ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC) VOL. 17, NO. 3(2016)
PAGES 325-333

AERODYNAMIC COEFFICIENTS FOR A RECTANGULAR TALL BUILDING UNDER SUB-URBAN TERRAIN USING WIND TUNNEL

H. Sarath Kumar[1*], S. Selvi Rajan[2], A. Joseph Andrew[2], G. Ramesh Babu[2], N. Srinivasa Rao[a] and J. Guru Jawahar[1]
[1]Anamacharaya Institute of Technology and Sciences, Tirupati, India
[2]Wind Engineering Lab, CSIR-SERC, Chennai

Received: 8 June 2015; **Accepted:** 29 September 2015

ABSTRACT

This paper deals with the experimental results on wind pressure distributions at all four faces of a rectangular tall building with 1:1.5:7 ratio. The model is made up of acrylic sheet with a geometric scale of 1:300 having plan dimension of 10 cm x 15 cm and height of 70 cm. The model is tested using a Boundary Layer Wind Tunnel (BLWT) facility at CSIR- SERC, Chennai for twelve angles of wind incidence (0°, 5°, 10°, 15°, 25°, 33.5°, 45°, 56.5°, 60°, 75°, 87.5° & 90°) under sub urban terrain condition. Mean pressure coefficients, mean value of drag, lift and torsional coefficients along the wind direction and perpendicular to the wind direction are calculated from the pressure measurement on the model. The value of mean drag coefficient is obtained from IS: 875 for 0° and 90° are 1.4 and 1.5 and experimental values obtained are 1.4 and 2.1. The difference could be due to the effect of boundary layer. The mean values of lift coefficient for 0° and 90° are zero, as expected could be due to symmetry.

Keywords: Boundary layer wind tunnel; wind pressure distribution; sub urban condition; high rise building model; drag; lift and torsional coefficient.

1. INTRODUCTION

Wind engineering deals with the wind characteristics and its effects on buildings and structures. Wind is basically turbulent in nature with randomly varying speed with time and space. Wind causes aerodynamic pressures on the surfaces of the buildings. These wind induced aerodynamic pressures also vary randomly with time and space [1]. With the continuous demand for residential and office space in urban environment, tall buildings are becoming more and more common and these are wind sensitive and prone to large

*E-mail address of the corresponding author: sarathkumar0142@gmail.com (H. Sarath Kumar)

wind-induced vibrations.

The assessment of wind loads on such tall buildings becomes necessary for their design. For the evaluation of wind loads, IS: 875 (Part 3) [2] provides pressure/force coefficients, which are based on wind tunnel studies on building models under uniform flow conditions. Further, these coefficients are available for only selected geometries and for selected angles of wind incidence, viz. 0° and 90°, i.e., with wind normal to any one face of the building.

The present model has an aspect ratio of 1:1.5 in plan, representing a prototype building of 210 m tall high-rise building. The pressure/force coefficients for tall building are observed to be different, both in magnitude and has variation along the height of the building.

During the past decades, pressure distribution on a rectangular model has been investigated by many researchers through wind tunnel test, Q.S. Li *et al.* [3], Anjana and Selvi [1], Xie and Gu [4]. A combined wind tunnel and full-scale study of wind effects on the super tall building in JinMao in Shangai was conducted in the wind tunnel test. Mean and fluctuating force components on the building model for the cases of an isolated JinMao Building and the building with existing surrounding condition were measured by a high-frequency force balance technique under suburban and urban boundary layer wind flow configurations. Building with varying plan shape was studied in detail using wind tunnel studies by Kim et al. [5]. Simple quasi-static treatment of wind loading, which is universally applied to design of typical low to medium-rise structures, can be unacceptably conservative for design of very tall buildings, Cook [6], Holmes [7], Simiu [8]. In the present study, the effect of aspect ratio of 1:1.5:7 and wind direction, on wind pressure distribution of rectangular high-rise building model at different levels are investigated experimentally. Instantaneous wind pressures are measured at pressure points on all faces and values of mean pressure coefficients are evaluated from the experimentally obtained pressure trace.

2. TEST SETUP

2.1 Wind tunnel

The experiment are carried out using Boundary Layer Wind tunnel (BLWT) facility of CSIR-SERC, Chennai, under sub urban condition. The wind tunnel has a test section of 18 m long with a cross sectional dimension of 2.5 m (width) x 1.8 m (height). Model is placed on the downstream side of the test section. Angle of wind incidence (θ) 0^{o} to 90^{o} viz. 0°, 5°, 10°, 15°, 25°, 33.5°, 45°, 56.5°, 60°, 75°, 87.5° & 90° are tested.

