# Chapter 7
# Wind Excitation Study of a Corner-Modified Square Tall Structure

**Arghyadip Das and Sujit Kumar Dalui**

**Abstract** The modern buildings are becoming taller due to lack of land space and this makes the tall buildings more sensitive to lateral loads such as wind. The outer shape of the building is one of the main parameters which affects the design wind loads. Various types of minor corner modifications on tall buildings result a huge change in force and pressure. The present study is carried out to find the effect of corner modification on square plan-shaped tall building. The corners are modified as corner recessed, corner chamfered, and corner rounded, and a series of simulation is done in ANSYS CFX ($k - \varepsilon$ model) to find out the effects on force coefficients, pressure coefficients, wind flow pattern around the buildings, etc. The numerical analyses are done considering the model scale as 1:300 and for 0° angle of wind attack.

**Keywords** Tall buildings · Pressure coefficients · Force coefficients · Domain · Boundary layer · Meshing · Wind attack

## 7.1 Introduction

The population of the world is increasing drastically, and to accommodate this population, the modern-day technology prefers to build the high-rise buildings due to lack of land space. So, these tall buildings are very much sensitive in lateral forces such as wind. The outer shape is one of the main parameters which affects the wind loads and responses. Various International Standards like IS:875 (part-3):2015 [7], ASCE-16 [2], and AS-NZS: 1180-2011 [1] are providing guidelines to calculate the wind-induced loads and responses for regular plan-shaped buildings but there are no such guidelines for the irregular and unconventional plan-shaped buildings.

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Many research works are done on various irregular plan-shaped buildings to find the wind-induced loads and responses. Tanaka et al. [16] provide some guidelines on aerodynamic forces and wind pressure on various unconventional configurations like corner cut, corner chamfered, tilted, tapered, helical, and cross-opening with basic square-shaped model by a series of wind tunnel investigation. Charkraborty et al. [3] investigated the '+'-shaped tall building for 0°–45° wind incidence angle. Gomes et al. [6] investigated on experimental outcomes of '*L*'- and '*U*'-shaped models with 1:100 length scale. Tse et al. [17] carried out his research to find out the wind loadings and wind-induced responses of square tall buildings with different sizes of chamfered and recessed corners. Li et al. [11] suggested that among the horizontal modifications, 10% corner cut model is most greatly reduced along wind load for specific wind direction. Verma et al. [18] investigated the variation of the pressure distribution of tall square plan-shaped building for various wind incidence angle. Kumar and Dalui [9] compare the pressure coefficients and force coefficients for regular and angular cross-plan-shaped buildings. Pal and Dalui [12] studied the pressure and force coefficients for '*Z*' plan-shaped tall buildings. Sanyal and Dalui [14] studied the variation of pressure on courtyard and opening of a rectangular plan-shaped building. Elshaer et al. [4] studied the building corner modification effects on square-shaped tall building and concluded that the corner round model has less drag coefficients among all models. Kwok et al. [10] studied on finned and slotted finned corner buildings and concluded that the fins and slotted fins increase the along wind responses and reduce the across wind responses. Kawai [8] investigated on square sections with rounded, chamfered, and recessed corners and concluded that the small chamfers and recessions are effective in preventing aeroelastic instability but rounded corners increase the aerodynamic damping. Tamura et al. [15] carried out his research on square sections with rounded and chamfered corners using smooth uniform flows and concluded about the reliability of CFD in predicting the wind loads.

## 7.2 Scope of the Work

In this study, the square model is considered as the basic model with cross section 250 mm × 250 mm and 750 mm height with length scale 1:300 shown in Fig. 7.1a. The corner recessing is done in the next model with 25 mm recess that is 10% corner recess and shown in Fig. 7.1b, and the corner rounding and corner chamfering are also done successively with 25 mm rounding radius and 25 mm chamfering distance and shown in Fig. 7.1c, d. The isometric view of square model is shown in Fig. 7.1e. All the models are prepared using ANSYS CFX software package. The wind incidence angle is considered as 0° for each case. Pressure distribution is evaluated for each model, and pressure coefficients are represented in tabulated form as well as graphical form.

