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Research Paper

Numerical simulation of Wind induced mean interference between two tall buildings

Santosh Gurjar, Jignesh. A. Amin*

[a] *Department of Civil Engineering, Sardar Vallabhbhai Patel Institute of Technology, Vasad, India*

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ABSTRACT

The assessment of wind loads on structure is generally carried out using existing codes/standards. The specifications of these codes are based on wind tunnel experiment performed on an isolated building. However, the buildings seldom exist in isolated condition. Neighbouring building may either increase or decrease the wind loads on principal building, this effect is known as interference effect. In this paper interference effect between two buildings is studied through numerical simulation using ANSYS CFX. Total drag force and interference factors for the principal building is calculated in the presence of interfering building having height ratio of 0.5, 0.75,1, 1.25, and 1.5. The results show that the upstream interfering buildings cause certain shielding effect by decreasing the mean wind load on the downstream principal building. However an amplification effect is also observed for certain location of the interfering building on upstream side. For buildings of the same cross-section, the interference factor (IF) decreases with the increase of the height of interfering building, indicating increase in the shielding effects. However the shielding effect on principal building is found to be significant when the heights of interfering buildings range from 0.75 to 1.5 of the height of the principal building. The along-wind force of the downstream principal building reduced to zero when the upstream interference building of height ratio more than one was two to three times the building breadth away from the principal building.

1 Introduction

The trends for construction of tall buildings are increasing day by day due to the increase in population, scarcity of land, and the consequent increase in land prices especially in metropolitan areas. The development of more advanced construction materials such as high strength concrete with compressive strength exceeding 100MPa and advances in structural analysis and design has made construction of tall buildings more feasible. Design of tall building is mainly governed by the lateral load namely the wind loads therefore the estimation of wind loads on tall building is significant. However, tall buildings rarely exist in an isolated condition in the urban areas. The presence of the neighbouring buildings changes the pattern of wind flow around the buildings. Neighbouring building may either increase or decrease the wind loads on principal buildings. The main parameters which affect the interference mechanism are size and shape of the buildings, wind velocity, wind direction, type of terrain, location and proximity of interfering building.

* *Corresponding author. Tel.: +091 992554327.*
E-mail address: jamin_svit@yahoo.com

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The wind induces forces and vibrations are not recent concerns. Many researchers had worked and still working on the various area of wind engineering, like characteristics of wind pressure for tall as well as low-rise buildings, wind flow around buildings, dynamic response of tall structures, interference effects etc. There have been fairly good amount of interference studies between smaller group buildings with specific arrangement of buildings. Harris [1] found that torque on the Empire State Building in New York would be doubled, if two building blocks were built across the two streets adjacent to building. However, resurrection of studies on the interference effects occurred in the early seventies. This sudden interest could perhaps be traced back to the collapse of three out of the eight natural draft-cooling towers at Ferrybridge, England in 1965, which was attributed to the interference effects. Kelnhofer [2], Melbourne and Sharp [3], and Ahuja et al. [4], have measured the effects of changing the relative height of upstream building on wind loads on a downstream building. For a couple of buildings of same size in tandem arrangement, Sakamoto and Haniu [5] investigated that the along-wind force of the downstream building reduced to zero when the upstream building was three times the building breadth away from the downstream building and the mean drag force might be negative when the spacing was less than this critical distance. Taniike [6] observed that the shielding effects could be still noticeable when the upstream interfering building was sixteen times of the building breadth away from the downstream principal building. Author had suggested a mean interference factor of 0.8, for mean alongwind forces on the downstream building. Khanduri et.al [7] summaries the research advancements in the area of wind-induced interference on structures and highlighted the seriousness of the interference effects. Xie and Gu [8] investigated the interference effect between two and three tall structures using wind tunnel tests. Shielding and channelling effects are discussed to understand the complexity of the multiple building effects. Gomes et al. [9] investigated the wind pressure distributions experimentally and numerically using CFD software Fluent on the inner faces of L-shape and U-shape models. The authors found general good agreement between the wind tunnel and numerical results for normal wind incidence, whereas some differences have occurred for other directions. Amin and Ahuja [10, 11] investigated the mean interference effects between two rectangular buildings arranged in close proximity in a geometrical configuration of 'L' and 'T' plan shape through wind tunnel test and also assessed the effectiveness of wind orientation and location of upstream building in changing the responses of tall buildings. Agarwal et. al. [12] analyzed the interference effect between two tall rectangular building using boundary layer wind tunnel testing and also discussed the effect of reduced wind velocity on the interference mechanism. Weerasuriya [13] evaluated the wind pressure distribution on 112 m tall building using CFD simulation and compared it with wind tunnel test results. Mittal et. al. [14] addressed the issues of pedestrian wind environment near tall buildings and interference effect between two and three tall buildings.

Wind tunnel tests are frequently used to evaluate the wind loads or interfering mechanism of high rise structures. It provides more accurate assessment of wind flow around a high rise structure but it is time consuming and costly, Whereas CFD offers more flexibility in conducting parametric studies for different flow conditions, geometries and complex surroundings at a cheaper cost. While phenomenon has been investigated; there is still shortage of information related to the effects of the height of the interfering building on the principal building. In this paper effort are made to investigate the mean alongwind interference effects between two tall rectangular buildings using CFD package ANSYS CFX. Total drag force and Interference factors for the principal building is calculated in the presence of interfering building having height ratio of 0.5,0.75,1, 1.25, and 1.5.