2.2 Simulation studies

Simulation of the characteristics of the natural wind inside the tunnel to a reduced scale is the foremost and important step in any wind tunnel experiment. The tall rectangular building model has been tested under simulated boundary layer flow condition corresponding to sub urban terrain. The mean velocity profile with a power law coefficient of 0.205, turbulence intensity profile and spectrum of horizontal wind speed corresponding to an sub-urban terrain conditions were simulated to a scale ratio of 1:300.

2.3 Details of model

The experimental model is made up of acrylic sheet (6 mm thickness) with a geometric scale of 1:300. The model is instrumented with 192 numbers of pressure taps at eight different levels denoted as Level 1, Level 2, Level 3, Level 4, Level 5 Level 6, Level 7 and Level 8 corresponding to z/H ratio of (where H is height of the model) 0.10, 0.20, 0.30, 0.50, 0.70, 0.80, 0.90 and 0.95, respectively, as shown in Fig. 1. These pressure ports are placed as near as possible to the edges of the faces to capture the high pressure variation at the corners, Fig. 2.

3. INSTRUMENTATION

The surface pressure measurements were carried out using Electronic Pressure Scanners (EPS) and a high-speed 32-bit Online Data Acquisition (DAQ) system. A total of eight EPS with 32 ports have been deployed. The raw data was acquired through a windows-based real time embedded system equipped with 32-bit online DAQ board. The time series of the pressure signals from all the EPS were acquired and processed to obtain the mean, maximum and minimum values of pressure coefficients for various ports on the building model. The raw data were acquired for 15 seconds at a sampling rate of 800 samples/second/channel, at each angle of wind incidence. Thus, a total of 12000 samples were acquired at each pressure port and for each of angle of wind incidence. The mean wind speed measured at the height of the model using Pitot tube is about 16 m/s.

