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Wind Induced Pressure Variation on High-rise Geometrically Modified Building having Interference through CFD Simulation

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ABSTRACT

The wind different forms i.e. cyclones, hurricanes, storms, tornados, etc., loads various structures which come in their way. To minimize the wind effects, different techniques have been used and geometrical modification is one of them. In this study, the pressure variation on a geometrically modified high-rise corner-cut building having interference has been evaluated. The study is carried out using ANSYS FLUENT in which CFD simulation is carried out for the different models at different wind incidence angles viz. 0°, 45°, and 90°. Two building models are used in this study, one is high rise Corner-cut building, which is called the principal or primary building. The other is a high-rise rectangular building, which is called interfering or secondary building. The results obtained in case of interference are then compared to that of an isolated corner-cut building. In general, from the present investigation, it is noticed that the suction effect increases due to the interference effect. When wind strikes obliquely the effect of interference is relatively lower.

1. Introduction

At present, progressively more tall structures are being constructed close to each other due to the scarcity of land. Due to the mutual interference, the pressure distribution or wind flow pattern

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gets altered from that of an isolated building. Limited wind load provisions are available for studying the wind-induced interference effects on tall buildings. The wind is essentially a dynamic load. High winds, such as cyclone, tornado, or heavy gale, causes extensive damage to the structures. Thus for designing the structures, wind load should be considered along with other loads.

There are many ways to investigate the effect of wind on a building. Wind tunnel testing is one of the ways to determine the wind loading for structures. But this is a burdensome procedure as it requires more effort and it is an expensive process. And the numerical study is also a good alternative to different experimental investigations, different numerical studies using various software or methods have been carried out in past [1–8]. For the alternate of wind tunnel testing, the CFD simulation is used nowadays for determining the effect of wind on the structures [9–20]. A large amount of study has been carried out using CFD simulation as an alternative to wind tunnel experiments and the outcomes obtained from CFD simulation are almost matching when compared to experimental results [10,21–27]. Huge research work has already been carried out through CFD simulation of various structures with different base shapes and roof types [10,21,28–31].

Also, different wind codes i.e. Indian wind code, Australian/New Zealand wind standard, American wind code, Wind code of Japan are used worldwide for assessing the effect of wind loads [32–34]. Some of the codes in which these effects are incorporated for studying the wind loads are Japanese wind provision and Australian/New Zealand wind standard [33,35], these codes have taken into account only the shielding effect which is only one of the interfering effects. Wind loads are difficult to assess since the huge number of variables involved, like building shape and size, the direction of the wind, terrain conditions, etc.

Variation in wind load is caused by many factors such as building shape, height, wind attack angle, roof slope, interference, geometrical modifications, etc. The interference effect of nearby buildings or similar objects has been examined in many past studies. The interference effect on external pressure and local peak pressure coefficient has been investigated between two high-rise buildings with different geometries like flat, conical, and hemispherical roofs with a cylindrical model [36–39]. Along with the interference effect, the geometrical modifications also influence the wind pressure distribution on walls or roof surfaces of buildings significantly [40,41].

As most of the research work carried out in past is on isolated buildings, and effects of various parameters have been studied individually, then it is also required to examine the combined effect of various parameters in different pairs. So in the present study, the combined effect of interference of square plan-shaped building and geometrical modification i.e. corner-cutting is being taken into consideration. Furthermore, the present study has been carried out to find the interference effects on peak pressure coefficient on Corner-cut buildings, and the results are then compared to that of an isolated Taper building. This work consists of a CFD simulation of ABL airflow on geometrically modified buildings, with and without interference. The numerical simulation is carried out through Ansys Fluent software.

The approach used in the present study i.e. CFD modeling and simulation is widely used for wind load investigation of different kinds of buildings. The CFD method of wind load analysis is approachable and provides results with high resolution. The CFD is time-saving and cheaper than other methods such as wind tunnels or wall of wind methods. Furthermore, it provides data for more quantities while the traditional methods give results for limited parameters. The past validation studies show the significant similarity between CFD results and wind tunnel results.