2 Description of Simulation

2.1 Simulation of Wind Velocity Profile

The velocity profile may be represented by the logarithmic law or power law. Generally for civil engineering application power law are widely used. In this study, the wind velocity profile similar to terrain category-II as mentioned in IS 875 part-III [15] having a power law exponent 0.133 is simulated. As per the power law the wind velocity is defined using following equation.

$$U(z) = U_0 \left(\frac{z}{z_0} \right)^{\alpha} \tag{1}$$

Where U_0 is the basic wind speed taken as 12 m/s at the top of the building under consideration. In the present study, computational fluid dynamic package called ANSYS CFX is used to evaluate the wind pressures on the principal building in isolated condition as well as in presence of the interfering building.

2.2 Details of building model

The buildings are modelled with a geometrical scale of 1:300 and K-ε model for the numerical simulation. The k- ε models use the gradient diffusion hypothesis to relate the Reynolds stresses to the mean velocity gradients and the turbulent viscosity. The turbulent viscosity is modelled as the product of a turbulent velocity and turbulent length scale. k is the turbulence kinetic energy and is defined as the variance of the fluctuations in velocity. It has dimensions of (L^2 T^{-2}). ε is the turbulence eddy dissipation and has dimensions of per unit time. The continuity equation and momentum equations are:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho U_j\right) = 0 \tag{2}$$

$$\frac{\partial U_i}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho U_i U_j\right) = -\frac{\partial p'}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu_{eff}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right] + S_M \tag{3}$$

Where S_M is the sum of body forces, μ_{eff} is the effective viscosity accounting for turbulence, and p is the modified pressure. ρ and U denote density and velocity respectively. The k-ε model is based on the eddy viscosity concept, so that

$$\mu_{eff} = \mu + \mu t \tag{4}$$

μt is the turbulence viscosity.

$$\mu t = C_{\mu\rho}\frac{k^2}{\varepsilon}x^2 \tag{5}$$

The values of k and ε come directly from the differential transport equations for the turbulence kinetic energy and turbulence dissipation rate:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho k U_j\right) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu t}{\sigma k}\right)\frac{\partial k}{\partial x_j}\right] + P_k + P_b - \rho\varepsilon - Y_M + S_k \tag{6}$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial}{\partial x_j}\left(\rho \varepsilon U_j\right) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu t}{\sigma \varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \rho C_1 S_\varepsilon - \rho C_2 \frac{\varepsilon^2}{k + \sqrt{\upsilon\varepsilon}} + C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}P_b + S_\varepsilon \tag{7}$$

P_k represents the generation of turbulence kinetic energy due to the mean velocity gradients, P_b is the generation of turbulence kinetic energy due to buoyancy and Y_M represents the contribution of the fluctuating dilatation in compressible turbulence to the overall dissipation rate, C_1 and C_2 are constants. $\boldsymbol{\sigma}_k$ and $\boldsymbol{\sigma}_\varepsilon$ are the turbulent prandtl numbers for k (turbulence kinetic energy) and ε (dissipation rate). The values considered for $C_{1\varepsilon}$, $\boldsymbol{\sigma}_k$ and $\boldsymbol{\sigma}_\varepsilon$ are 1.44, 1 and 1.2 respectively.

2.3 Details of domain and meshing

Domain should be large enough to avoid reflecting of fluid streams, which may cause abnormal pressure fields around the model. In the present study, domain size is decided as per the guideline given by Franke et al. [16]. The domain has 5h upstream fetch, 15h downstream fetch, 5h side and top clearance, where h represents the height of the building model as shown in Fig. 1. Such a domain is large enough for the formation of vortex on the leeward side and avoids reverse wind flow. Furthermore, no blockage correction is required. For meshing the domain, tetrahedron elements having three sides and three nodes are used. The finer mesh is used near the building compared to other location so as to accurately determine the higher gradient region of the fluid flow. To avoid any unconventional flow, the mesh inflation is provided near the boundaries. The velocity of wind provided at inlet of domain is according to the wind velocity profile generated using power law equation. No slip wall is used for building faces, whereas for top and side faces of the domain free slip wall is used. The relative pressure at outlet is 0 Pa. The operating pressure considered in the domain is 1 atm, i.e. 101,325 Pa. The Reynolds number of the model ranges from 3.7×10^6 to 4.0×10^6.