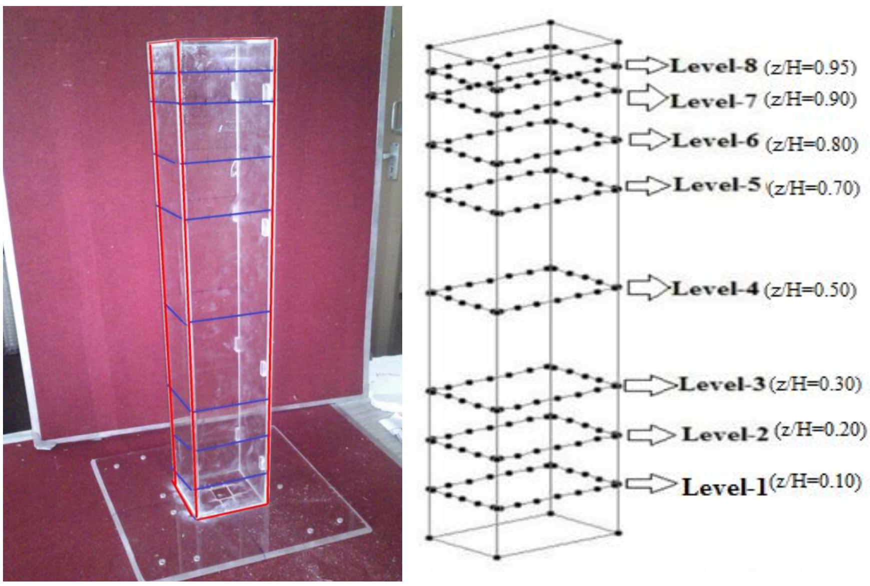

Figure 1. Schematic 3-D diagram showing instrumented levels

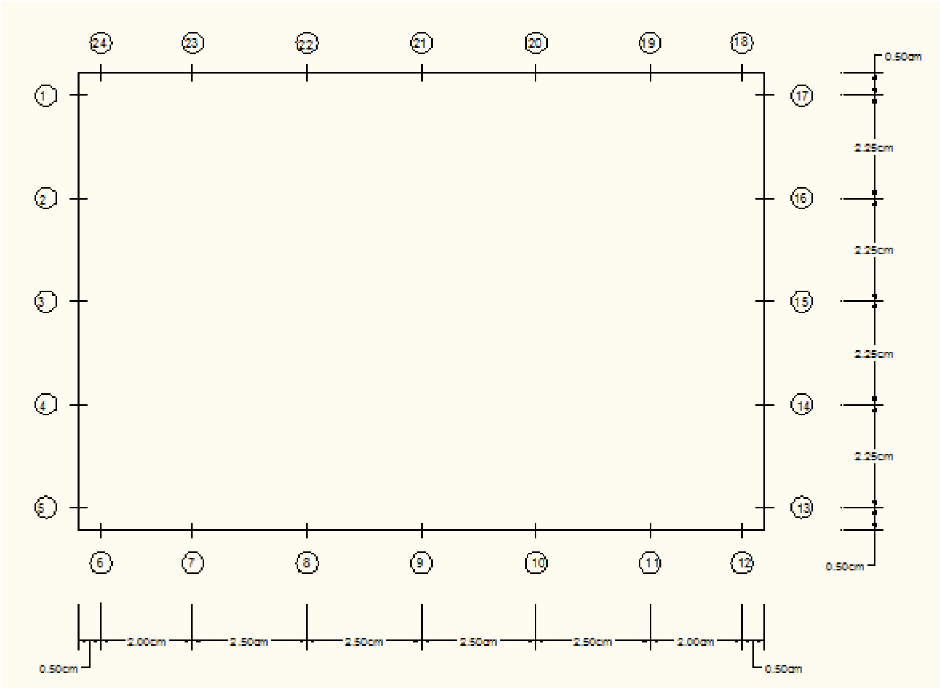

Figure 2. Pressure tap locations along the perimeter of the rectangular cross section model with tributary width (typical level)

4. DATA ANALYSIS

The measured pressure data has been processed to evaluate the pressure and force coefficients.

4.1 Pressure coefficient

The measured pressure data has been processed to obtain pressure coefficients as given below [2].

$$\boldsymbol{C_P = \frac{P}{P_{ref}}}$$

Where, p = measured pressure on the building model surface – static pressure (obtained from pitot tube)

p_{ref} = reference pressure derived from power-law coefficient of 0.205 = 0.5 ρ U_z^2

Where, ρ = density of air

U_z = mean wind velocity at individual level, z, based on variation of velocity profile

4.2 Force coefficient

The measured pressure data has been integrated with tributary widths (Fig. 2) corresponding to each pressure port and resolved in the direction of wind and perpendicular to the direction of wind to obtain drag (F_d) and lift (F_l) forces per unit height on the building model. These evaluated forces have further been processed to obtain drag (C_d) and lift (C_l) force coefficients as given below [2]:

$$C_d = \frac{F_d}{P_{ref}\, B'}$$

$$C_l = \frac{F_l}{P_{ref}\, D'}$$

where, B' = projected width normal to wind direction as shown in Fig. 3.
where, *D'* = projected width parallel to wind direction, as shown in Fig. 3.

The torsional moment per unit height, T, for all angles of wind incidence with respect to the origin, for all the levels has been evaluated using the measured pressure along with lever arms at each level. The torsionalmoment coefficient (C_T) for each level has been evaluated using the following expression [2]:

$$C_T = \frac{T}{P_{ref}\, B'\, D'}$$

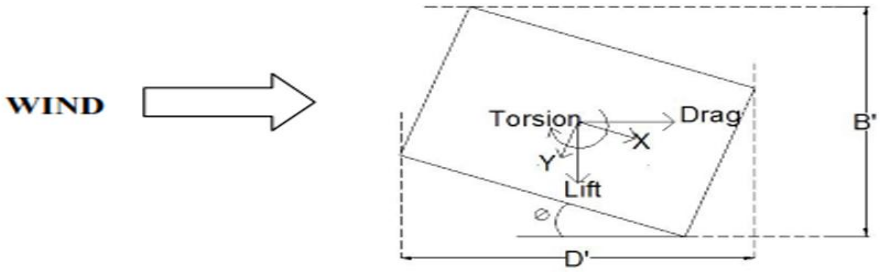

Figure 3. Details of projected width and orientation of various forces with reference to the body fixed axis

Figure 4. Typical views of instrumented building model inside the wind tunnel for (a) 0° and (b) 56.5°

5. RESULTS AND DISCUSSIONS

5.1 Mean pressure coefficients

Typical photographs showing the model inside the wind tunnel for two different angles of wind incidence are shown in Fig. 4. The mean pressure coefficients from all 192 pressure taps were obtained and the distribution of pressure coefficients along the circumference of the building model was studied.

Mean pressure coefficient depends on the shape of the bluff body and variation of the flow pattern around the structure at different angles of wind incidence. So, when flow impinges from different wind angles, the variation of pressure coefficients will follow a different trend. The C_p values for all the twelve angle of wind incidence at all faces have been discussed below, in addition to values of $C_{d,}$ C_l and C_T.