The study has been explained in various parts. After a brief introduction, the modeling in ICEM has been described in section 2. After the description of models, geometry, and meshing in section 2, results have been presented in section 3. And the analytical approach is presented in section 5. Then, a brief conclusion has been provided at the end of the study i.e. in section 4.

2. Modelling in ICEM CFD

The model consists of a principal high-rise corner-cut building and an interfering square-shaped high-rise building. The dimension of the Corner-cut building and the interfering building are shown in Fig. 1 and 2. The height of both the building being 300 m. the base dimension of the corner-cut building is 175 m x 57 m. The corner-cut of the building having dimensions of 17.5m x 5.7m and this cut is provided at all four edges of the building. The dimension of the interfering building is 57.1 m x 57.1 m x 300 m. The dimension of the domain is as shown in Fig. 3 [42]. Meshing used to carry out the CFD simulation is shown in Fig. 4.

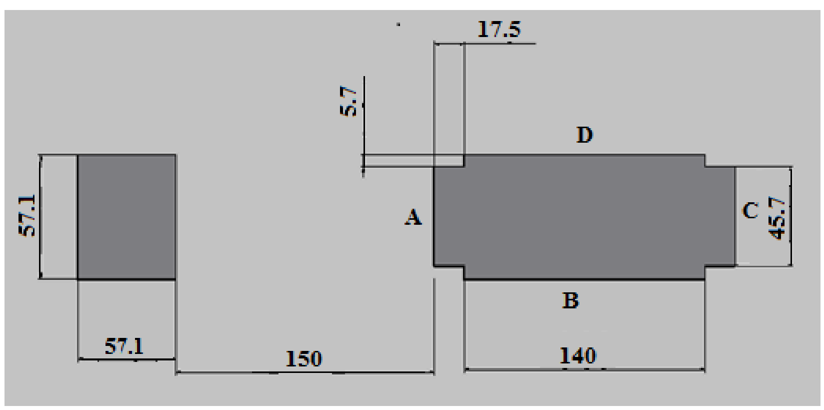

Fig. 1. Plan of Corner-cut and interfering building (all dimensions in meter).

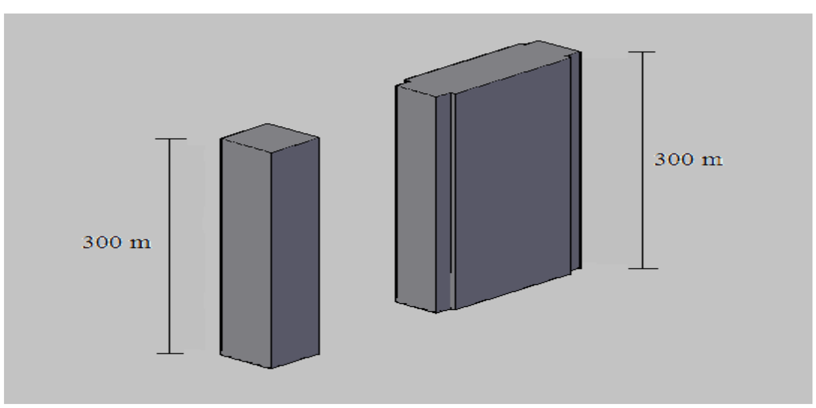

Fig. 2. Isometric view of the building models.