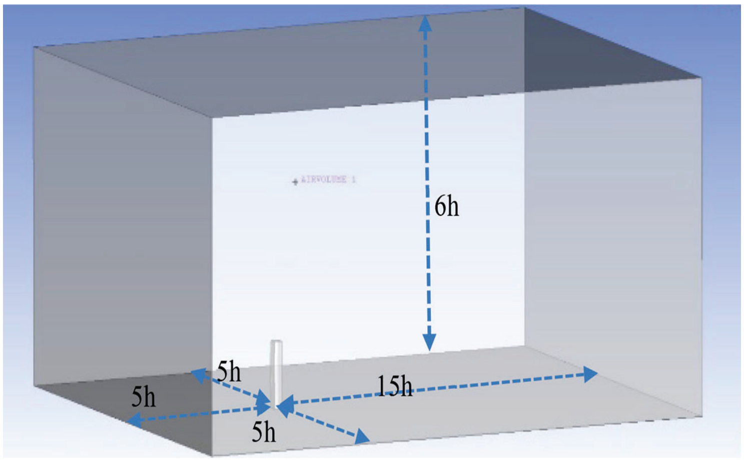

Fig.1- Computational domain for numerical simulation

3 Parametric Study

Prototype principal building having a cross sectional dimensional of 30 m x30 m and height of 150 m. Interfering building is considered with same cross-sectional area as that of the principal building but having different height i.e. 0.5h,0.75h,1h,1.25h and 1.5h, where h is the height of the principal building. The considered buildings as well as velocity profile are modelled at length scale of 1:300 using commercially available SFD software ANSYS CFX. The scaled down dimension of the principal building is 100 mm ×100 mm × 500 mm. Turbulence is modelled using the standard k-ε model due to its low computational time, high numerical stability, and availability of verification data for wide variety of flows. The numerical simulation is carried out for the principal building in the isolated as well as in interference conditions. Different arrangement of buildings for interference study is shown in Fig. 2. The principal building-C is placed at fixed position i.e. at (0, 0). The interfering building-A is placed at different X and Y co-ordinate from the principal building. X coordinate varies from 2b to 10b (2b.4b, 6b, 8b, 10b) and Y coordinate varies from b to 3b (b, 2b, 3b).

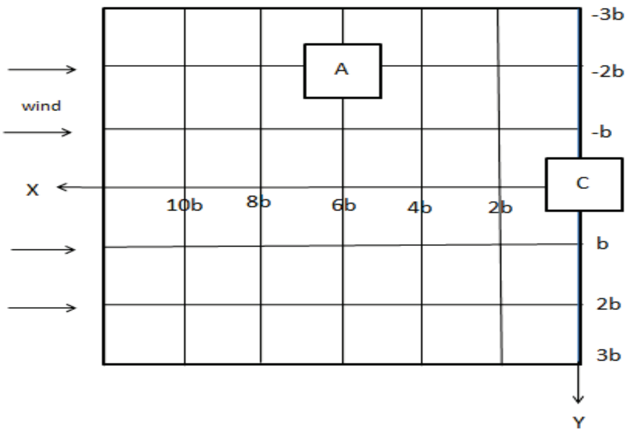

Fig.2- Arrangement of principal as well as interfering building

Generally, wind induced interference effect is represented in terms of interference factor (IF), which can be defined as:

$$IF = \frac{\text{Drag force on a building when interfering building is present}}{\text{Drag force on duilding when building is situated in isolated condition}}$$

The interference factor represents the severity of the neighboring interferences on the wind induced responses of the principal building. The interference factor less than one indicate the reduction in the wind induced drag forces i.e. shielding effects, whereas the IF equal to one indicate the presence of the obstruction building causes no change on the alonwind force or response, values more than one indicate increase in the alongwind force on the principal building as compared to building in isolation. The main parameters which affect the manner in which one building modifies the forces on another nearby building are size and shape of the building, wind velocity and direction, type of terrain and above all, the location and proximity of neighbouring building.

3.1 Wind pressures on principal building in isolated condition

The pattern of wind flow around principal building in isolated condition is shown in Fig.3. The positive wind pressure coefficient distribution is observed on the windward face. The values of the pressure coefficients are increasing from bottom to top due to the boundary layer wind flow. The negative wind pressure distribution is observed on the leeward face due to formation of wake on the downstream side. On the side faces, negative wind pressure coefficient zone is developed. The high value of pressure coefficient is observed on edges and corners of side faces, due to flow separation. The magnitude of the pressure efficient on leeward wall is lower than that of the side wall pressure coefficients. The contours of pressure coefficient on different faces of considered isolated building are shown in Fig. 3. For validation of the ANSYS CFX results, the pressure coefficients obtained on the square isolated building using ANSYS CFX are compared with the available pressure coefficients on the similar buildings having an aspect ratio of 5 in various Codes/Standards and experimental results of Amin and Ahuja [17]. Table 1 shows the evaluated pressure coefficients using ANSYS CFX on wind ward and leeward faces, which are almost comparable with experimental results of Amin and Ahuja [17], ASCE-7 [18] and AS/NZS 1170-02 [19]. Little discrepancy in the pressure coefficient on the leeward faces may be due to formation of the unsteady vortices in the wake regions near to leeward faces.

