

Chapter 3

Spectral Density at Roof of Setback Tall Building Due to Time Variant Wind Load



Amlan Kumar Bairagi  and Sujit Kumar Dalui 

Abstract Turbulence due to wind around conventional square shape bluff body creates the pressure difference of different planes of the body. Nevertheless, the unconventional bluff body creates a large amount of turbulence around its face and on the roof region. This paper highlights the pressure variation of top roof and setback roof of square and setback tall building with respect to different time domains. The frequency of the roof due to wind also affects the pressure fluctuation on neighbor faces. Most of the pressure fluctuation develops at 0.06 s which forms the initial time and maximum pressure difference occurred at the setback roof for along wind condition. The present study concentrated on the fluctuation of time-dependent pressure between top and setback roof to take special care during the design.

Keywords Spectral density · Setback tall building · Roof pressure

3.1 Introduction

Velocity of wind changes continuously with the building height. Similarly, the pressure around the building always fluctuates with respect to time, and therefore, the frequency and the spectral density change abruptly. The turbulence around the conventional tall building changes its vortex for the unconventional setback tall building. The turbulence, pressure, frequency and spectral density on the top roof of the building have some amount of difference in setback roof of the building. A number of past studies were highlighted the wind effect on different unconventional tall buildings. Kim et al. [1] studied the tapered tall building aeroelastic models with different taper ratios. Kim and Kanda [2] highlighted the static and dynamic wind pressure distribution on tapered and setback tall building. Tanaka et al. [3] presented the wind flow

A. K. Bairagi (✉) · S. K. Dalui
Department of Civil Engineering, Indian Institute of Engineering Science and Technology,
Shibpur, Howrah, India
e-mail: bairagiak@gmail.com

S. K. Dalui
e-mail: sujit_dalui@rediffmail.com

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characteristics on thirty-four number of tall buildings with analytical and experimental tools. Bairagi and Dalui [4, 5] estimated the optimum distance where interference effects nullify and principal building behave like isolate building. Mukherjee and Bairagi [6] focused the wind behavior around 'N' plan shape tall building by CFD analysis. Mendis et al. [7] developed the solution of different mistakes of CFD analysis. Xu and Xie [8] evaluated the optimization of aerodynamic effect on tall building and perfect fitted wind angle. Roy and Bairagi [9] presented the wind-induced pressure and force variation on setback tall building with different geometrical shapes. Tamura et al. [10] estimated the dynamic response on tall building for different configurations. Elshaer and Bitsuamlak [11] optimized the opening of tall building to reduce the wind-induced load. Bairagi and Dalui [12] compared the different aerodynamic parameters between various setback tall buildings. Namchu et al. [13] highlighted the pressure coefficients on tall chimney for different wind terrain conditions. Bairagi and Dalui [14] highlighted the aerodynamic effects and power spectral density on setback roof compared to the top roof of setback model. Mukherjee and Bairagi [15] studied the interference effect on square plan shape tall building due to setback model for different orientations. Rajasekarababu and Vinayagamurthy [16] studied the experimental analysis of sharp edge setback model of aspect ratio 1:5. The study described the hybrid turbulence models, which used delayed detached eddy simulation (DDES) and improved delayed detached eddy simulation (IDDES) and introduced the treatment of wall for roughness parameter combination.

The present study is based on computational fluid dynamics (CFD) simulation and highlights the variation of pressure on top roof and the setback roof on different time intervals and the spectral density of that particular region for along and across wind conditions. The considered models are square plan shape bluff body and a setback tall model of the setback roof on both sides and at half of the height from base of the model.

3.2 Model Detail

Two numbers of analytical models have been placed inside the domain and analyze the spectral density and pressure variations on the top surfaces of the models. The square (SQ) model has length (L): breath (B) which was 1 and height (H): length (L) which was 2. A setback (SB) model also considered with the same aspect ratio of SQ model. The setback distance used 20% of the length of the model and placed on both sides and half-height of model from base. As the setbacks are equally distributed, the total area of setback roof and top roof of the SB model compared it to SQ model. The wind incidence angels are considered from 0° to 90° at 15° intervals (see Fig. 3.1).