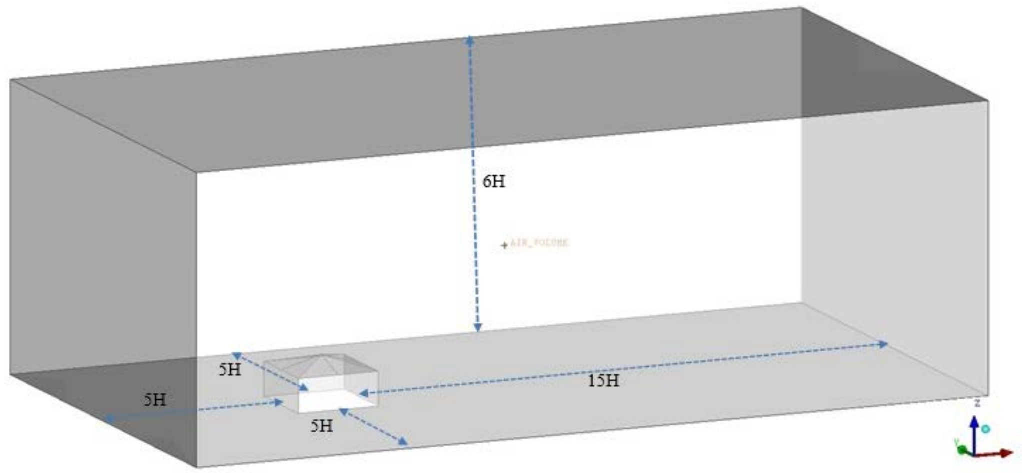

Fig. 3. Computational domain of the building models [42].

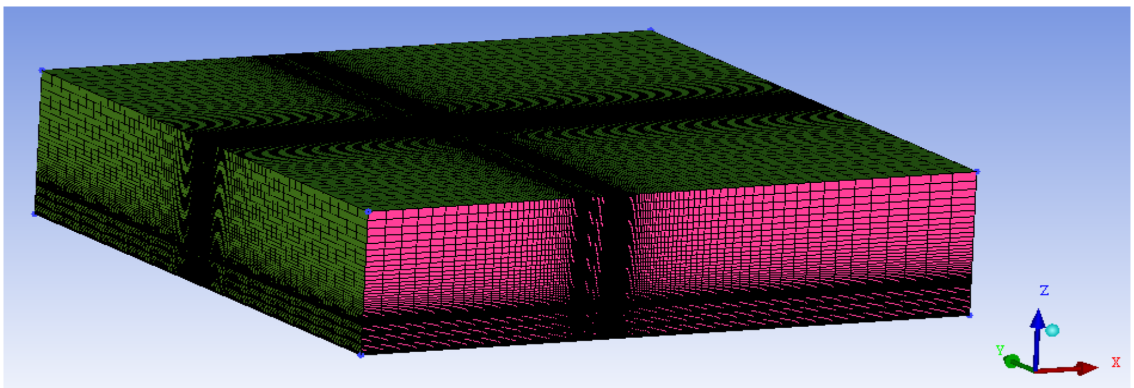

Fig. 4. Isometric view of the meshing of the domain.

For generating mesh in ICEM, a hexagonal grid has been used throughout the domain and the mesh quality (more than 0.5, on a scale of 0 to 1) has been ensured for the model. The structured mesh has been converted to unstructured mesh for simulation in Ansys Fluent (Ansys fluent supports unstructured grid only). Boundary conditions for the simulation part have been taken from Roy et. al study, carried out at IIT Roorkee [43]. And the convergence criteria for the simulation have been taken 10^{-4}, which means the residual reaches a value of 10^{-4} for all the equations.

3. Results and discussion

Results of the present study comprise contours of pressure coefficients for all four faces of a building model and comparison among pressure coefficients on different faces through tables and graphs. The variation in color from red to dark blue shows variation in pressure coefficients. The red color represents the maximum positive pressure coefficient, while the dark blue color illustrates the maximum negative pressure coefficient. The contours of the pressure coefficient depicting the variation of pressure coefficient on different faces of the corner cut building are shown below in Fig 5(a), Fig. 5(b) and Fig. 5(c) and the values of pressure coefficients are tabulated in Table 1(a), 1(b), 1(c) and 1(d).