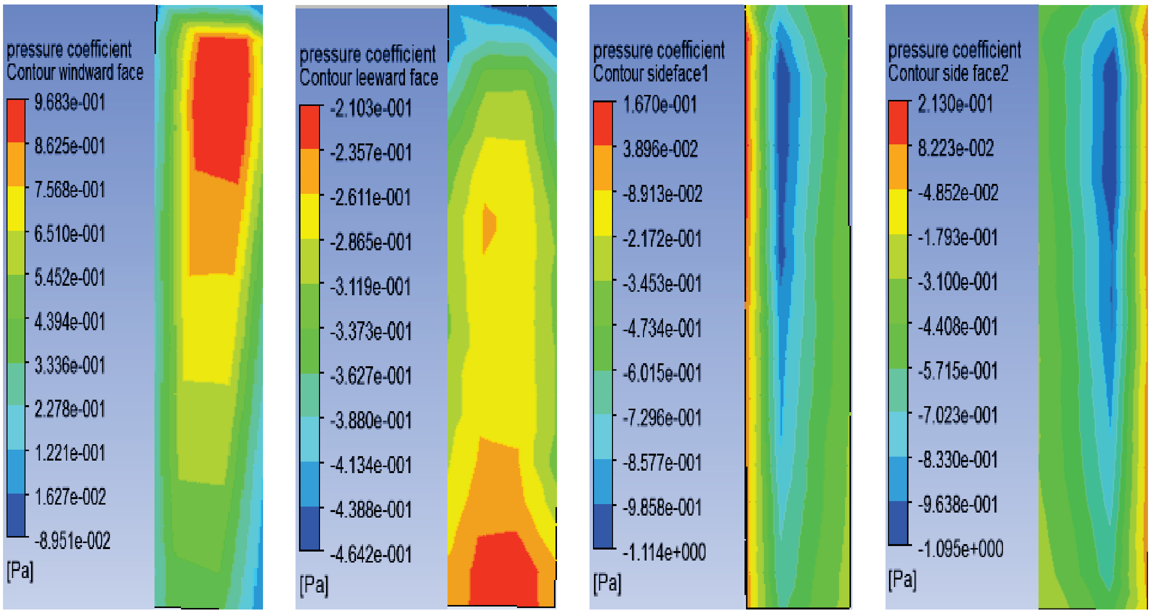

Fig.3- Pressure coefficient contour on all faces of square plan shaped building in isolated condition

Table 1 - Comparison of wind pressure coefficient on principal building model

Wind loading standards	Windward face	Leeward face	Side face	Side face
ANSYS CFX (Present study)	0.78	-0.4	-0.71	-0.71
IS: 875, Part-III [15]	0.8	-0.25	-0.8	-0.8
ASCE 7-10 [18]	0.8	-0.5	-0.7	-0.7
AS/NZS1170-2 (2002) [19]	0.8	-0.5	-0.65	-0.65
Amin and Ahuja [17]	0.74	-0.5	-0.69	-0.69

4 Results and Discussions of Interference Effects

The wind pressure coefficients on the principal buildings are evaluated in the presence of the interference building on upstream side at different position as mentioned in Fig. 2 at wind incidence angle of 0^0. The flow pattern of wind around isolated building and when interfering building is placed at centre to centre distance of 4b from the principal building is shown in Fig. 4.

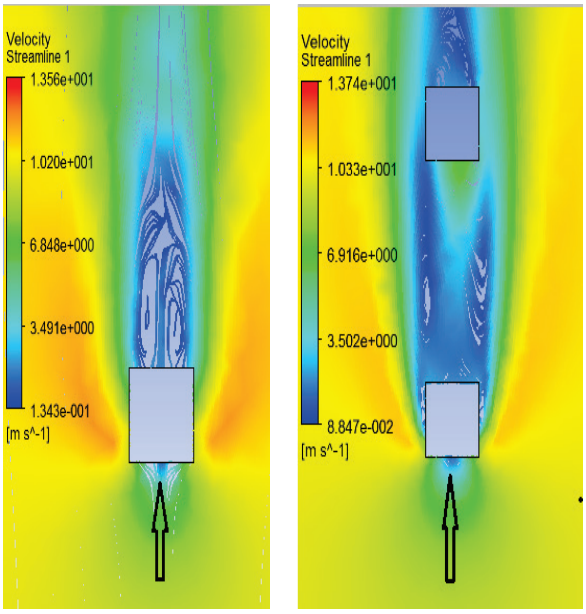

Fig.4 wind flow pattern around isolated building as well as in interference condition

English [20], incorporated several results from wind tunnel test and gave a polynomial regression equation to obtain the interference factor of the downstream building for two buildings placed in tandem arrangement as below.

$$IF = -0.05+0.65x+0.29x^2-0.24x^3 \quad (8)$$

Where, $x = \log [S(h+b)/hb]$, S is the clear spacing between the two buildings placed in tandem arrangement, b is the width of the principal buildings, and h represents the height of the principal buildings. The comparison of interference factor obtained from the present study and the obtained from the regression equation given by English [20], when two buildings are placed in tandem arrangement is shown in Table-2 to check the accuracy of the results of present study. Although some difference in IF is found due to different flow condition and method of testing, the comparison shows a good agreement between the interference factor of present study and the results obtain from the equation proposed by English [20]. However the difference in the interference factors obtained in the present study and that of obtained by English [21], are reduces with the increase of spacing of interfering building.