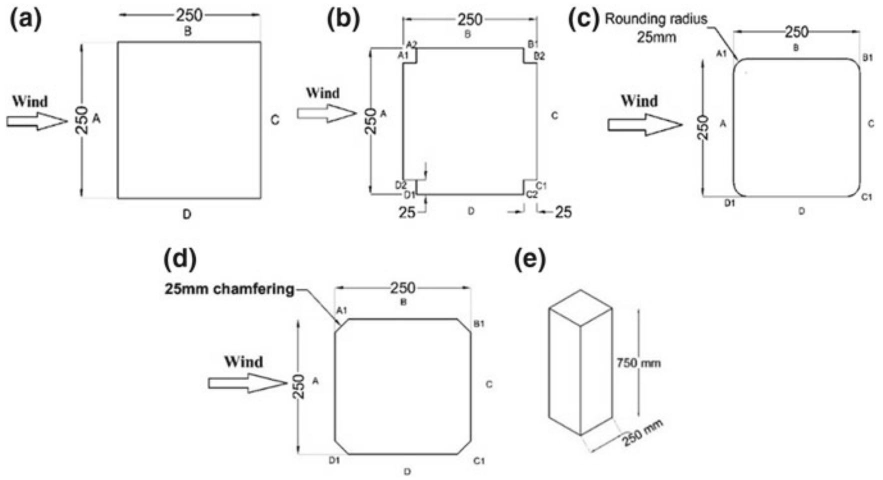



**Fig. 7.1** Model details of various corner modifications. **a** Square model, **b** corner recessed model, **c** corner rounded model, **d** Corner chamfered model, and **e** isometric view of square model

## 7.3 Computational Domain, Boundary Condition and Meshing

The computational domain has some specific sizes as per the guidelines of Frank et al. [5] and Revuz et al. [13]. As per the guidelines, the upstream, downstream, sidewall, and top wall clearance is taken as 5*H*, 15*H*, 5*H,* and 6*H* successively, where *H* is the height of the mode. The details of domain size are shown in Fig. 7.2a, b.

The velocity of the wind is considered as 10 m/s, and the turbulence intensity is taken as 1% (low intensity). The relative pressure at outlet is taken as zero. Sidewalls of the domain boundary are considered as the free slip walls, and the model walls are considered as the no slip walls. The ground roughness ($\alpha$) is taken as 0.133. Overall temperature of the domain is considered as 25 °C. The numerical analysis

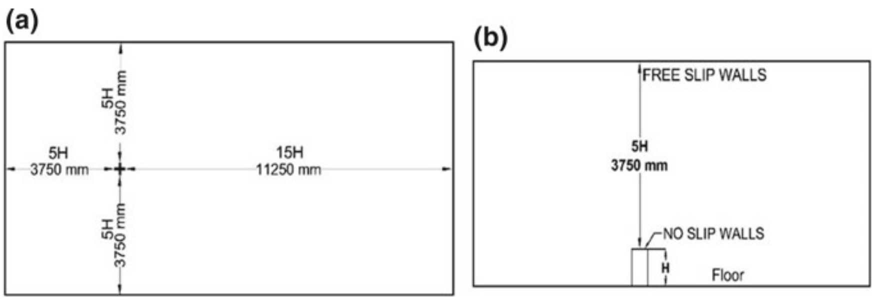



**Fig. 7.2** **a** Plan and **b** elevation view of computational domain used in CFD

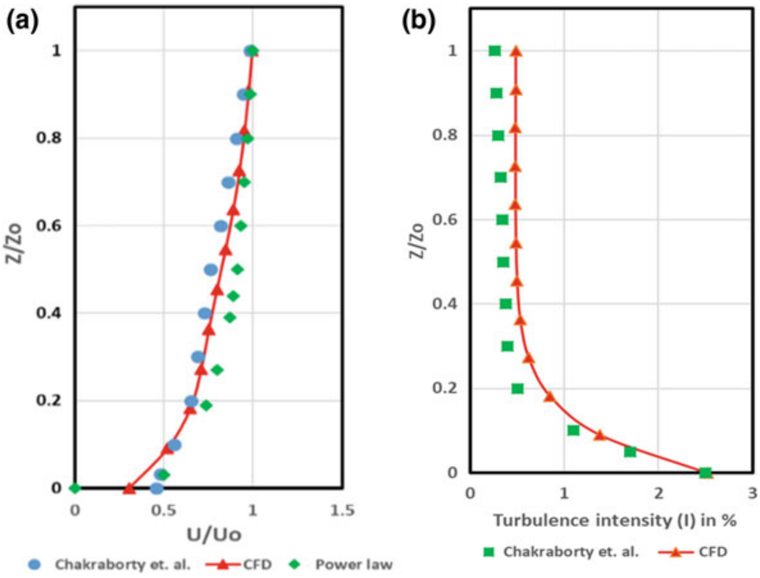



**Fig. 7.3** Comparison of **a** velocity profile and **b** turbulent profile

data are compared with previously published data of same type of geometric model, and power law is also used to generate such profile with exponent coefficient as 0.133.