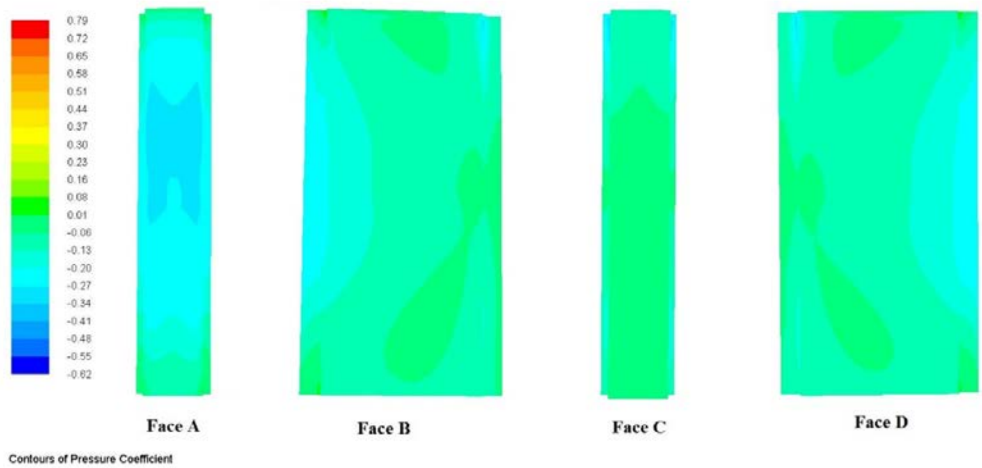

Fig. 5(a). Contours of pressure coefficient at 0° Wind incidence angle.

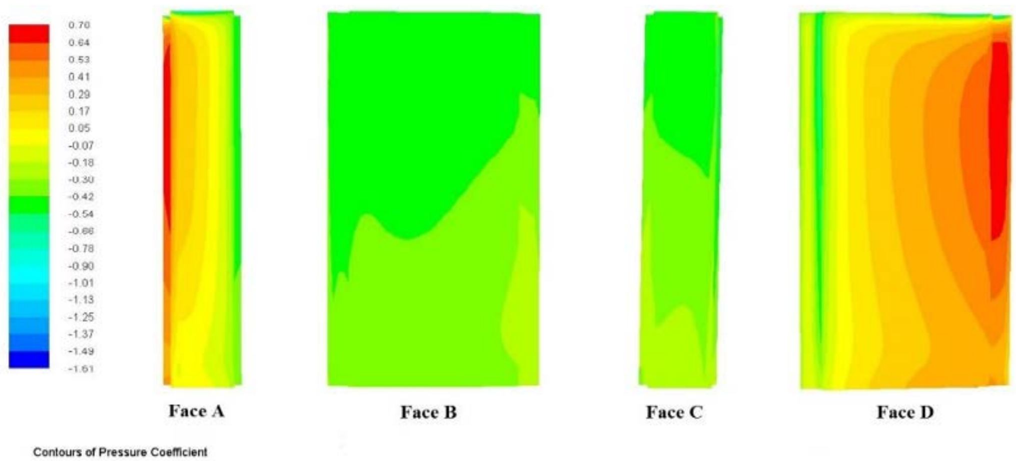

Fig. 5(b). Contours of pressure coefficient at 45° Wind incidence angle.

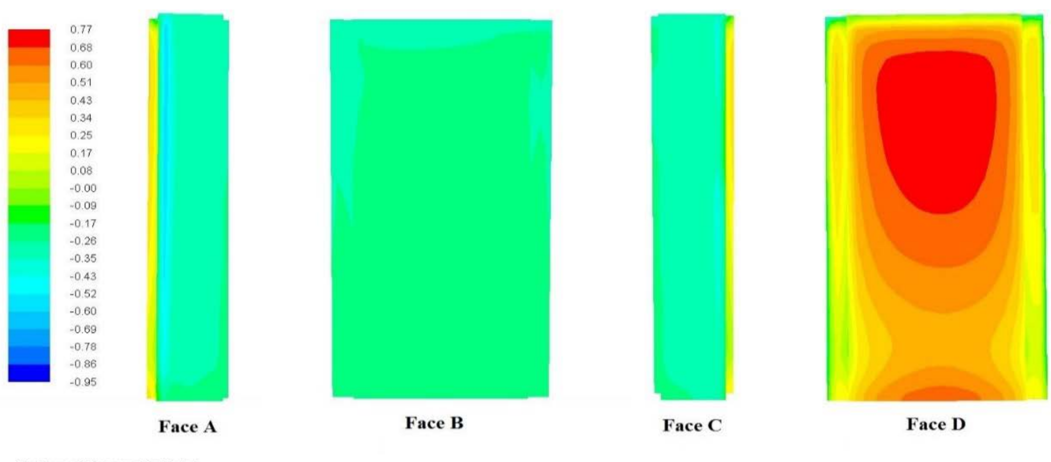

Fig. 5(c). Contours of pressure coefficient at 90° Wind incidence angle.

