkuma and H. Marikawa (2001), “Motion-induced wind forces acting on rectangular high-rise buildings with side ratio of 2”, Journal of Wind Engineering and Industrial Aerodynamics 89.

4) J.A. Amin and A.k. Ahuja (2007), “Wind Pressure Distribution on Rectangular Tall buildings of Different Side Ratios”, Proceedings of the Fourth National conference on Wind Engineering

5) M. Keerthana, P. Harikrishna, G. Ramesh Babu, A. Abraham and S. Selvi Rajan (2013), “Experimental validation of Numerical simulation of Wind induced pressures on 2:1 rectangular section under smooth flow”, The eight Asia-Pacific Conference on Wind Engineering

6) Rajeev Gupta and K. Poddar (2007), “Experimental Study on Tall Residential Towers at NWTF”, Proceedings of the Fourth National conference on Wind Engineering.

7) S.k. Verma, A.K. Ahuja and A.D. Pandey (2007), “Wind Pressure Distribution on Structurally Coupled Square Shape Buildings”, Proceedings of the Fourth National conference on Wind Engineering.

8) S.K. Dalui, A.K. Ahuja and V.K. Gupta (2007), “Distribution of Wind Pressure on a Tall Building with Varying Plan Shape”, Proceedings of the Fourth National conference on Wind Engineering.

9) Shinichi Oka, Takeshi Ishihara (2009), “Numerical study of aerodynamic characteristics of a square prism in a uniform flow”, Journal of Wind Engineering and Industrial Aerodynamics.

10) Thepmongkorn, S. Kwok, K.C.S (2002), “Wind-induced responses of tall buildings experiencing complex motion”, Journal of Wind Engineering and Industrial Aerodynamics 90 (2002) 515-526.