Table 2 - comparison of IF values when buildings are placed in tandem arrangement

Co-ordinate	(2b,0)	(4b,0)	(6b,0)	(8b,0)	(10b,0)
English [20]	0.00	0.36	0.52	0.6	0.67
Present Study	0.01	0.31	0.45	0.54	0.61

In the present study, efforts are made to evaluate the along-wind interference effects of principal rectangular tall building subjected to interference from another tall building of same cross-section as that of principal building but having different heights. The different height ratios (height of principal to interference building) of 0.5, 0.75,1, 1.25 and 1.5 are considered in this study to evaluate the effects of height of interference on the along-wind forces on the principal building. The interference effects on the principal building due to interference building of different height are discussed as follows.

Case I: Effect of interfering building with the height ratio 1

Windward face of the principal building is subjected to negative pressure coefficient for some location of interfering building being it in wake region. The magnitude and distribution of pressures on wind ward and side faces of principal building is varies considerably in presence of interference building at different locations as compared to pressures on similar building in isolated case. Presence of interference building reduces the magnitude of pressure coefficients on the leeward face of principal building as compared to isolated condition. The IF contour for the along-wind forces on the principal building due to the interference of upstream building of height ratio of 1 (Hr = 1) is shown in Fig. 5(a). It is apparent that, the mean along-wind force on downstream principal building is reduced due to the presence of the upstream interference building. Significant amount of shielding or reduction in drag force on the principal building is observed when both buildings are in tandem arrangement. Interference factor is found negligible when the interfering building placed at a distance of two times building breadth away from the principal building in tandem arrangement, indicating a major shielding effects. The drag force on the principal building is reduces as much as 69%, when the interfering building is placed at centre to centre distance of 4b from the principal building. In the IF contour, values of interference factor is observed one in some regions indicating that principle building behaves like an isolated building when interfering building is present in these regions. The drag force on principal building is increases as much as 12% for some position of interfering buildings of height ratio of one.

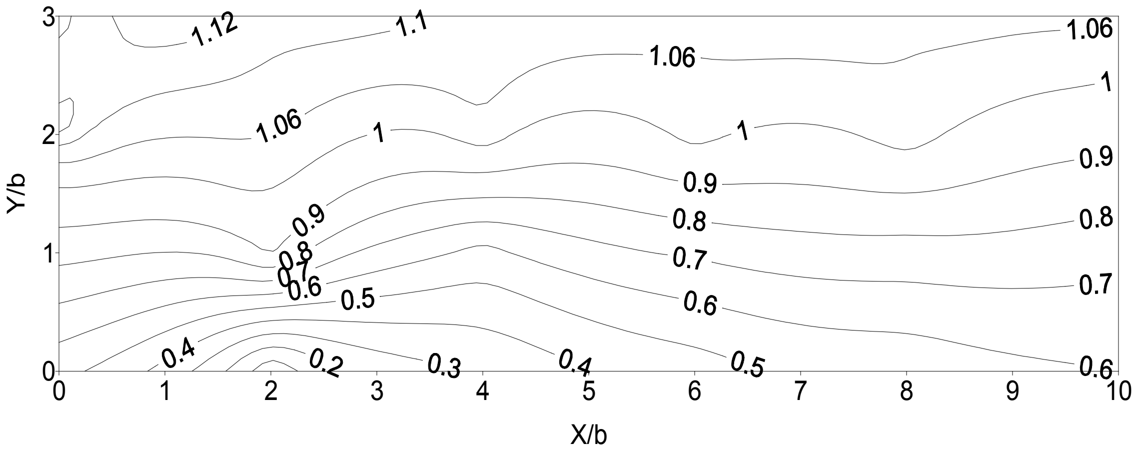

Fig. 5 (a) Contour of interference factor for Hr=1

Case II: Effect of interfering building with height ratio 0.5

The entire leeward face as well as bottom part of windward face of the principal building is subjected to comparatively lesser pressure as compared to similar building in isolated position in presence of upstream interfering building of height ratio 0.5. However the values of wind pressure coefficient on leeward faces of the principal building (case-II) are higher as compared to case I (Hr=1). The IF contour for the along-wind forces on the principal building due to the presence of upstream interfering building of height ratio of 0.5 (Hr = 0.5) is shown in Fig. 5(b). The along-wind force on the principal building is reduces as much as 20% due to the presence of upstream interference building of height 0.5h at coordinate (2b, 0). When the upstream interference building has the 50% less height than the downstream principal building, it produces insignificant shielding effect. The drag force on downstream principal building is increases as much as 6% for some position of upstream interfering building of height ratio of 0.5.

