Chapter 4
Distribution of Wind Pressure Around Different Shape Tall Building

Amlan Kumar Bairagi and Sujit Kumar Dalui

Abstract Wind effect is the most interesting and important parameter for different structural elements like sidewall, roof and around the building also. A number of researchers were presented their thoughtful inspections on different, unconventional tall buildings due to wind issue. The present study focuses on the pressure distribution around the square and setback tall buildings due to wind load. The models have single and double type setback at different elevations. The pressure calculation was conducted by analytical study of plane and highlights the pressure fluctuation. Some amount of pressure bulb was observed on the leeward side of setback model, which mean the increase of suction on that particular region. The excessive amount of suction envelop recognized at the top roof of setback model compared to square model.

Keywords Setback model · Pressure coefficient · Tall building

4.1 Introduction

According to architectural point of view, setback tall building always robbed the feather of elegance. Environmental effects like wind also claim to reveal around the building and its surrounding region. Mendis et al. [1] enumerated simple quasi-static treatment of wind load on tall buildings. Irwin et al. [2] established the energy in tall building increased with the increase in the height of a tall building. Kim et al. [3] carried out for three aeroelastic, tapered, tall building models with taper ratios of 5, 10 and 15%. Kim and Kanda [4] focused the wind pressure on the setback and tapered shape tall buildings in both static and dynamic for different flow condition. Tanaka et al. [5] studied the aerodynamic response due to wind and

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flow characteristics of tall buildings with thirty-four numbers unconventional shapes in wind tunnel test and CFD simulation. Bairagi and Dalui [6, 7] evaluated the interference effects, pressure coefficients and optimum distance on parallel high-rise buildings for different orientation using CFD. Mukherjee and Bairagi [8] studied the '*N*' plan shape tall building and evaluated the pressure, force and velocity around the model. Mendis et al. [9] discussed a number of problems, mistakes and solutions for CFD wind analysis. Baby et al. [10] presented an overview of the optimal external shape and structural system for tall buildings subject to aerodynamic loads and the response of a structure through a comprehensive investigation of the building. Xu and Xie [11] focused the aerodynamic optimization of tall buildings and best compromise wind issues. Roy and Bairagi [12] discussed wind pressure and force coefficients on stepped tall building at different geometrical shape placed on above to each other like rectangular, square and triangular. Tamura et al. [13] conferred pedestrian level and aerodynamic wind characteristics of super-tall buildings with various configurations and conducted the dynamic wind response. Mittal H et al. [14] investigated the effect of building shape (square, tapered and setback) and wind direction on pedestrian level. Bairagi and Dalui [15] discussed comparison of aerodynamic coefficients between two setbacks tall buildings due to wind load. Namchu et al. [16] highlighted the pressure coefficients on tall chimney for different wind terrain condition. Bairagi and Dalui [17] highlighted the aerodynamic effects and power spectral density on setback roof compare to the top roof of setback model. Bairagi and Dalui [18] focussed on pressure coefficient on square and both side setback tall building and concluded the pressure coefficient of the setback roof was 205.4% more effective than the top roof. The present study discussed the pressure coefficient around the square and the setback tall building at different plane for along and across wind condition.

4.2 Description of Model

Different types of unconventional modes were analyzed by the wind tunnel test and the test is expensive. To overcome this situation, computational fluid dynamics (CFD) is a widely acceptable simulation process of wind analysis. This study based on this type of simulation. Three sets of models, namely S1, S2 and S3, are used in this study. All the models have l/b ratio is 1 and the h/b is 2. The S1 model has same plan area along height, but S2 and S3 changed their plan area $h/2$ and $h/3$ level from the ground. The S2 model has 20% setback at $h/2$ level and S3 has 10% setback at each $h/3$ and $2h/3$ level. The attacking wind angles are from 0° to 180° at 15° interval. The considered h, b and l are 500 mm, 250 mm and 250 mm, respectively (see Fig. 4.1).

