Chapter 10
Effect of Aerodynamic Modifications on a Tall Building with Horizontal Irregularity

Shanku Mandal , **Sujit Kumar Dalui** and **Soumya Bhattacharjya**

Abstract Impact of wind force is more critical on tall buildings with an increase in height. Horizontal irregularity on plan shape and randomness of wind makes the structure more vulnerable. A detail analytical study has been done considering various wind incidence angle ranging from 0° to 90° at an interval of 30° using computational fluid dynamics (CFD) on U-plan shaped tall building with corner modifications. The present study has shown that the introduction of minor aerodynamic modifications has major a role in minimizing the wind-induced responses. Drag coefficient and the lift coefficient are reduced due to the application of corner chamfered and corner roundness on the basic model. Most of the cases both maximum pressure and suction occur on the different faces of corner chamfered models. It is also noted that the modified corner exerts more pressure than the basic model.

Keywords Horizontal irregularity · Wind incidence angle · Computational fluid dynamics · Aerodynamic modification

10.1 Introduction

Corner modifications do not only enhance the aesthetic beauty of the structure but also play a major role for drastic chance in wind pressure on structural elements of tall building faces. The unconventional shape of the buildings makes them more sensitive to wind than those with a regular shape. Kim and You [1] performed several wind tunnel tests and concluded that the tapering effect has a more significant effect in across-wind direction than that in along-wind direction. Gomes et al. [2] used a

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

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

S. Bhattacharjya
e-mail: soumya@civil.iiests.ac.in

closed circuit wind tunnel for testing 1:100 scale irregular-plan shaped models with different wind incidence angles and find out the noticeable difference in pressure distributions on inner faces due to the influence of the additional wing which transforms the L into U-shaped model. Ilgin and Gunel [3] suggested different design methods and major aerodynamics modification like tapering, setbacks, sculptured building tops, varying the shape and openings, etc., should be adopted to ensure the functional performance of flexible structure and control the wind-induced motion of tall buildings. Tse et al. [4] investigated the impact of the amount and type of corner modifications. Recessed corners modifications are shown to be an effective minimizer of the wind-induced loads than chamfered corners. The overall construction costs can be reduced with the application of corner modifications. Sevalia et al. [5] numerically studied the force coefficient of different geometric plan configurations like square, circular, hexagon and octagon tall building having the same plan area. They conclude that the circular plan shape of building is much better when compare to the other plan shape of building in terms of both wind pressure coefficient as well as total drag force on building. Tanaka et al. [6] found out that helical has better aerodynamics behavior over other configurations like corner cut, setback due to shed irregularity throughout the height. Xie [7] considered aerodynamic optimization is the most efficient way to ensure the structure safety in strong winds and control the wind-induced motion of super-tall buildings. Kim and Kand [8] discussed the effectiveness of aerodynamic modification in reducing wind loads due to the fact that change in building shape with height promotes frequent, random and incoherent vortex formation at different levels. Bandi et al. [9] tested different cross-sectional tall buildings with configurations of straight triangle, corner cut, 60° helical, 180° helical and 360° helical, and clover to investigate the variations in along-wind and cross-wind overturning moment coefficients. Sharma et al. [10] experimentally investigate the advantages of tapered and setback model over regular conventional shapes. Setback building model is the effective minimizer of the wind loads compare to taper modified building. Present study mainly focuses on the effect of rounded corner and chamfered corner on U-plan shaped tall building at different wind incidence angles. Comparison of force coefficient and mean pressure coefficient of various models are shown.

10.2   Scope of Study

The effect of wind force on regular-plan shaped building is available in various codal provisions but very limited data are available for irregular-plan shaped building. Detail study should be done to evaluate the wind responses due to the abundant presence of U-plan shaped buildings. Numerical simulation using computational fluid dynamics (CFD) is the best-suited alternative where wind tunnel facility is not available.

