WIND INDUCED INTERFERENCE EFFECTS ON A ROW OF THREE BUILDINGS WITH IRREGULAR PLAN SHAPE

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ABSTRACT

Pressure measurements on a model of a tall building with irregular plan shape have been carried out in a boundary layer wind tunnel under isolated and grouped conditions to study the interference effects. The grouped condition includes a row of three buildings with same plan shape and with fixed center to center spacing. The principal instrumented building model has been placed in center and edge locations of the grouped condition. The interference effects on mean pressure coefficients, various mean force coefficients and mean torsion moment coefficients have been investigated for different angles of wind incidence. Interference effects are observed to be significant on the largest mean drag coefficient and largest absolute mean lift coefficient of the center building. Whereas, only largest absolute mean lift coefficient of the edge building is affected due to interference. Further, the interference effects on r.m.s and peak force/moment coefficients have also been studied.

Keywords: Tall building, Irregular plan shape, Wind tunnel, Force coefficients, Interference effects

Introduction

In urban environments, irregular plan shapes are being considered for many of the tall buildings due to various functional reasons/requirements. Further, rows of such tall buildings with same plan shape are being constructed in townships, which are becoming common in many of the metropolitan cities in India and in other Asian countries. Lam et al. (2008 & 2011) studied the interference effects on a row of closely placed five square plan tall building models in wind tunnel with parallel and diamond patterns by measuring forces using base balance technique and also by measuring pressures on each face. Hui et al. (2012 & 2013) studied interference effects on local peak pressure coefficients of two high rise building models with different plan shapes (square/rectangle) for various relative locations and angles of wind incidence. However, very few studies are reported in literature on buildings with irregular plan shapes. Earlier, the interference effects on mean drag, lift and torsion moment coefficients of a 101 m tall residential building with a specific irregular plan shape as shown in Figure 1(a) have been studied in a boundary layer wind tunnel under grouped condition of a row of three building models in diamond arrangement (Arunachalam et.al., 2011). In the present study, the interference effects on the mean and r.m.s force/moment coefficients of the building have been investigated under a grouped condition of row of three building models in parallel arrangement with fixed center to center spacing. The interference effects on the center building (Figure 1(b)) and the edge building (Figure 1(c)) have been studied by comparing the
evaluated mean drag and lift coefficients, and mean torsion moment coefficient values for different angles of wind incidence. The interference effects on r.m.s and peak force/moment coefficients have also been studied.

![Schematic plan views of the building model](image)

**Fig. 1** Schematic plan views of the building model (a) isolated condition (with pressure tap numbers) (b) center location in grouped condition (c) edge location in grouped condition

**Pressure Measurement Studies in Boundary Layer Wind Tunnel**

The present study has been conducted in the Boundary Layer Wind Tunnel (BLWT) available at CSIR-Structural Engineering Research Centre, Chennai, India. It has a test section of 2.5 m (width) x 1.8 m (height). The mean velocity profile (power law coefficient of 0.21), turbulence intensity profile and along-wind turbulence spectrum corresponding to sub-urban terrain have been simulated with a simulation length scale of 1:250. The model of the building has been instrumented at two levels (L1 and L2) corresponding to $z = 0.7H$ and $0.35H$ (where $H$ is the total height of the model = 472 mm, $z$ is the elevation from the base of the model), respectively. At each level, 30 pressure taps have been provided along the periphery of the building model as shown in Figure 1(a). Pressure measurements have been made using a Hi-Scan Multi-Channel Pressure Measurement System supplied by PSI Pressure Measurements, USA. Simultaneous pressure measurements have been made with a sampling rate of 600 samples per second per channel, for a duration of 15 s and with mean velocity at the height of the model ($\bar{U}_H$) equal to 13.4 m/s. For the isolated and each of the grouped conditions, 16 different angles of wind incidence ($\theta$) (Figure 1(a)) have been considered between $0^\circ$ and $360^\circ$.