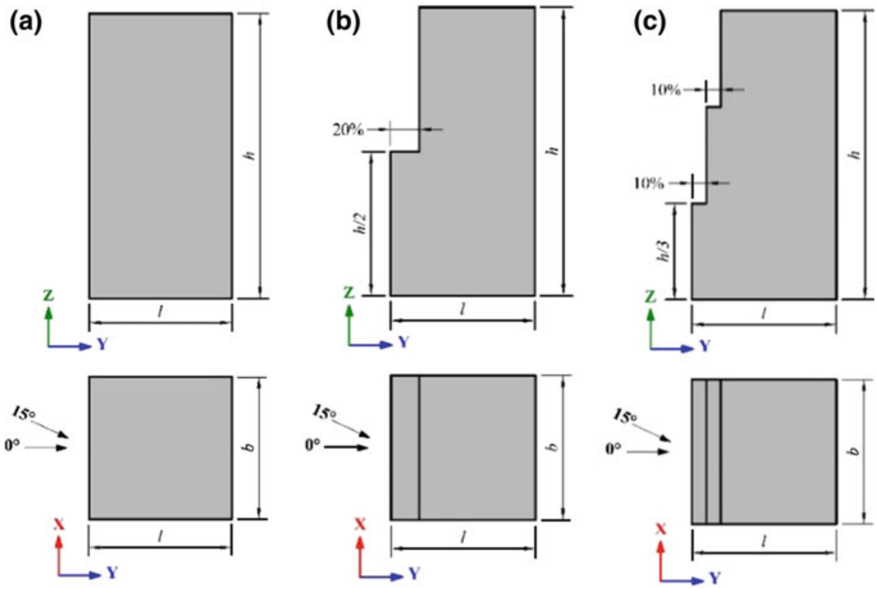


Fig. 4.1 Elevation and plan of model. **a** S1, **b** S2 and **c** S3

4.3 Analytical Domain and Mesh

The three models were placed inside the domain for CFD simulation. The boundary of domain has been set 5*H* from inlet and both sidewalls and 6*H* from the base of model as stated by Frank et al. [19], Revuz et al. [20] (see Fig. 4.2a). Here, *H* is the height of the analytical model. The boundary conditions for different walls and different non-dimensional parameters are stated in Table 4.1.

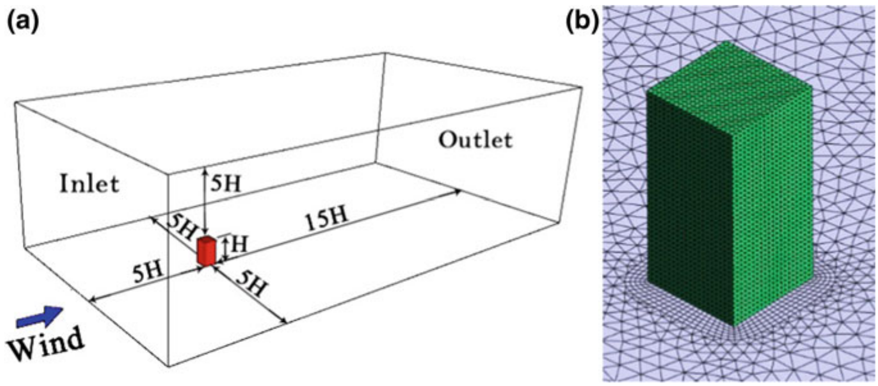


Fig. 4.2 **a** Computational domain for CFD simulation. **b** Mesh detail of square model

Table 4.1 Boundary conditions and non-dimensional parameters

Condition	Parameters
Flow regime	Subsonic
Turbulence intensity	Low (1%)
Method of mesh	Tetrahedron
Inlet	$U/U_H = (Z/Z_H)^\alpha$
Relative pressure of outlet	Zero
Sidewall	Free slip
Model wall	No slip
Air temperature	25 °C
Model wall roughness	Smooth wall
Velocity of wind	10 m/s
Ground roughness (α)	0.133
k	$3/2\ (U_{\mathrm{avg}} \times I)^2$
ε	$C_\mu^{(3/4)} \times \left[k^{(3/2)}/l\right]$

Where U is the horizontal wind speed at an elevation Z; U_H is the speed at the reference elevation Z_H; which was 10 m/s; Z_H is 1.0 m; k is the kinetic energy of turbulence and ε is the dissipation rate; U_{avg} is the mean velocity at the inlet; I is the turbulence intensity; l is the turbulence length scale; C_μ is the turbulence model constant, i.e., 0.09. The mesh detail of the S1 model (see Fig. 4.2b).