Different models as shown in Fig. 10.1 have been analyzed by ANSYS CFX considering 0° to 90° wind incidence angle at an interval of 30°. The U1 model has a
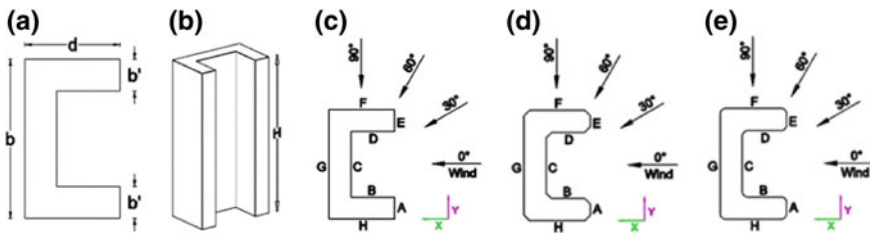
Fig. 10.1 Analytical models **a** plan view of basic model, **b** elevation view of basic model, **c** basic model with face name and wind incident angle (U1), **d** corner chamfered model with face name and wind incident angle (U2) and **e** corner rounded model with face name and wind incident angle (U3)

uniform cross section throughout the height. U2 model has been modified with corner chamfer of $0.25b'$ and the same amount of corner roundness has been provided in case of U3 model. Here, b, b', d and H are considered as 250 mm, 50 mm, 150 mm and 500 mm, respectively.

10.3 Computational Setup and Meshing

The wind-induced responses of the analytical models have been studied on the domain recommended by Frank et al. [11] and Revuz et al. [12]. The building model has been placed at $5H$ from inlet, sidewalls and roof of the domain, and $15H$ from the outlet as shown in Fig. 10.2. The height of the analytical model has been taken as H. The flow of the wind is not restricted and all the characteristic behaviors of wind can be observed in this domain. No blockage correction is needed for this domain.

The k-ε turbulence model is considered in our present study. The boundary condition for sidewalls and roof of the domain has been taken as free slip walls, and the walls of the building and the floor of the domain are taken as no-slip walls. The terrain category II is adopted as per Indian standard IS: 875-2015 (part 3) [13]. The analytical model has been modeled at a geometric scale of 1:300. The free stream velocity of wind at inlet is taken 10 m/s.

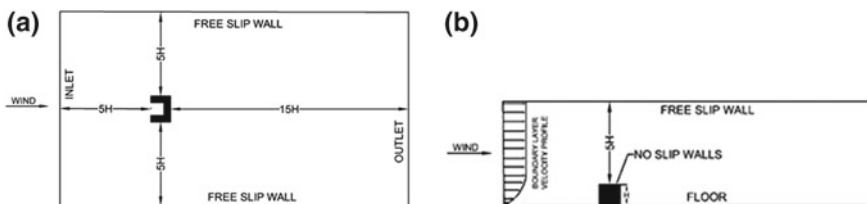The equation of atmospheric boundary layer (ABL) wind profile is taken as

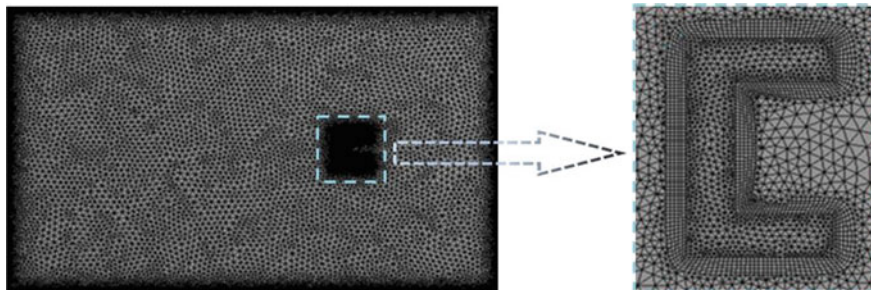**Fig. 10.2 a** Plan view and **b** elevation view of computational domain used for CFD simulation

Fig. 10.3 Domain meshing of U-plan shaped building model

$$\frac{U_x}{U_\infty} = \left(\frac{x}{x_0}\right)^\alpha \qquad (10.1)$$

U_x is the velocity at any height 'x' from ground.
U_∞ is the free steam velocity.
x is the height at any point above ground surface.
x_0 is the atmospheric boundary layer height.
α is a power-law exponent which depends on the roughness of the terrain.

The value of the exponent α is taken as 0.133 conforming to terrain category II as per IS: 875-2015 (part 3) [13]. The boundary layer height (x_0) is taken as 1 m.

The domain and the building meshing are done using tetrahedral elements as recommended by Lo et al. [14]. Finer meshing is employed around building models to capture the more efficient flow for accurately analyze the higher gradient of the wind flow as shown in Fig. 10.3.