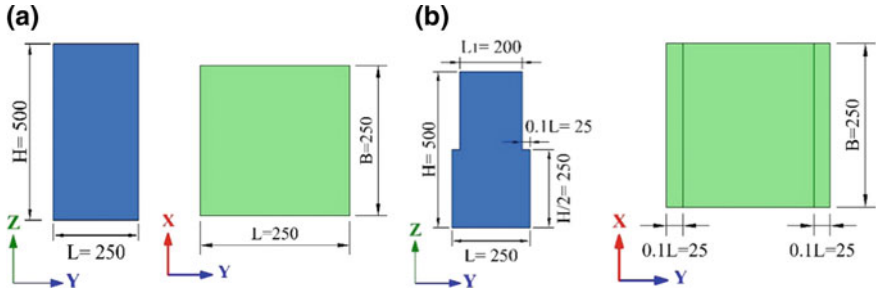


Fig. 3.1 Model details for a SQ and b SB

3.3 Analytical Domain and Mesh

The computational fluid dynamics (CFD) is a widely accepted method of for the analytical application of wind engineering. The present study based on this CFD simulation. The models are placed inside the analytical domain at $5H$ from the extreme edge of the model to the inlet and sidewalls of the domain and $15H$ and $6H$ for outlet and top of model, respectively, as stated by Frank et al. [17] (see Fig. 3.2a). The height of analytical model is presented by H . The boundary conditions are free slip for the sidewall of domain, i.e., $U_{wall} = 0$, $\tau_w = 0$ and no slip for model wall, i.e., $U_{wall} = 0$. Here, U_{wall} is velocity normal to the wall, and τ_w is the wall shear stress. The power law is introduced in this study to estimate the velocity around the experimental model as explained in SP:64 (S&T) [18] as shown in Eq. 3.1.

$$U/U_H = (Z/Z_H)^\alpha \tag{3.1}$$

where U represents the horizontal wind speed at an elevation Z ; U_H represents the 10 m/s speed at the reference elevation Z_H ; α represents the power law index 0.133 for terrain category 2; and Z_H is 1.0 m. The kinetic energy of turbulence and its

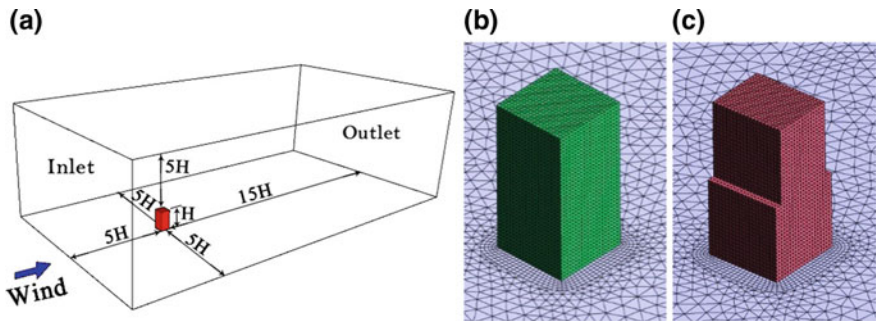


Fig. 3.2 a Computational domain for CFD simulation; b mesh detail of SQ model; and c mesh detail of SB model