4.4 Comparison with Analytical Study

The analytical study validated with the experimental study of square model discussed by Kim and Kanda [21]. The experimental study was conducted in Eiffel-type wind tunnel at the University of Tokyo. The experimental model had $L = 100$ mm, $B = 100$ mm, $H = 400$ mm and length scale 1/400 with $\alpha = 0.13$. The blockage ratio was 1.2% with wind flow at 6.5 m/s. The simulated square model has the same aspect ratio and has same non-dimensional parameters adopted by the author. The validation of turbulence intensity and mean wind speed as shown in Fig. 4.3.

4.5 Results and Discussion

Pressure contour around the models S1, S2 and S3 are presented in this study. The pressure distribution on *YZ* and *XZ* plane has been studied for along the wind and across wind conditions. Figure 4.4a shows the wind pressure contour at *YZ* plane and at the center of model for along wind condition for S1 model. For along wind

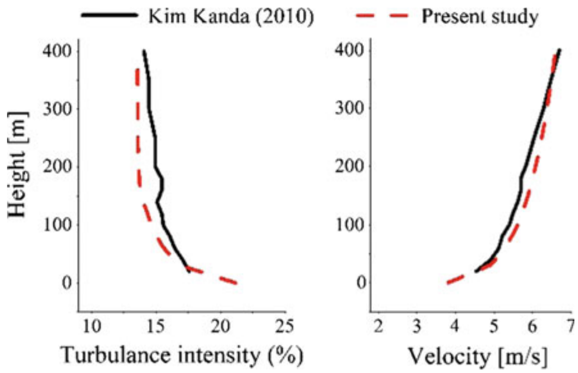


Fig. 4.3 Validation of turbulence intensity and mean wind speed of square model with Kim and Kanda [21] and present study

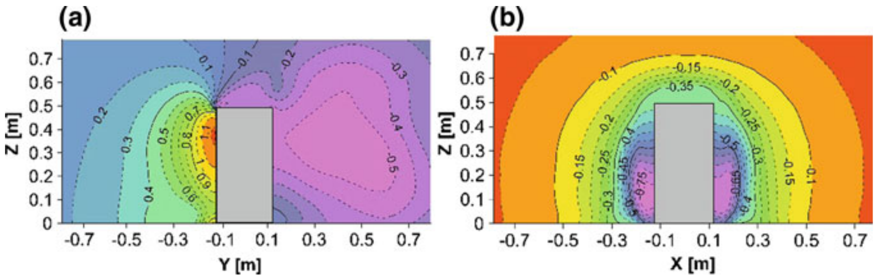
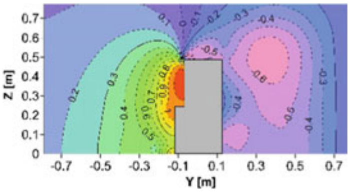
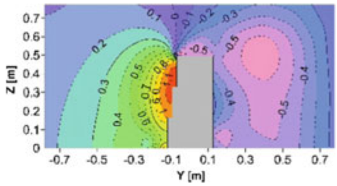
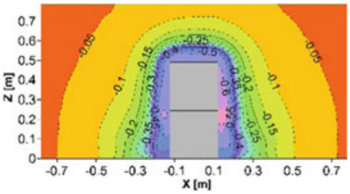
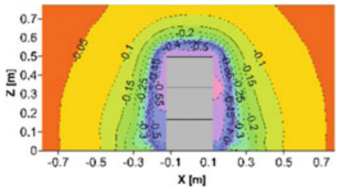
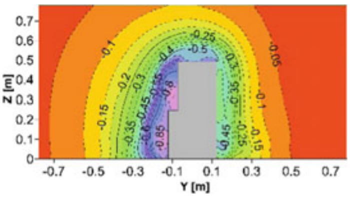
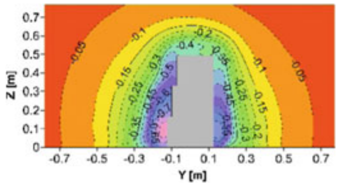
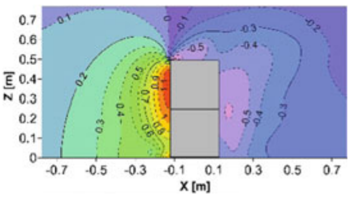
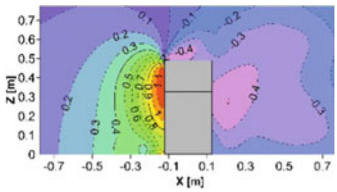
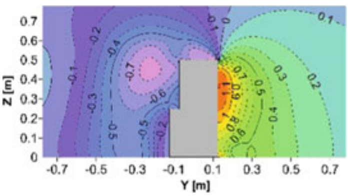
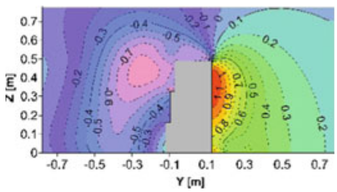
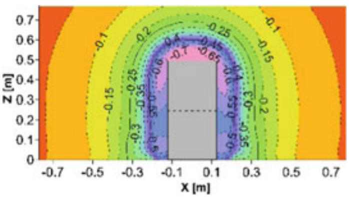
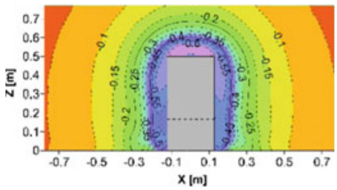