10.4   Comparison with the Previous Study

Figure 10.4a, b shows the comparison of wind velocity profile and turbulence intensity profile between the data obtained from the present study, wind tunnel study by Dalui [15] and CFD by Kar et al. [16]. The comparison shows more or less similar characteristics with the previous study due to generation of similar type of wind environment on every case. Figure 10.4c displays pressure coefficients along vertical centerline at face C of U-plan shaped model for 0° wind incidence angle. To validate the current analytical study, a comparison of pressure coefficient between the current study and the previous study of Gomes et al. [2] has been done.
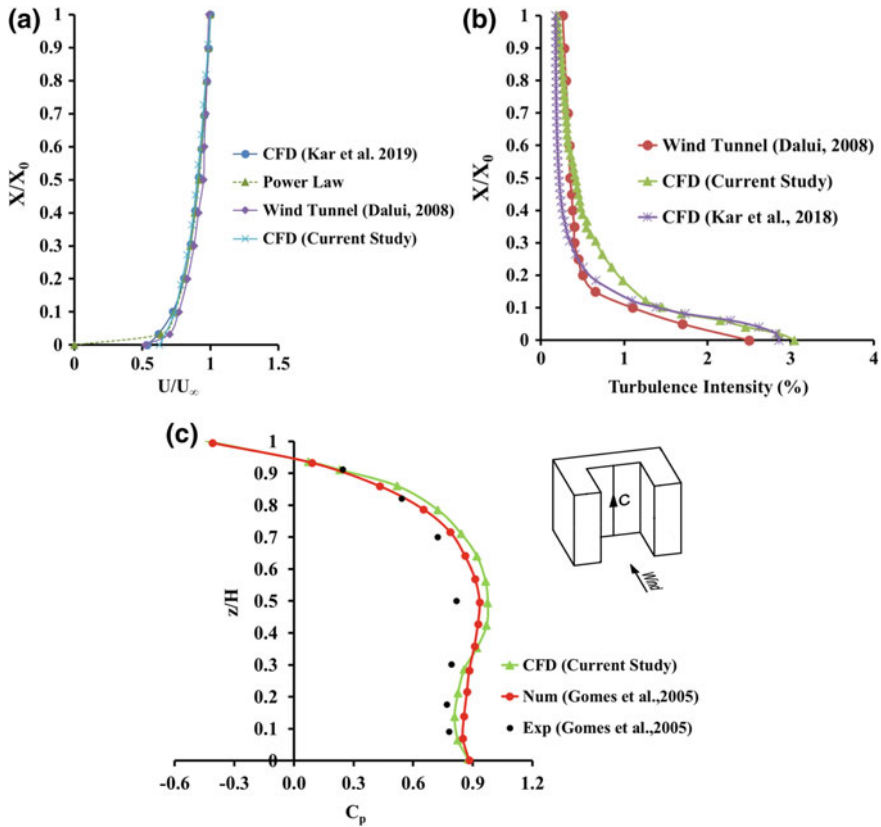
Fig. 10.4 Comparison with the previous study **a** velocity profile, **b** turbulence intensity and **c** pressure coefficients along vertical centerline at face C of U-shaped model for 0° wind incidence angle