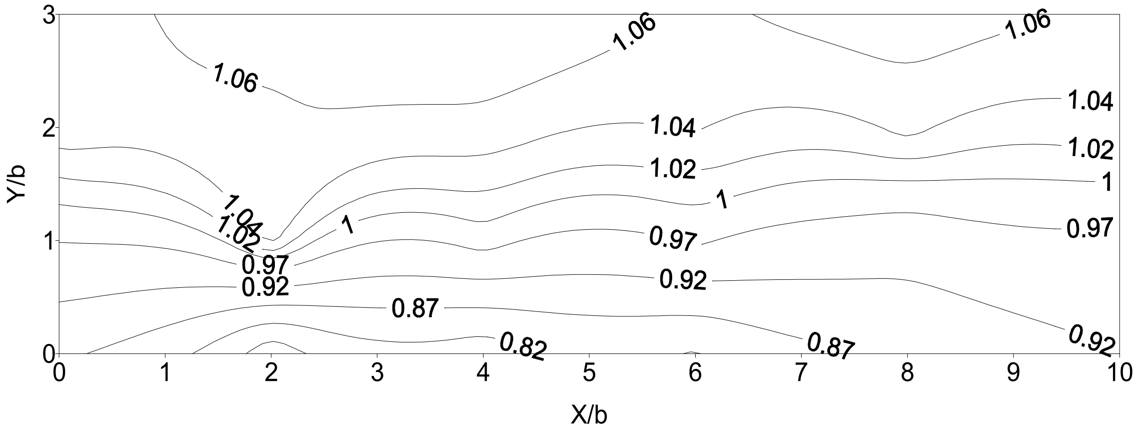

Fig. 5(b) Contour of interference factor for Hr = 0.5

Case III: Effect of Interfering building with height ratio 0.75

Bottom part of the windward face of the principal building is subjected to negative pressure, whereas the upper part is experience the positive pressure due to the presence of the upstream interference building at some location in tandem arrangement. The leeward face and windward face of the principal building is subjected to comparatively lesser pressure as compared to similar building in isolated position in presence of upstream interfering building of height ratio 0.75. However the values of wind pressure coefficient on leeward faces of the principal building (Hr = 0.75, case-III) are slightly higher as compared to case I (Hr=1). The IF contour for the along-wind forces on the principal building due to the interference of upstream interfering building of height ratio of 0.75 (Hr = 0.75) is shown in Fig. 5(c). For this type of arrangement, the value of interference factor varies from 0.45 to 1.07. In general, the shielding produced by the interfering building (Hr = 0.75) is comparatively higher as compared to that of produced by the interfering building of height ratio 0.5. Maximum interfering factor of 1.07 is observed, indicating the interfering buildings of height ratio of 0.75 can increase the along-wind load on the principal building nearly 7%.

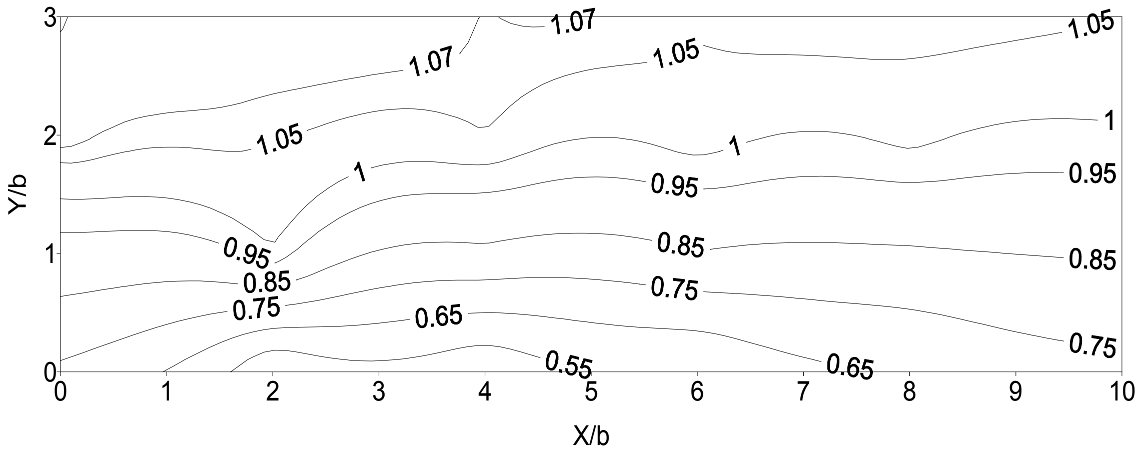

Fig.5(c) Contour of interference factor for Hr=0.75

Case IV: Effect of Interfering building with height ratio 1.25

Windward face of the principal building is subjected to negative pressure due to the presence of the interfering building of height ratio 1.25 exactly in front of the principal building at a distance of 2b to 6b in tandem arrangement. Contour of IF for the along-wind forces on the principal building due to the presence of upstream interfering building of height ratio 1.25 (Hr = 1.25) is shown in Fig. 5(d). The along-wind force of the downstream principal building reduced to zero when the upstream interference building was two to four times the building breadth away from the downstream building. The along-wind force on principal building is increases as much as 12% or even more for some position of interfering buildings of height ratio of 1.25.