Fig. 4.4 Wind pressure coefficient around S1 model for **a** along wind condition, **b** across wind condition

condition, the windward face encircled by the ranged from 1.2 to 0.1 and the top and leeward faces ranged from −0.1 to −0.5. In this connection, the excessive amount of suction shown in purple color at −0.5 on leeward zone. Similarly, the pressure contour at the *XZ* plane and the center of the model for across wind conditions showcased in Fig. 4.4b. For this condition, the pressure envelope ranged from −0.1 to −0.75 and the values are high suction. A comparative study also carried out between S2 and S3 models on *YZ* and *XZ* plane for 0°, 90° and 180° wind incidence angles as shown in Table 4.2. Mou et al. [22] found the large amount of pressure difference on leeward surface further established the negative and positive pressure around the building depends upon the width of the building. No special change has been focused for along wind condition for 0° wind on *YZ* and *XZ* plane except the bulb region on the leeward face of S2 and S3 models compared to S1 model. However, large amounts of pressure variant take place on opposite sides of the setback face on the *YZ* plane for 90° wind angle. S2 model has line −0.85 near the top and bottom of setback zone. However, S3 model has the same line at the lowest part of setback zone. A beautiful violet color zone (−0.7) observed between *Y* ranges from 0.1 to 0.2. Simultaneously, model S2 has a light green color (−0.45) on that particular Y range. For along wind

Table 4.2 Wind pressure coefficient around models S2 and S3 at *YZ* and *XZ* plane for 0°, 90° and 180° wind angle

Wind angle	Pressure plane	S2	S3
0°	*YZ*		
	XZ		
90°	*YZ*		
	XZ		
180°	*YZ*		
	XZ		

condition on the *XZ* plane has a pressure contour line −0.3, which covered in most of the area for the S3 model. However, S2 model has a line range from −0.2 to −0.6. Therefore, it is clear that the large amount of suction developed in the leeward region due to decrease of number of setback roof for 90° wind angle. For 180° wind angle, the windward face has line 1.2 and −0.1 at the leeward face of S2 model. On the other hand, the S3 model has a large area of line −0.6 on the leeward side, but no lines of 1.2 are visible at windward face. The *XZ* plane for 180° wind angle has large amount of suction on the top roof at line −0.7 for S2 model and line −0.6 at the rooftop of S3 model. It is clear that the pressure on top of the setback roof has maximum suction (−0.7) for S2 model compared to S1 model (−0.35).

4.6 Conclusion

The present paper focused on the wind pressure variation around the square and different setback models for along the wind and across the wind conditions. The following conclusions are made after a lot of analytical simulations.

- The leeward pressure is maximum on S1 model for 0° wind of line −0.5. A bulb region created on the leeward side of S2 and S3 models of line −0.4.
- The excessive amount of suction matured at leeward side due to decrease of number of setback roof for 90° wind angle.
- The pressure coefficient is quite large for along wind condition on S2 model for 180° wind angle.
- The pressure on the rooftop of S1 model has maximum compared to other two models.

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