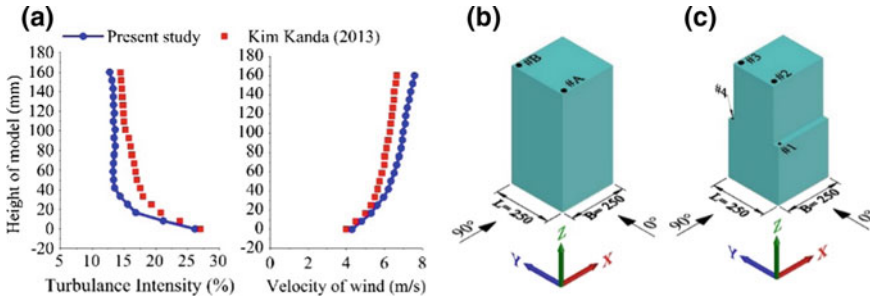


Fig. 3.3 a Validation of velocity and turbulence intensity of wind between present studies with Kim Kanda [2]; b pressure tapping points on the roof of SQ; and c for SB

dissipation rate at the inlet section are calculated according to Eq. 3.2.

$$k = 1.5(U_{avg} \times I)^2 \text{ and } \varepsilon = C_{\mu}^{0.75} \times [k^{1.5}/l] \tag{3.2}$$

where U_{avg} represents the mean velocity at the inlet; I represents the turbulence intensity; and l denotes the turbulence integral length scale. The $k - \varepsilon$ turbulence model has air temperature 25 °C with tetrahedron meshing (see Fig. 3.2a, b).

3.4 Comparison with Analytical Study

This analytical study also validated with the experimental study of setback model discussed by Kim and Kanda [2]. The experimental model was 40 m × 24 m × 160 m with 8 m setback in 1:400 scale was a study in 1.8 m × 1.8 m × 12.5 m wind tunnel at the University of Tokyo. The simulated model has the same aspect ratio with the same boundary conditions. The velocity profile and turbulence intensity of present study validated with Kim and Kanda [2] as shown in Fig. 3.3a.

3.5 Results and Discussion

Pressure variation of unconventional rooftop is quite different compared to the conventional rooftop of tall building. In this study, the setback model has three numbers of roof. One is top and another two are setback at half of the building height. The attacking wind creates a huge amount of turbulence near the setback roof and surrounding surface of the model. Bairagi and Dalui [19] conferred the variation of spectral density on the setback roof of tall model. The authors were considered an unconventional setback model which had setback on one side. This study is discussed the pressure variation, and the power spectral density calculation is carried out in

this study for along the wind and across the wind conditions. The pressure tapping points are considered at the edge of the roof of SQ and SB model (see Fig. 3.3b, c). The points #A and #B are located at 0.04 L from the edge of top roof of SQ model. Similarly, for the SB model has #1, #2, #3 and #4 are the pressure tapping points. The points #1 and #4 are situated at 0.15L from the edge and #2 and #3 are 0.24 L and 0.96 L, respectively, from the edge.

3.5.1 Pressure-Transient Analysis

The change of pressure over time is the pressure-transient analysis. This study highlighted the pressure fluctuation at the rooftop of SQ and SB model followed by Eq. 3.3.

$$C_p(t) = [P(t) - P_0]/(0.5\rho V_z^2) \tag{3.3}$$

where $P(t)$ is the pressure at time t , P_0 is the reference static pressure of that particular point, ρ is the density of air and V_z is the mean velocity at the height of the roof. Here, negative sign denotes suction, and positive sign presents the pressure.

Pressure coefficient at top roof and setback roof with respect to time for along and across wind conditions has been plotted (see Fig. 3.4). From the figures, it is clear that the high amount of pressure fluctuation is developed at first 0.06 s. The maximum pressure coefficient (3.52) observed at the beginning of the flow of the SB model at the tapping point #3 and maximum suction (-1.8) noticed at 1.43 s at tapping point