The effect of the interfering building is visible on the principal building in Fig 5. As in the case of 0° wind angle, there is very low pressure or negative pressure on all faces of principal building while in the case of 45° and 90° wind angle, there is positive pressure on one face and suction on all other three faces. This is because of the attacking angle, as the wind angle changes from 0° to 45°, and 45° to 90°, the face having direct prevailing wind changes, and so the pressure variation.

3.1. Comparison of results with that of an isolated Corner-cut building

The comparison of pressure coefficients on different faces of the principal building has been illustrated in Table 1(a, b, c). There are negative pressure coefficients on the faces of the principal building, while there are positive pressure coefficients on the faces of the interfering building, and this is because of the interference effect.

The interference effect is the maximum in case of 0° wind incidence angle and is minimum in case of 90° wind angle. In the case of 0°, there is a maximum blockage to the wind flow which aims to the principal building, while it is least in case of 90°.

Table 1(a)
Mean pressure coefficient on corner-cut building, with and without interference at 0° wind incidence angle.

Face	Pressure coefficient on isolated Corner-cut building	Pressure coefficient on Corner-cut building having interference
Face A	0.23	-0.18
Face B	0.31	-0.10
Face C	-0.12	-0.07
Face D	-0.32	-0.09

Table 1(b)
Mean pressure coefficient on corner-cut building, with and without interference at 45° wind incidence angle.

Face	Pressure coefficient on isolated Corner-cut building	Pressure coefficient on Corner-cut building having interference
Face A	0.23	-0.18
Face B	0.31	-0.10
Face C	-0.12	-0.07
Face D	-0.32	-0.09

Table 1(c)
Mean pressure coefficient on corner-cut building, with and without interference at 90° wind incidence angle.

Face	Pressure coefficient on isolated Corner-cut building	Pressure coefficient on Corner-cut building having interference
Face A	0.23	-0.18
Face B	0.31	-0.10
Face C	-0.12	-0.07
Face D	-0.32	-0.09

Face A

As observed from Table 1(a),1(b), and 1(c) that for this face the value of pressure coefficient considerably changes when interference is provided from that of an isolated building at 0° wind incidence angle. This increase in suction is due to turbulence generated due to interference. When there is an isolated building the wind strikes directly at face A and we get a high value of positive pressure coefficient. For the 90° wind incidence angle, there is a decrease in suction pressure from -0.87 to -0.18.

For 0° and 90° wind incidence angles, the value of the Pressure coefficient increases up to 200m height, and then it decreases at the top due to an increase in wind velocity for building having interference. For the 45° wind incidence angle, there is suction at the top, and the value of the pressure coefficient increases as the height decreases. The variation of pressure coefficient with height for Face A, with and without interference is as shown in Fig. 6.