10.5 Results and Discussion

The wind-induced effect on different faces of basic and corner modified U-plan shaped tall buildings are shown considering 0° as well as 30°, 60° and 90° wind incidence angle. The typical wind flow patterns around basic and corner modified building models are shown in Fig. 10.5. Symmetrical vortices are formed on the leeward side of basic model due to normal wind incidence angle, but asymmetric vortices are formed on the corner modified building models. The formation of vortices varies significantly with the change in wind angle. The horizontal irregularity of the U-plan shaped building promotes the production of unsymmetrical and irregular vortices in the wake region. Corner modification as well as self-interfering limbs of the building also form irregular vortices with the change in angle of wind attack.
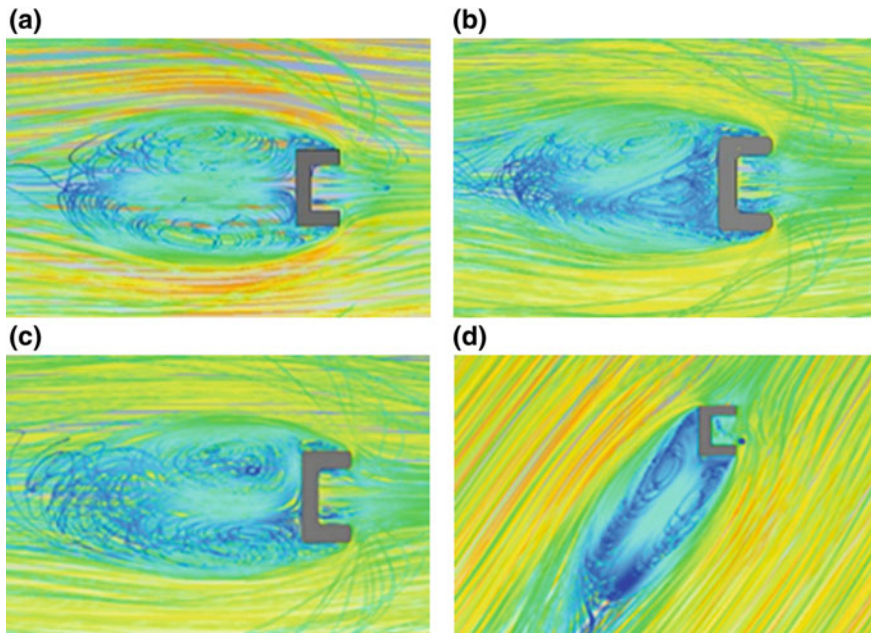
Fig. 10.5 Wind flow pattern around various model **a** basic, **b** corner chamfered, **c** corner rounded and **d** 60° wind incidence angle

Comparison of drag coefficient and lift coefficient of basic U-shaped and corner modified U-shaped models are shown in Fig. 10.6. It is clearly visible that sharp corner model or basic U-shaped model attracts more wind force in comparison with corner modified models. Corner modifications are efficient to reduce drag coefficient as well as lift coefficient. Corner roundness is more effective to reduce wind-induced responses in along-wind direction. In some cases, corner chamfered shows less attraction to wind force on across-wind direction with change in attack of wind angle. At 60° wind incidence angle, the effect of wind-induced responses is critical in across-wind direction.
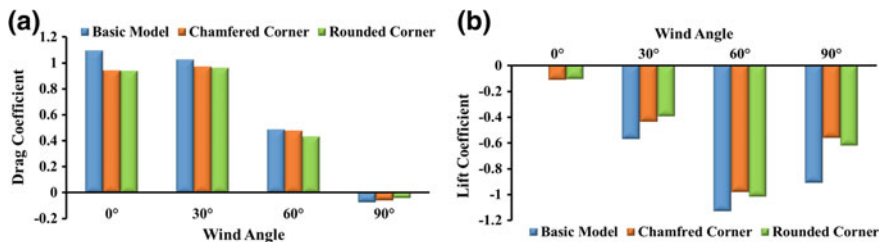

Fig. 10.6 Comparison of force coefficient of various models with different wind incidence angle **a** drag coefficient and **b** lift coefficient
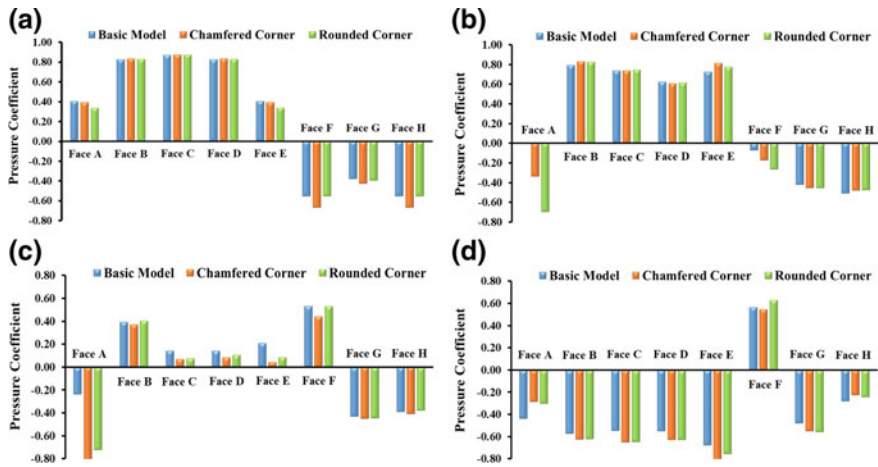
Fig. 10.7 Comparison of mean pressure coefficient on all faces of various model at **a** 0°, **b** 30°, **c** 60° and **d** 90° wind incidence angle