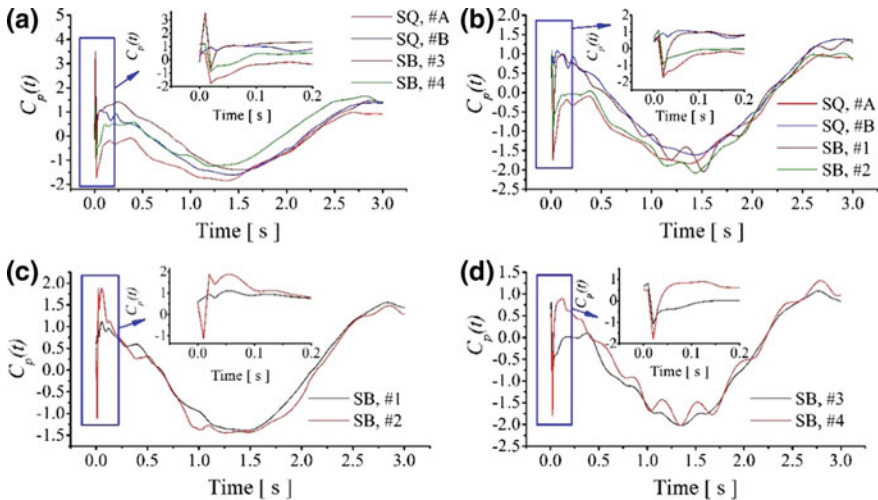


Fig. 3.4 Comparison of pressure transient for SQ and SB model at **a, b** top roof along wind and across wind; **c, d** setback roof of SB model along wind and across wind

#A of SQ model for along wind condition as shown in Fig. 3.4a. The point #B and #3 has maximum pressure 1.38 for 2.85 s and 1.66 for 2.82 s and suction is -1.6 for 1.46 s and -1.25 for 1.2 s. For across wind condition, maximum pressure (1.38) is developed at #B for SQ model at 2.87 s and maximum suction -2.08 at #3 for 1.42 s (see Fig. 3.4b). After that, it may be said that the pressure coefficient of SB is greater than the SQ model. Again, the pressure in the setback zone at #1 and #4 has 1.55 and 1.87 for 2.82 s and 0.02 s for along wind condition (see Fig. 3.4c), where maximum suction is 1.44 in 1.28 s at #4 point. For across wind condition, pressure has 1.07 and 1.30 in 2.56 s and 2.79 s. The suction is -2.02 is same for #1 and #4 points for 1.34 s (see Fig. 3.4d). According to the above condition, it may be said that the pressure variation is maximum at setback region due to a large amount of turbulence due to setback for along wind condition.

3.5.2 Spectral Density on Top and Setback Roof

Power spectral density (PSD) is the process, which defines the strength of energy as a function of frequency variation of a particular point. In this connection, anyone can calculate the frequency and amplitude of a variable signal in a time series. Another non-dimensional part Strouhal number takes place in this oscillating flow mechanism. The equations of PSD and Strouhal number are described under Eqs. (3.4)–(3.5), respectively.

$$[S_p(f)]/\sigma^2 \quad (3.4)$$

$$f B/U \quad (3.5)$$

where S_p is the power spectral density in energy/frequency, f is the frequency in Hz, σ is the standard deviation of pressure variation with respect to time, U is the flow velocity in m/s and B is height of pressure tapping point marked as #.

Figure 3.5 represents the PSD of top roof and the setback roof of SQ and SB models for across and along wind conditions at the points as stated in the previous section. For along wind condition, the spectral density of farthest point #B has high value compared to the #A at the Strouhal number 0.1 (see Fig. 3.5a). Similarly, the farthest point #2 has high spectral density with respect to #1 and has Strouhal number 0.05. Again for across wind condition, the SB model has less spectral value compared to SQ model at the Strouhal number 0.07 in Fig. 3.5b. In the case of setback roof, the spectral value of #1 is 0.12 for the fB/U value 0.025, whereas at point #4 has spectral value 0.05 for fB/U value 0.038 (see Fig. 3.5c). From this graph, it may be said that the high amount of pressure fluctuation observed in the setback zone of SB model for along wind condition. Figure 3.5d presents the spectral density curve for across wind condition. Here, the spectral density fluctuation is minimum except the Strouhal number 0.076. In this zone, high amount of spectral density variation is