$$\frac{U}{U_0} = \left(\frac{Z}{Z_0}\right)^{\alpha} \tag{7.1}$$

where $U_0$ is the basic wind speed taken as 10 m/s and $Z_0$ is boundary layer height of 1 m. A similar type of velocity profile was used by Chakraborty et al [3]. A comparison of the velocity profile and turbulent profile is shown in Fig. 7.3a, b. Tetrahedron meshing is used throughout the whole domain, and finer meshing is provided near the building to measure the accurate responses on the surface of the building. Comparatively coarser meshing is provided in the outer edges of the domain. The overall $y+$ values for all models are kept within the range of 30–300. A typical meshing of the corner chamfered model is shown in Fig. 7.4.

## 7.4 Results and Discussion

The average pressure coefficients and force coefficients of corner-modified models for various faces are calculated for 0° angle of wind attack and shown in Table 7.1. The average Reynolds number is calculated as 3.72 × 106. The basic square model has maximum positive pressure in windward face (face A) but side faces (face B

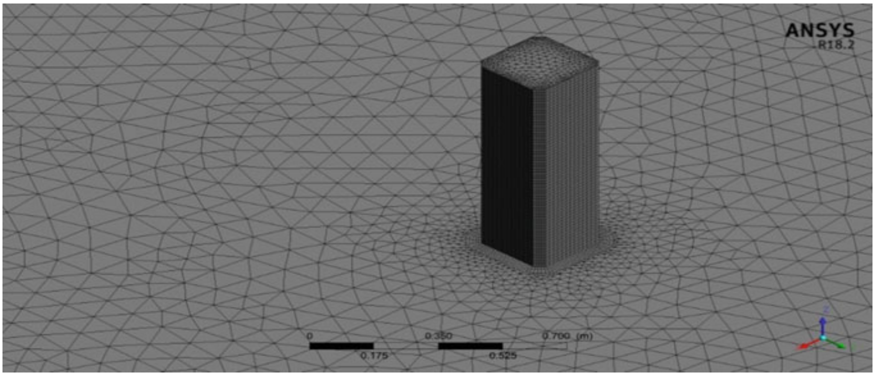



**Fig. 7.4** Mesh pattern of corner chamfered model

**Table 7.1** Average pressure and force coefficients for all types of model

| Sl. No. | Corner modification | Mean pressure coefficient | | | | Force coefficient |
|---|---|---|---|---|---|---|
| | | A | B | C | D | |
| 1 | Basic square model | 0.83 | −0.58 | −0.43 | −0.58 | 1.20 |
| 2 | Corner recessed model | 0.82 | −0.55 | −0.40 | −0.55 | 0.98 |
| 3 | Corner rounded model | 0.82 | −0.62 | −0.38 | −0.62 | 0.70 |
| 4 | Corner chamfered model | 0.80 | −0.64 | −0.37 | −0.64 | 0.71 |

and face D) and leeward face (face C) are experiencing negative pressure at the same time, whereas the corner recessed model is experiencing a bit lower positive pressure compared to the square model. Corner rounded and corner chamfered models are subjected to lesser pressure in face A, but corner chamfered model is experiencing the maximum negative pressure in face D (leeward face). Among all four models, the square model has maximum force coefficient as 1.20 and corner chamfered model has minimum force coefficient as 0.70 along '*X*'-direction.