The distribution of mean C_p along the ports of the model at different levels for 0° is shown in Fig. 5. The mean C_p distribution pattern for all the levels on the wind ward face (Face A, chord length 0 to 100mm) are observed well comparable for θ of 0°, which shows the positive values on the wind ward face for θ of 0°,5°,10°,15° for all the levels. Whereas, the suction pressure coefficients on the side & leeward faces are observed to be negative values for θ of 0°,5°,10°,15° for all the levels. The values of suction pressure coefficients at all levels on the side faces, Face B & D are observed to be relatively high when compared with leeward face, Face C at for θ of 0°,5°,10°,15° for all the levels. This may be due to wake occurring on the transverse side. The values on the leeward face at all the levels are almost same which suggest that here the wake turbulence effect is negligible.

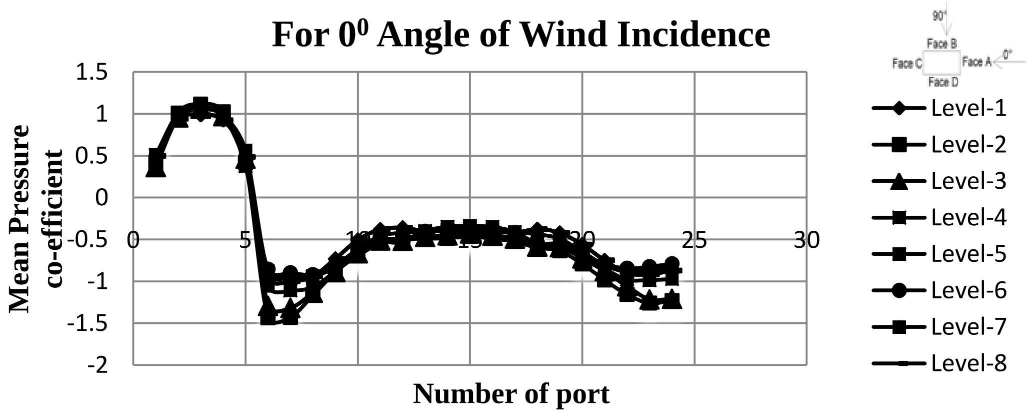

Figure 5. Distribution of Mean C_p along chord length for θ of 0°

The distribution of mean C_p along the ports of the model at different levels for 56.5° gives the largest projected area of the model which is shown in Fig. 6. The mean C_p distribution for all the levels excluding Level 8 on the wind ward face (Face B, chord length between 100 and 250 mm) are observed to be well comparable which indicates that the edge effects are significantly pronounced for Level 8 (35 mm from top) on the wind ward face (Face B width 150mm) for θ of 75°,87.5° & 90° rather than on the wind ward face (Face A, chord length 0 to 100mm) for θ of 0°,5°,10°,15°, owing to tripping effect of 3-demensional flow above the roof.

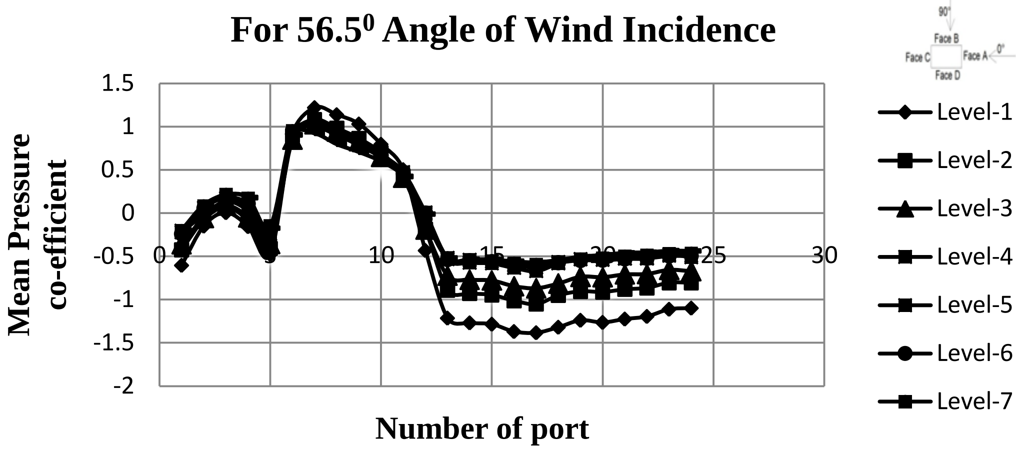

Figure 6. Distribution of mean C_p along chord length for θ of 56.5°

The mean suction pressure coefficient on the leeward side for 0° (Face C) -0.63 is more or less same when compared to that of the mean suction value on the leeward side for 90° (Face D) -0.65. The suction pressure coefficients of face B, C & D for θ of 0° & 5° have also observed to be same distribution of Cp. The Suction pressure coefficients of Face C & D for θ of 15°, 25, 33.5°,45°, 56.5° & 60° have a similar distribution of Cp.