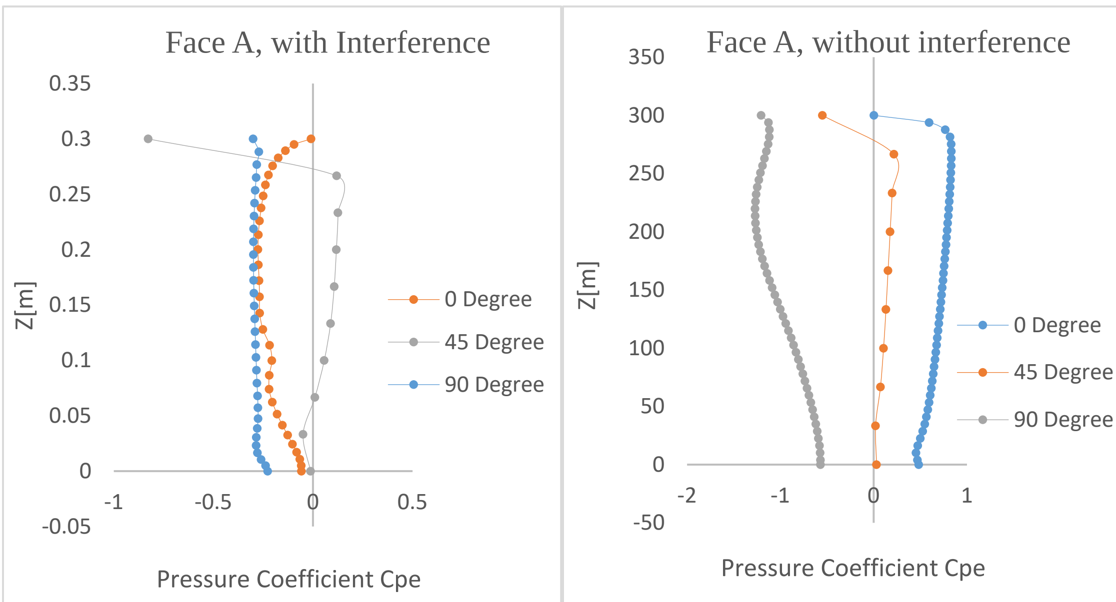

Fig. 6. Variation of pressure coefficient with height for Face A with Interference and without interference.

Face B

It experiences suction at 0°, 45°, and 90° wind incidence angles. From Table 1(a), 1(b), and 1(c) it is observed that the suction decreases when the interference is provided. The variation of pressure coefficient with height for two different cases i.e. with and without interference is shown in Figures 7.

During interference, the suction is minimum for 0° wind incidence angle and maximum for 45° wind incidence angle. The value of the pressure coefficient increases up to height 200 m for 0° wind incidence angle and above that, it starts decreasing. It has been observed that trend of pressure coefficient is considerably altered at 45° and 90° wind incidence angle when compared with an isolated case.

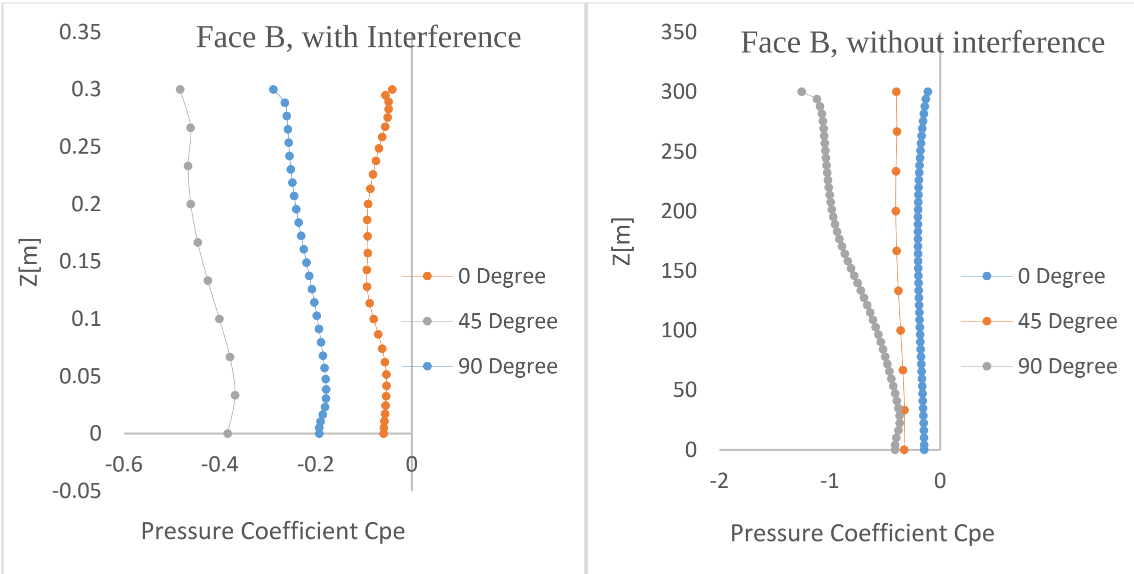

Fig. 7. Variation of pressure coefficient with height for Face B with Interference and without interference.

Face C

It also experiences suction at 0°, 45°, and 90° wind incidence angles. The value of suction decreases for 0° and 45° wind incidence angle but it increased slightly for 90° wind incidence angle for the building having interference. The variation of pressure coefficient with height for two different cases i.e. with and without interference is shown in Figures 8. During interference, the suction is minimum for 0° wind incidence angle and maximum for 90° wind incidence angle.