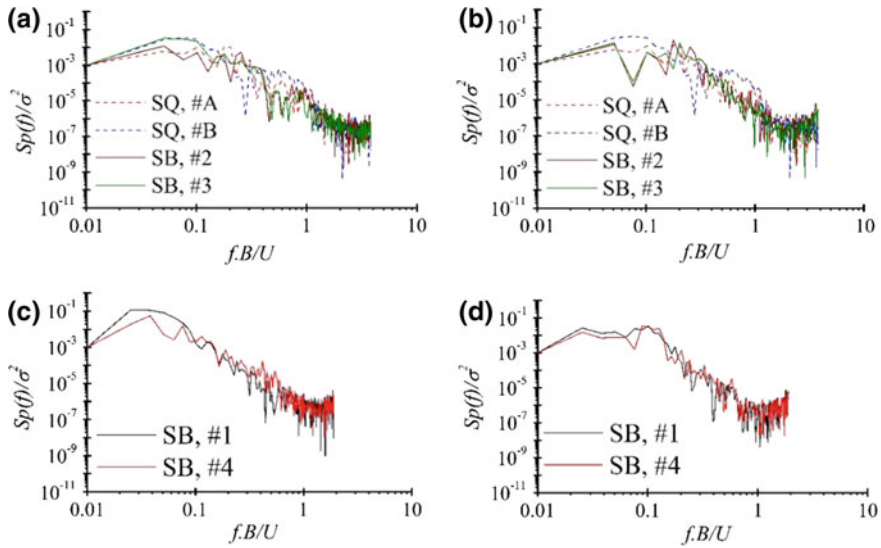


Fig. 3.5 Comparison of spectral density of SQ and SB model at **a, b** top roof along wind and across wind; **c, d** setback roof of SB model along wind and across wind

compared to #1 and #4. According to those graphs, it is clear that the SB model has higher spectral density variation in its setback region and affects the neighbor faces to change its frequency due to the high amount of turbulence. Therefore, special care should be adopted to design the setback roof and the neighbor face compared to the conventional roof of a tall building.

3.6 Conclusion

The CFD simulation has been studied in this paper for square and setback tall model to calculate the pressure transient and power spectral density at the top roof and setback roof. The number of simulations has been conducted in CFD analysis for along and across wind conditions. The results convey the message to the designer to consider special care to design the setback roof and adjacent wall of the setback tall building. The number of important features is observed in this study and stated as follows.

- High amount of pressure fluctuation is observed at first 0.06 s for both square and setback model.
- Maximum pressure (3.52) has been developed on the top roof of the setback model at the initial time for along wind condition. However, the square model has less pressure at the same time series.

- The maximum pressure variation has been observed for across wind condition on the setback model for 0.15 s.
- The farthest setback roof for along wind condition has maximum pressure coefficient 1.87 for 0.02 s and 1.30 for 2.77 s and has the same suction (-2.02) for 1.34 s.