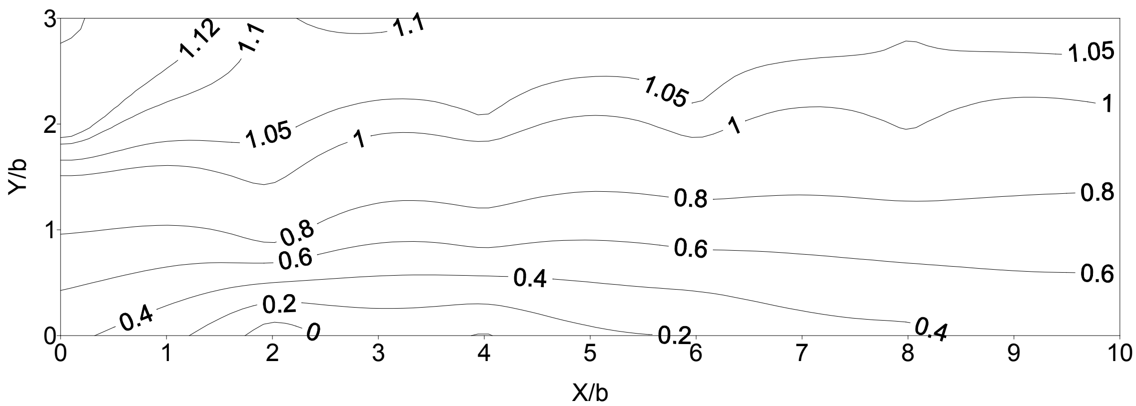

Fig. 5 (d) Contour of interference factor for Hr=1.25

Case V: Effect of interfering building with height ratio 1.5:

The pressure coefficient distribution on windward face and leeward face of the principal building in this case is almost similar as that of the case-IV, i.e. when the interfering building with the height ratio 1.25 is present in front of downstream building. The contour of IF for the along-wind forces on the principal building in presence of upstream interference building of height ratio of 1.5 (Hr = 1.5) is shown in Fig. 5(e). The presence of the upstream building having height more than the principal building produces significant shielding effect. The along-wind force on the principal building is reduces as much as 90% due to the presence of upstream interference building of height 1.5h at coordinate (4b, 0) to (5b,0). The along-wind force of the downstream principal building reduced to zero when the upstream interference building was two to four times the building breadth away from the downstream building. The drag force on principal building is increases as much as 13% or even more for some position of interfering buildings of height ratio of 1.5.

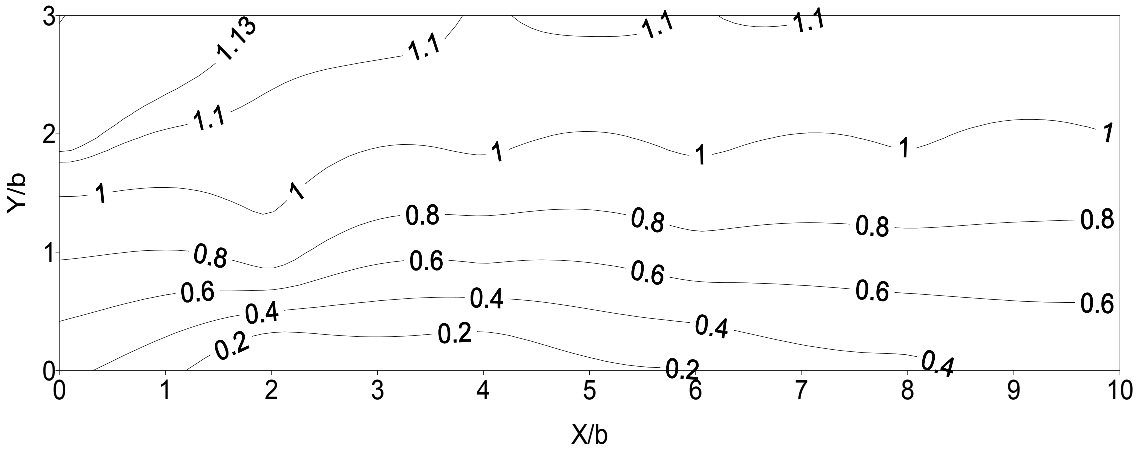

Fig. 5(e) Contour of interference factor for Hr =1.5

Fig. 6 (a), 6(b), 6(c) shows the variation of pressure coefficient along the vertical centreline of the wind ward face, leeward face and side face of principal building model respectively when interfering building placed at coordinate (4b,0). The pressure coefficients on different faces of principal building as well as the along-wind interference effects are sensitive to the height of the interfering building. It is also observed that the entire windward face of the principal building is subjected to suction being in wake region due to the presence of the interfering building of height ratio 1.25 and 1.5. Whereas the pressure coefficient on the leeward face and side face of the principal building is reduces in presence of upstream interfering building of all height ratio as compared to similar building in an isolated position.