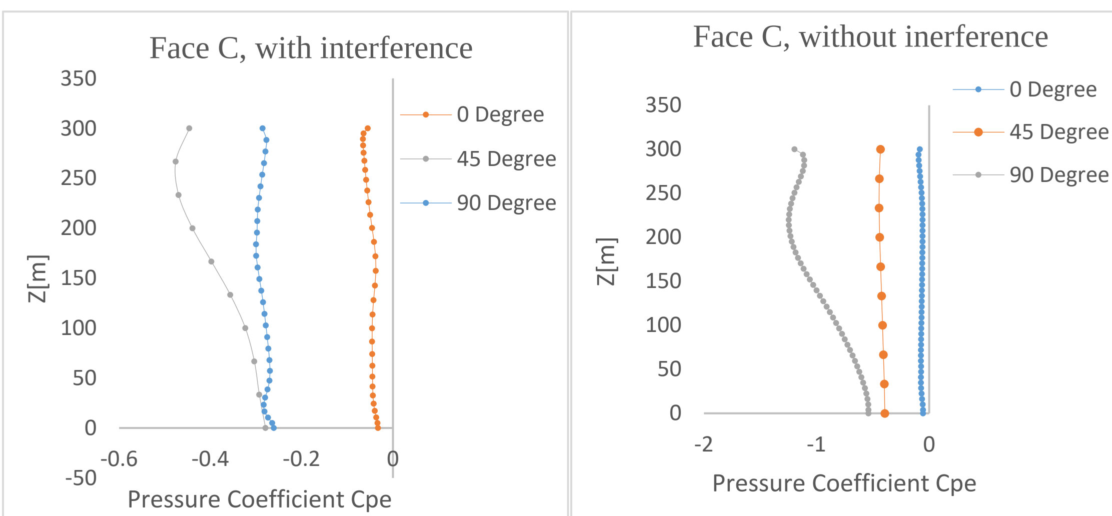

Fig. 8. Variation of pressure coefficient with height for Face C with Interference and without interference.

Face D

For this face which is the side face, it is observed from table 1 the value of suction decreases during interference at 0° wind incidence angle from that of isolated building. At 90° in both cases, there is a positive pressure coefficient as the wind strikes directly on this face when the wind incidence angle is 90° and at 45 wind incidence angle there is a decrease in positive pressure when the interference is provided.

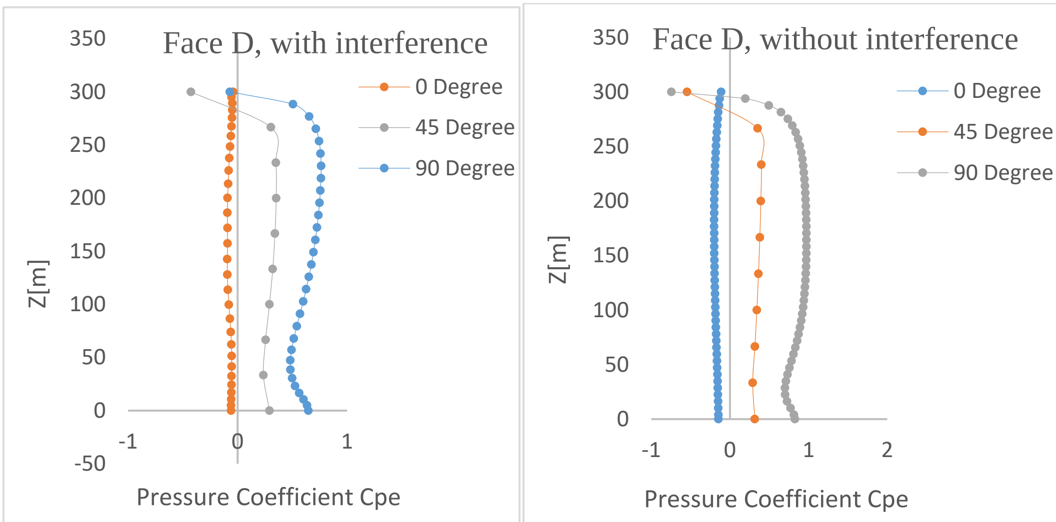

Fig. 9. Variation of pressure coefficient with height for Face D with Interference and without interference.