References

1. Kim, Y.M., You, K.P., Ko, N.H.: Across-wind responses of an aeroelastic tapered tall building. *J. Wind Eng. Ind. Aerodyn.* **96**, 1307–1319 (2008)
2. Kim, Y.C., Kanda, J.: Wind pressures on tapered and set-back tall buildings. *J. Fluids Struct.* **39**, 306–321 (2013)
3. Tanaka, H., Tamura, Y., Ohtake, K., Nakai, M., Kim, Y.C., Bandi, E.K.: Aerodynamic and flow characteristics of all buildings with various unconventional configurations. *Int. J. High-Rise Build.* **2**, 213–228 (2013)
4. Bairagi, A.K., Dalui, S.K.: Evaluation of interference effects on parallel high-rise buildings for different orientation using CFD. In: 3rd World Conference on Applied Sciences, Engineering & Technology, pp. 764–774. Kathmandu, Nepal (2014)
5. Bairagi, A.K., Dalui, S.K.: Optimization of interference effects on high-rise building for different wind angle using CFD simulation. *Electron. J. Struct. Eng.* **14**, 39–49 (2014)
6. Mukherjee, A., Bairagi, A.K.: Wind pressure and velocity pattern around ‘N’ plan shape tall building—A case study. *Asian J. Civil Eng. (BHRC)* **18**, 1241–1258 (2017)
7. Mendis, P., Mohotti, D., Ngo, T.: Wind design of tall buildings, problems, mistakes and solutions. In: 1st International Conference on Infrastructure Failures and Consequences, Melbourne, Australia (2014)
8. Xu, Z., Xie, J.: Assessment of across-wind responses for aerodynamic optimization of tall buildings. *Wind Struct.* **21**, 505–521 (2015). (Techno-Press Ltd.)
9. Roy, K., Bairagi, A.K.: Wind pressure and velocity around stepped unsymmetrical plan shape tall building using CFD simulation—A case study. *Asian J. Civil Eng. (BHRC)* **17**, 1055–1075 (2016)
10. Tamura, Y., Xua, X., Tanakac, H., Kima, Y.C., Yoshidaa, A., Yangd, Q.: Aerodynamic and pedestrian-level wind characteristics of super-tall buildings with various configurations. In: 10th International Conference on Structural Dynamics, EURO-DYN, vol. 199, pp. 28–37. Procedia Engineering (2017)
11. Elshaer, A., Bitsuamlak, G.: Multiobjective aerodynamic optimization of tall building openings for wind-induced load reduction. American Society of Civil Engineers (2018)
12. Bairagi, A.K., Dalui, S.K.: Comparison of aerodynamic coefficients of setback tall buildings due to wind load. *Asian J. Civil Eng. Build. Housing* **19**, 205–221 (2018)
13. Namchu, A.D., Bairagi, A.K., Chakroborty, S.: Aerodynamic coefficients of steel stacks under different terrain category. In: Proceeding of International Conference on Frontier in Engineering Applied Science and Technology (FEAST’18), pp. 133–138. NIT Tiruchirappalli (2018)
14. Bairagi, A.K., Dalui, S.K.: Aerodynamic effects on setback tall building using CFD simulation. In: 2nd International Conference on Advances in Dynamics, Vibration and Control, pp. 381–388. NIT Durgapur (2018)
15. Mukherjee, S., Bairagi, A.K.: Interference effect on principal building due to setback tall building under wind excitation. In: SEC18, Proceedings of the 11th Structural Engineering Convention—2018. Jadavpur University, Kolkata, India (2018)
16. Rajasekarababu, K.B., Vinayagamurthy, G.: Experimental and computational simulation of an open terrain wind flow around a setback building using hybrid turbulence models. *J. Appl. Fluid Mech.* **12**, 145–154 (2019)

17. Franke, J., Hirsch, C., Jensen, A., Krüs, H., Schatzmann, M., Westbury, P., Miles, S., Wisse, J., Wright, N.G.: Recommendations on the use of CFD in wind engineering. COST Action C14. Impact of Wind and Storm on City Life and Built Environment. Von Karman Institute for Fluid Dynamics (2004)
18. SP 64 (S&T): Explanatory Hand Book on Indian Standard Code of Practice for the Design Loads (Other than Earthquake) for Buildings and Structures (Part-3. Wind Loads) [IS:875 (Part-3):1987]. Bureau of Indian Standards, New Delhi, India (2001)
19. Bairagi, A.K., Dalui, S.K.: Comparison of pressure coefficient between square and setback tall building due to wind load. In: SEC18, Proceedings of the 11th Structural Engineering Convention—2018. Jadavpur University, Kolkata, India (2018)