**Results and Discussion**

The measured pressure data has been analysed to evaluate pressure coefficients using the reference pressure corresponding to mean wind velocity values at $z = 0.7H$ and $0.35H$ for L1 and L2, respectively, as given below.
where,

\[ p_{\text{ref}} = \frac{1}{2} \rho \bar{U}_z^2 \quad (\text{N/m}^2) \]  

\[ \bar{U}_z = \text{Mean velocity at height ‘}z\text{’ of the model (m/s) (for L1: } z = 0.7H; \text{ L2: } z = 0.35H) \]

Further, force coefficients along the two orthogonal body fixed axes (Figure 1(a)) have been evaluated using Eq. (3) for the both levels by using a reference width \((B)\) of 0.212 m for all angles of wind incidence. These force coefficients have been further resolved into drag and lift directions as shown in Figure 1(a) to obtain drag \((C_{D})\) and lift \((C_{L})\) coefficients.

\[ C_{F_x}(t) = \frac{F_x(t)}{B p_{\text{ref}}}; \quad C_{F_y}(t) = \frac{F_y(t)}{B p_{\text{ref}}}; \]  

where \(F_x(t)\) and \(F_y(t)\) = wind induced forces along \(X\) and \(Y\) axes, respectively, derived using \(p(t)\)

The torsional moment coefficient values have also been obtained for both the levels by using the reference width \((B)\) of 0.212 m for all angles of wind incidence as given below:

\[ C_T(t) = \frac{T(t)}{B^2 p_{\text{ref}}} \]  

where \(T(t)\) = wind induced torsional moment derived using \(p(t)\)

**Comparison of mean coefficients for L1**

Figure 2 shows the comparison of the variation of mean drag coefficient values for L1. It can be seen from Figure 2 that the mean drag coefficient values for the center building are significantly more than the isolated building values for \(\theta\) in the ranges of 0°–45° and 150°–210° and are significantly shielded for \(\theta\) in the ranges of 60°–120° and 240°–300°. For the edge building, the mean drag coefficient values are comparable to the isolated building values for most values of \(\theta\) except around 90°. The largest mean drag coefficient value for the center building is observed to be 1.63 (for \(\theta = 0^\circ\)), which is about 25% more than that for the isolated building. The increase in mean drag coefficient value has been studied by comparing the mean pressure coefficients for \(\theta = 0^\circ\) (Figure 3). The mean suction pressure coefficient values on the leeward faces (pressure taps 19 to 25) of the center building are observed to be significantly more than the isolated building values, which lead to the significant increase in the mean drag coefficient for the center building. The largest absolute mean lift coefficient values are observed to be 0.416 (for \(\theta = 240^\circ\)) and 0.6 (for \(\theta = 330^\circ\)) for the center and edge buildings, respectively, which are about 27% and 83% more than that for the isolated building (Figure 4). However, mean lift coefficient values are observed to be less than the mean drag coefficients. Figure 5 shows that except for \(\theta\) of 90° and 270°, the mean torsional moment
coefficient values are negative. The largest absolute mean torsional moment coefficient values for the center and edge buildings are observed to be comparable to the isolated building value.

Fig. 2 Comparison of mean drag coefficient values for L1

Fig. 3 Comparison of mean pressure coefficient values for L1 ($\theta = 0^\circ$)

Fig. 4 Comparison of mean lift coefficient values for L1

Fig. 5 Comparison of mean torsional moment coefficient values for L1
Comparison of r.m.s coefficients for L1

Figure 6 shows the comparison of variation of r.m.s drag coefficients with angle of wind incidence for L1. It can be seen from Figure 6 that the r.m.s drag coefficient values for the center building are significantly more than the isolated building values for $\theta$ in the ranges of $0^\circ$–$45^\circ$, $150^\circ$–$210^\circ$ and $330^\circ$–$360^\circ$ and are significantly less for other $\theta$. For the edge building, the r.m.s drag coefficient values are either comparable to or less than the isolated building values for most values of $\theta$ except for $315^\circ$. The largest r.m.s drag coefficient value for the center building is observed to be 0.43 (for $\theta = 0^\circ$), which is about 8% more than that for the isolated building. Figure 7 shows that the r.m.s lift coefficient for center building is significantly more than the value for isolated building for $\theta$ of $0^\circ$ and $180^\circ$. Similarly for edge building, the r.m.s lift coefficient value is more for $\theta$ of $180^\circ$. The largest r.m.s lift coefficient values are observed to be 0.328 (for $\theta = 0^\circ$) and 0.315 (for $\theta = 180^\circ$) for the center and edge buildings, respectively, which are about 12% and 8% more than that for the isolated building (Figure 7). However, it is to be noted that r.m.s lift coefficient values are observed to be less than the r.m.s drag coefficients, which could due to the irregular plan shape of the building. Figure 8 shows that the largest r.m.s torsional moment coefficient values for the center and edge buildings are observed to be less than the value for isolated building.