### *7.4.1 Variation of Pressure Coefficients Along the Vertical Centerline, Flow Pattern and Pressure Contour of Various Faces of the Building*

The pressure coefficients ($C_p$) along vertical centerline of all faces of the building models are evaluated and plotted in graph shown in Fig. 7.5. In face A, it is found that the maximum pressure coefficient is at 600 mm height. The square model is showing less $C_p$ value at 600 mm height compared to corner recessed and corner chamfered models for face A. In the comparison of face B, the corner recessed model

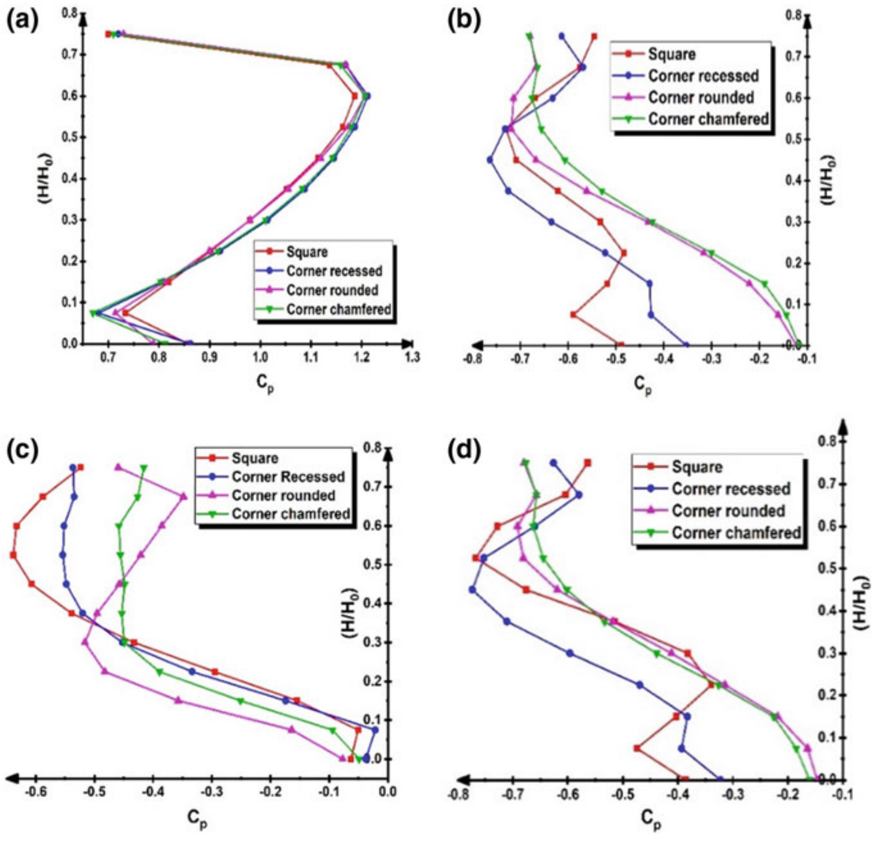
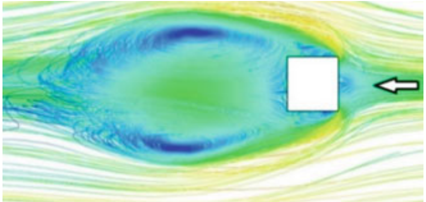
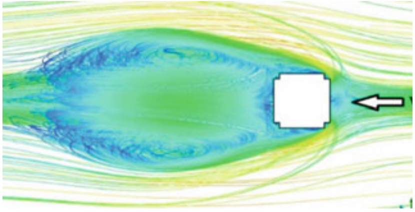



**Fig. 7.5** Comparison of avg. $C_p$ values along vertical centerline for various faces of all type of buildings

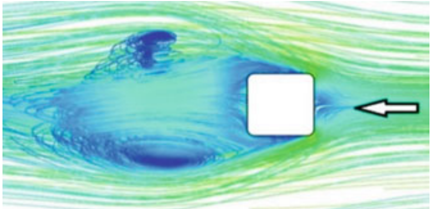
is showing maximum suction at 450 mm height, whereas the corner recessed and corner chamfered models have maximum suction at 600 mm height. Face B and face D are showing maximum negative pressure along the vertical centerline. The ratio of height of any point from the base ($H$) with respect to the overall height of the building ($H_o$) is depicted in the $Y$-axis as the ratio of ($H/H_o$). Due to symmetry of the building models and 0° angle of wind attack, the pressure coefficients ($C_p$) along vertical centerline are similar for sidewalls. The wind flow pattern around the building models is shown in Fig. 7.6. The vortex generated in the leeward side of the building models indicates the generation of negative pressure. Due to symmetry of the building models with respect to both axes and 0° wind angle, the vortex formation is also symmetric in the wake region of the buildings. Large separation of flow is observed for corner rounded and corner chamfered building models. The side view of vortex generation around the corner rounded building is also shown in Fig. 7.6. The comparison of pressure contour is shown in Fig. 7.7.