5.2 Mean drag coefficients

The relative difference in mean C_d values corresponding to different levels is observed to be less than 20%. It is observed that the variation of mean Cd for 0° to 15° are decreases gradually, and for 25° to 60° increases gradually and for75° to 90° the pattern is gradually increase comparing to 25° to 60° values . Levels 5 and 6 have higher values compare to other levels. The average value of the mean C_d from the experiment are observed to be 1.4 and 2.1 whereas the values obtained from IS: 875(Part-3) are 1.4 and 1.5 for θ of 0° and 90°, respectively.

5.3 Mean lift coefficients

The difference in mean C_l among all the levels can be divided into three different regions viz. 0° to 10°, 10° to 75° and 75° to 90°.It can be seen that the mean lift coefficient values for 0° and 90° are zero as expected due to symmetry in the geometrical dimension. The C_l values increases by negative to positive in the range of angle from 10° to 75° and the maximum positive value is obtained at 60° to 75° range for all the levels. Further, the positive value suddenly drops in the region from 75° to 90°.

5.4 Mean torsional coefficients

The maximum value is obtained at 15° and minimum value is obtained at 60°. The maximum value of torsional coefficient is +0.15 and the minimum value is -0.25. These values of force coefficients can be directly used for the purpose of design.

6. CONCLUSIONS

Wind tunnel experiments were conducted on a rectangular building model having plan dimensions 10 cm × 15 cm with a height of 70 cm under sub urban 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 16 m/s. The acrylic model used in this experiment was instrumented with pressure taps on the surface of model distributed at eight levels along the height of model. Instantaneous pressure data had been collected by a pitot tube placed at height of 70 cm. The measured pressure data has been processed to obtain mean and pressure coefficients and by integrating the pressure, force coefficients are derived using MATLAB program, corresponding to the respective reference height.

Based on the study the following conclusions have been derived:

- The mean pressure coefficient values on the wind ward side (Face A) are almost comparable at all levels.
- The mean suction pressure coefficient on the leeward side for 0° is more or less same for all the levels when compared to that of the mean suction value on the leeward side for 90°, could be due to symmetry in the geometry.
- Mean pressure coefficients values for Level 8 are always lower than all the other levels due to wake turbulence occurring from the effect of 3-dimensional flow past over the roof and edge effect at top levels of the model.
- The value of mean drag coefficient is obtained from IS: 875 for 0° and 90° are 1.4 and 1.5 and experimental values obtained are 1.4 and 2.1. The difference could be due to the effect of boundarylayer.
- The mean values of lift coefficient for 0° and 90° are zero, as expected could be due to symmetry.
- The torsional moment coefficient have a maximum value of +0.15 at 15° and minimum value of -0.25 at 60°.

Acknowledgements: This study was carried out at the CSIR-Structural Engineering Research Centre, Chennai. The authors wish to thank the staff of Wind Engineering Laboratory, SERC, for their cooperation extended in conducting the wind tunnel tests. This paper is being published with the kind approval of Director, CSIR-SERC, Chennai.

REFERENCES

1. Anjana SJA, Selvi RS. Estimation of design wind forces for a tall building based on wind tunnel study, *International Journal of Structural and Civil Engineering Research*, **3**(2014) 38-44.
2. 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, 1989.
3. Li QS, Fu JY, Xiao YQ, Li ZN, Ni ZH, Xie ZN, Gu M. Wind tunnel and full-scale study of wind effects on China's tallest building, *Engineering Structures*, **28**(2006) 1745-58.

4. Xie ZN, Gu M. Simplified formulas for evaluation of wind-induced interference effects among three tall buildings, *Journal of Wind Engineering and Industrial Aerodynamics*, **95**(2007) 31-52.
5. Kim YC, Tamura Y, Tanaka H, Ohtake K, Bandi EK, Yoshida A. Wind-induced responses of super-tall buildings with various atypical building shapes, *Journal of Wind Engineering and Industrial Aerodynamics*, **133** (2014) 191-9.
6. Cook NJ. *The Designer's Guide to Wind Loading of Building Structures: Part 2 - Static Structures*, Building Research Establishment, Butterworth's, London, 1990.
7. John D. Holmes. *Wind Loading of Structures*, 1st Edition, New York, 2001.
8. Simiu E, Scanlan RH. *Wind Effects on Structures-Fundamentals and Applications to Design*, John Wiley & Sons, New York, 1996.