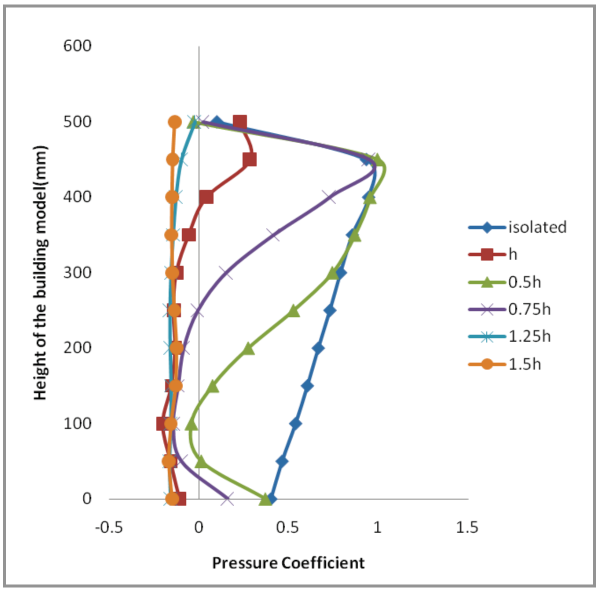

Fig. 6(a)- Variation of pressure coefficient along vertical centreline of windward face

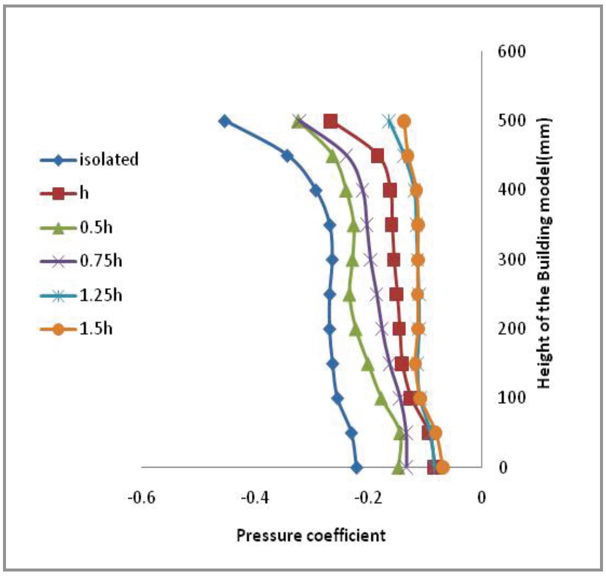

Fig. 6(b)- Variation of pressure coefficient along vertical centreline of leeward face

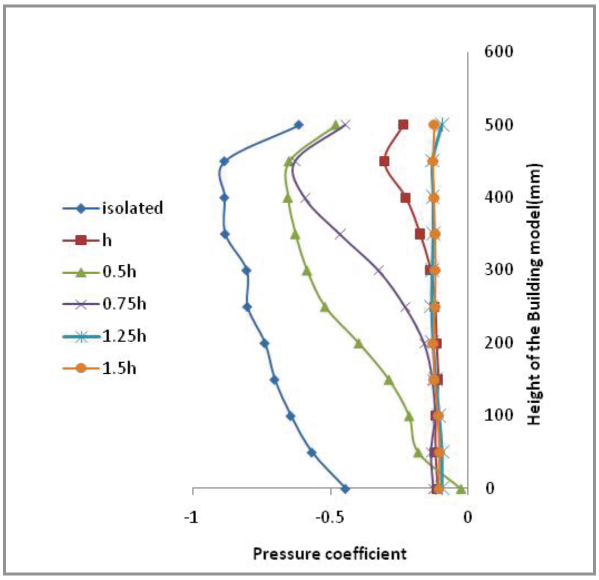

Fig. 6(c)- Variation of pressure coefficient along vertical centreline of side face

Channeling effect

When two buildings are placed in side by side arrangement, the pressures acting on the on the principal buildings are increased due to wind flow passing through the passage between the two buildings. This effect of increased in pressure or along-wind load on principal building is known as channeling effects. Channeling effect has been mentioned in various literature, but detail discussion on this effect is not found in the previous studies because this effect is relatively insignificant compared to the shielding effect. The maximum interference factor 1.13 is noticed in the present study when the location of interfering building of Hr =1.5 is located side-by-side at the coordinate (0,2b) to (0,3b) from the principal building. Interfering buildings of height ratio (Hr ≥1) cause stronger channeling effect, and the mean along-wind load on the principal building may increase with the increase of the height of the interfering buildings. The mean wind load on the principal building can be increase as much as 15 to 20% depending on the height and spacing of the interfering building.

5 Conclusions

The mean interference effects between two buildings are investigated by computational fluid dynamics using ANSYS CFX software. The effects of the height of upstream interference on principal building are also discussed. The significant outcomes of the present study are summaries as follows.

- The effects of the upstream interference building in tandem arrangement shows shielding effects and the corresponding mean along-wind interference factors are less than 1.0. The along-wind force of the downstream principal building reduced to zero when the upstream interference building (Hr ≥1) was two to three times the building breadth away from the downstream building. However the some location of interfering building away from tandem arrangement produces amplification of along-wind force as much as 10% as compared to building in isolation and the corresponding mean interference factors are more than 1.0.
- Channelling effect is observed when two building is placed at side-by-side arrangement. Maximum interference factor of 1.13 is observed, when interfering building is placed at (0,3b) coordinate. The mean wind load on the principal building can be increase as much as 15 to 20% depending on the height and spacing of the interfering building.
- Wind load on the principal building could also affected by the height of the interfering buildings. The interference effects are sensitive to the breadth of the interfering buildings. The results show that interference from lower interfering building with Hr ≤ 0.5 is negligible. Whereas the interference from the interfering building in the range of 0.5 to 1.25 is significant. The shielding effect is almost constant for interfering building with Hr ≥ 1.25.

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