During the interference effect there is the suction on this face for 0° wind incidence angle and 45° and 90° wind incidence angles, at the top, pressure is negative which changes to positive as the height decreases. For 90° the value of the positive pressure coefficient is maximum. The variation of pressure coefficient with height is as shown in Figure 9.

4. Analytical study

The analytical investigation for the present work has been carried out using IS-875part-3 i.e. Indian wind standard. Different multipliers and factors are presented in Table 2 from the Indian wind code. And the designed pressure has been illustrated in Table 3 for various heights. The basic wind speed (Vb) has been taken as 44m/s for the coastal region (Mumbai for the present study).

Table 2

Values of different multipliers or factors from IS-875part-3 [32].

Factor or Multiplier	Description	Values
k_1	It is based on the return period/age of the building (General building's age has been taken as 50 years)	1.0
k_2	Terrain category (terrain category 2 has been considered for the present study) and height multiplier (pressure has been calculated for heights 50m, 100m, 150m, 200m, 250m), so values for various heights have been given respectively	1.17, 1.24, 1.28, 1.30, 1.32
k_3	Topography factor, for the plane area the upwind slope will be <3°	1.0
k_4	The factor for the cyclonic region, the present building is a general building	1.0
k_d	Directionality factor, the building in the present study has a square base	0.9
k_a	Area averaging factor, as the area will be >100m^2 in each case	0.8
k_c	Combination factor for combined effects of wind loads	0.9

Table 3
Design pressure at various heights of the building.

Hourly mean wind speed, Vz (Vz = Vb.k1.k2.k3.k4) (m/s)	Wind pressure at height z, pz (pz = 0.6Vz2) (N/m^2)	Design wind pressure, pd (pd = kd.ka.kc.pz) (N/m^2)
51.48 (at height 50m)	1590.11	1144.88
54.56 (at height 100m)	1786.08	1285.98
56.32 (at height 150m)	1903.17	1370.28
57.2 (at height 200m)	1963.10	1413.43
58.08 (at height 250m)	2023.97	1457.26

From Table 3, it can be seen that the design pressure increases with the increase in height of the building, and it is because of the rise in velocity magnitude with an increase in height. The wind velocity increase with increasing height from the earth's surface since the effect of the earth's atmospheric boundary decreases with an increase in height. The magnitude of design pressure increases with the height of the building in a similar way as the pressure coefficient values increases in CFD results.

5. Conclusion

The main focus of this paper is to observe the influence of interference and wind direction on the wind-induced pressure on the principal building surface. It is found that variation of wind pressure depends upon the location of a point of observation and the generalization for predicting the influence of wind incident angles is difficult. A few conclusions derived from the study are given as:

- For Face A of the principal building opposing the interfering building, at 0° wind incidence angle, the value of pressure decreases by as during interference this face experiences negative pressure while when interference is not there this face experiences max. Positive pressure. While at 90° wind incidence angle its value decreases by 78% when interference is provided. These variations have been calculated regarding isolated building

- For Face B of the principal building, there is a decrease in the value of negative pressure, its value decreases by 68%, 4%, and 71% for 0°, 45°, and 90° wind incidence angle.

- For Face C, the value of the pressure changes maximum at 90° wind incidence angle. At this angle, the value of negative pressure decreases by nearly 80%.

- For Face D, at 0° wind incidence angle, there is negative pressure, and its value decreases by 71% when interference is provided. For 45° wind incidence angle, the value remains the same almost as wind strikes directly on this face. For the 90° wind incidence angle, the value of positive pressure decreases by 45%.

- In the case of 0° wind, there is negligible pressure all over the building surfaces, as the interfering building covers the principal building, while in the case of 45° and 90° wind, there is high positive pressure too.

- The pressure values from analytical analysis increase with the increase in height of the building in a similar way as the pressure coefficient values from CFD increase.

Due to interference, the windward face of the principal building experiences negative pressure (suction) because of the turbulence effect. The wind-induced pressure on the other faces also changes significantly. Thus this interference effect must be taken into consideration while designing the buildings close to other high-rise buildings.

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