![Fig. 6 Comparison of r.m.s drag coefficient values for L1](image1)

![Fig. 7 Comparison of r.m.s lift coefficient values for L1](image2)
Comparison of statistical peak drag coefficients for L1

Since the magnitudes of both mean and r.m.s drag coefficients are more than the mean and r.m.s lift coefficients, statistical peak drag coefficients have been evaluated by considering mean and r.m.s drag coefficients along with a statistical peak factor of 3.7 [AS/NZ 1170.2 (2002)]. Figure 9 shows the comparison of the variation of the evaluated statistical peak drag coefficient with angle of wind incidence for L1. The comparison is observed to be similar to that for mean drag coefficient values. The largest statistical peak drag coefficient value for the center and edge buildings are observed to be 3.25 (for $\theta = 0^\circ$) and 2.89 (for $\theta = 210^\circ$), which are about 20% and 7% more than that for the isolated building. The critical angles of wind incidence are observed to be $0^\circ$, $180^\circ$ and $210^\circ$ for the center building.

Comparison of drag coefficients for L2

The comparison of various evaluated coefficients are observed to be similar in nature to L1, only the comparison of mean, r.m.s and statistical peak drag coefficient values has been made. Figures 10-12 show the comparisons for mean, r.m.s and statistical peak drag coefficients for L2. The trends are observed to be almost similar for mean, r.m.s and statistical peak drag coefficients. The largest mean, r.m.s and statistical peak drag coefficient values for the center building are observed to be 1.86, 0.496 and 3.697 (for $\theta = 0^\circ$), which are about 30%, 15% and 25% more than the corresponding values for the isolated building. It is to be noted these coefficients L2 are observed to be 14-20% more than those for L1. Further, the interference
effects are also observed to be more for L2 than for L1. This could be due to the edge effects on L1 which is close to top of the building.

![Fig. 10 Comparison of mean drag coefficient values for L2](image)

![Fig. 11 Comparison of r.m.s drag coefficient values for L2](image)

![Fig. 12 Comparison of statistical peak drag coefficient values for L2](image)

**Conclusions**

In the present study, the interference effects on a row of three buildings with a specific irregular plan shape have been investigated using pressure measurements. The principal building model has been instrumented with 30 pressure taps at each of the two levels of 0.7\(H\) and 0.35\(H\) (L1 and L2). Pressure measurements have been made on the instrumented building model in the isolated condition, and in center and edge locations of the grouped condition. For the isolated building the mean drag coefficient values at L1 are observed to be 1.2, 0.94, 1.25
and 0.976 for 0°, 90°, 180° and 270° angles of wind incidence, respectively. The mean drag coefficient values are observed to be significantly increased for the center building under grouped condition for a few angle of wind incidence ranges. Based on the comparison of mean pressure coefficient distribution along the circumference of the building plan shape, the significant increase in the mean drag coefficient for center building is attributed to the significant increase in the mean suction pressure coefficients in the wake region. For mean and r.m.s values of drag and lift coefficients, the interference effects are observed to be more for center building than for edge building. Further, in general, mean and r.m.s drag coefficients are observed to be more than the mean and r.m.s lift coefficients for all the angles of wind incidence. Hence, statistical peak drag coefficient values have been evaluated and compared. The critical angles of wind incidence are observed to be 0°, 180° and 210° for the center building with high statistical peak drag coefficient values. For the center building, the largest values of peak drag coefficients among all the angles of incidence are observed to be 25%, 8% and 20% more than those corresponding to isolated building at L1. The largest mean, r.m.s and statistical peak drag coefficients for L2 are observed to be 14-20% more than those for L1. Further, the interference effects are also observed to be less for L1 than for L2. This could be due to the edge effects on L1 which is close to top of the building. The largest of absolute mean and r.m.s torsional moment coefficients for center and edge buildings are observed to be less than those observed for isolated building. Based on the study on three buildings in a row with specific irregular plan, the statistical peak drag coefficient values, which govern the design wind loads, for center building under grouped condition are observed to be more by about 20% and 25% than those for isolated building at L1 and L2, respectively.

Even though, the study corresponds to a building with specific plan shape and in a specific grouped condition, it highlights the magnitude of adverseness that can be caused by the surrounding buildings on both the strength design criteria of a building.

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