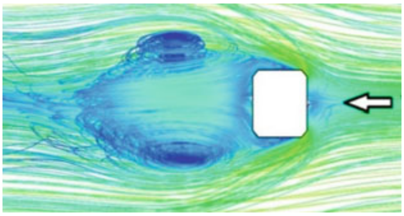
(a) Square model



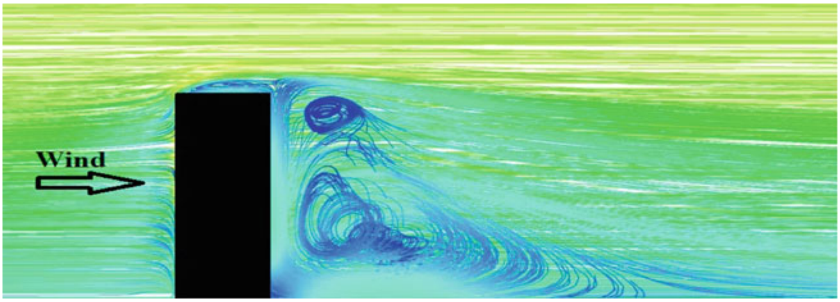
(b) Corner recessed model



(c) Corner rounded model



(d) Corner chamfered model




(e) Side view of vortex generation around corner rounded model

**Fig. 7.6** Flow pattern around all type of building model at 0° angle of wind attack

## 7.5 Conclusion

The corner modification has a huge impact in reducing the force and pressure coefficients on the building boundaries. Force and pressure coefficients are the most important parameters of building design, and reduction of those parameters is very much appreciated in the design point of view. The force coefficients are reduced around 18% in the case of corner recessed model as compared to the square basic model. But the best suited model is corner rounded model as it gives around 41% reduction in force coefficients along '$X$'-direction for 0° angle of wind attack. Corner chamfered model also gives satisfactory results (reduction of mean drag coefficient around 40%). Due to some complicacy in construction works for corner rounded

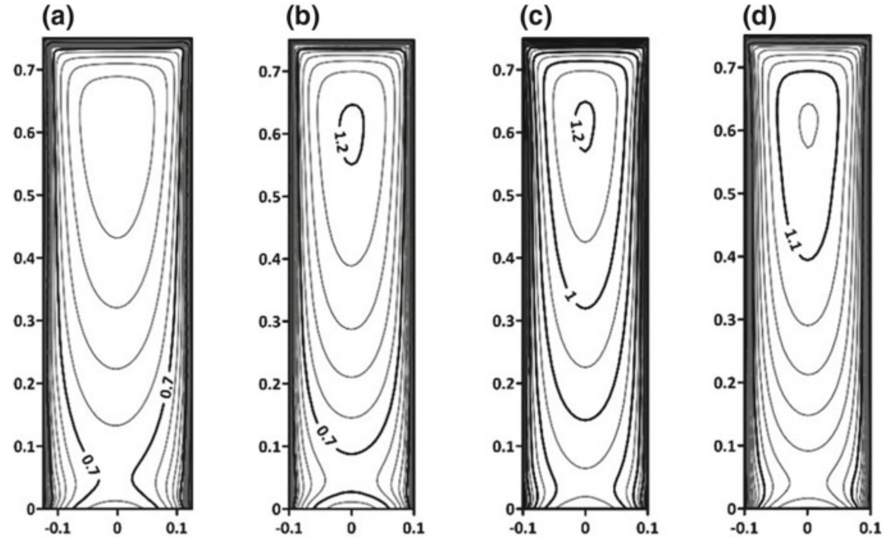



**Fig. 7.7** Comparison of pressure contour for face A for **a** square model, **b** corner recessed model, **c** corner rounded model, and **d** corner chamfered model

model, the corner chamfered model is the preferred model for reduction of wind-induced loads and responses. As compared to other minor modifications in building corners, chamfered model gives maximum utilization of plan area.

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