The mean pressure coefficients on different faces are shown in Fig. 10.7. Mean pressure coefficient on corner rounded models are less compare to other models in case of normal wind incidence angle. Corner chamfered models exert more pressure on side faces in most of the cases. Maximum positive pressure occurred on windward direction. Side faces and leeward faces exert suction due to side wash and formation of vortex, respectively. The change in mean pressure coefficient on various faces changes due to change in wind incidence angle. At 30° wind incidence angle on face A of basic model, mean wind pressure is negligible due to presence in both positive and negative pressure, but in case of corner modified models negative pressure is predominant on this face. At 60° wind angle maximum suction is occur on face A of corner chamfered model, but at 90° wind angle maximum suction is occur on face E. It is a clear indication that with the change in wind incidence angle, the variation in wind-induced responses shows mainly due to the presence of limbs on U-shaped buildings.

The comparison of pressure coefficient (C_p) along perimeter of building models is shown in Fig. 10.8 at 250 mm height from the base on horizontal direction. The important observation is to be noted that on the modified corner the pressure is more as compare to basic model in most of the cases.

10.6   Conclusion

The role of corner modification on irregular-plan shaped tall building at different wind incidence angles is presented in the current study. The effects of modification can be summarized as follows.
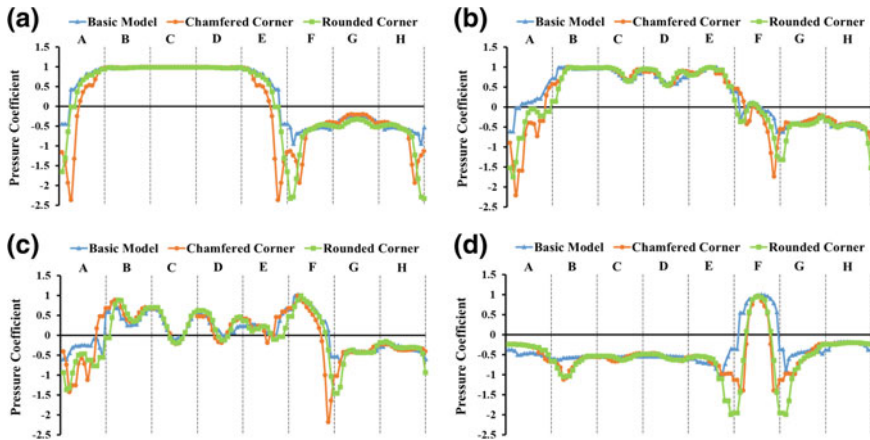
Fig. 10.8 Comparison of pressure coefficient along the horizontal center line of different models at **a** 0°, **b** 30°, **c** 60° and **d** 90° wind incidence angle

- The drag coefficient is maximum in case of normal wind incidence angle and minimum in case of 90° wind incidence angle.
- It is noticeable that the drag coefficient is reduced with the introduction of corner modifications. Though rounded and chamfered modification show almost similar reduction in drag coefficient, corner roundness is more efficient in reducing the drag coefficient.
- At 60° wind incidence angle, the lift coefficient is maximum in every case.
- It is observed that on corner rounded model lift coefficient is less than corner chamfered model at 0° and 30° wind incidence angle, but at 60° and 90° wind incidence angle the lift coefficient is more on corner rounded models than that of corner chamfered models.
- For each case, maximum positive pressure is generated on face C at 0° wind incidence angle, and face A of corner Chamfered model is experienced the maximum negative pressure at 60° wind incidence angle.
- At 90° angle, all the faces except face F exert suction.
- Most of the cases the corner modification exert more positive as well as negative pressure than that of basic model.

On the basis of obtained results, it is clear that corner modifications play an important role in reducing force coefficient on tall building. Providing corner roundness on basic model is more effective than chamfered corner. Current investigation gives a serious indication that the designer may provide modifications to minimize the wind force on structure but should take special care in case of designing the clad structural elements. The above study shows the necessity of detailed study considering the various angle of wind attack to find out the worst cases before designing any structure.

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