BBAA VI International Colloquium on:
Bluff Bodies Aerodynamics & Applications
Milano, Italy, July, 20-24 2008

EXPERIMENTAL STUDY OF WIND PRESSURES ON IRREGULAR-PLAN SHAPE BUILDINGS

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Keywords: Wind Pressure Coefficients, L-shape Building, T-shape Building, Bluff Body, Boundary Layer Flow, and Flow Separation.

Abstract

This paper presents the experimental results of wind tunnel model tests to evaluate wind pressure distributions on different faces of typical-plan shape buildings. Models, having the same plan area and height but varying plan shape ("L" and "T") are tested in a closed circuit wind tunnel under boundary layer flow. The models are made from Perspex sheets at a geometrical scale of 1:500. The effectiveness of the model shape in changing the surface pressure distribution is assessed over an extended range of wind directions from 0^0 to 180^0 at an interval of 15^0. Fluctuating values of wind pressure are measured at pressure points on all surfaces and mean, maximum, minimum and r.m.s. values of pressure coefficients are evaluated. The experimental data for "L" and "T" plan shaped building models showed different wall pressure distributions from those expected for rectangular/square models. It is also observed that there is a large variation in pressure along the height as well as along the width of different faces of the models. The location and magnitude of the measured peak pressure co-efficient vary considerably with wind direction. It is also observed that changing the plan dimensions considerably affects the wind pressure distributions on different faces of the building models.

1 INTRODUCTION

Resent advances in the development of high strength materials coupled with more advanced computational methods and design procedures have lead to a new generation of tall buildings which are slender and light. These buildings are very sensitive to the two common dynamic loads-wind and earthquakes. It is necessary to address the serviceability issue, such as human comfort and integrity of structural components during the strong winds. While designing high-rise buildings and its cladding for wind load, the designers refer to relevant codes/standards to pick the wind pressure coefficients and wind force coefficients [1-3]. The Indian code IS: 875 (part-3)-1987 [3] gives the design pressure coefficients and force coefficients for square and rectangular buildings having different side ratios and height, but this code remains silent about the pressure coefficients on typical plan shape tall buildings such as ‘L’ and ‘T’.

Further wind loads evaluated from codes have the following limitations. Wind load/pressure information in codes/standards (i) does not account for the aerodynamic effect of the actual shape of the structure since they are based on box like buildings and (ii) does not allow for any detailed directional effects and assume that the design wind speed will always occur from the aerodynamically severe wind direction. On the other hand, wind tunnel model studies, which are often used to assist in the prediction of the design wind loads for the cladding and structural frame specifically on tall buildings, (i) do physically simulate and predicts the aerodynamics effect of the actual shape of the structure by modeling building in detail, (ii) consider the directionality of the wind climate for the area where the study building is located, and (iii) overall, provide indispensable wind-effect data for the design of the cladding and structural frame work. Therefore, it is proposed to carry out wind tunnel studies on models of “L” and “T” plan shape tall buildings in order to obtain appropriate values of wind pressure coefficients as well as wind pressure distribution on different faces of models.

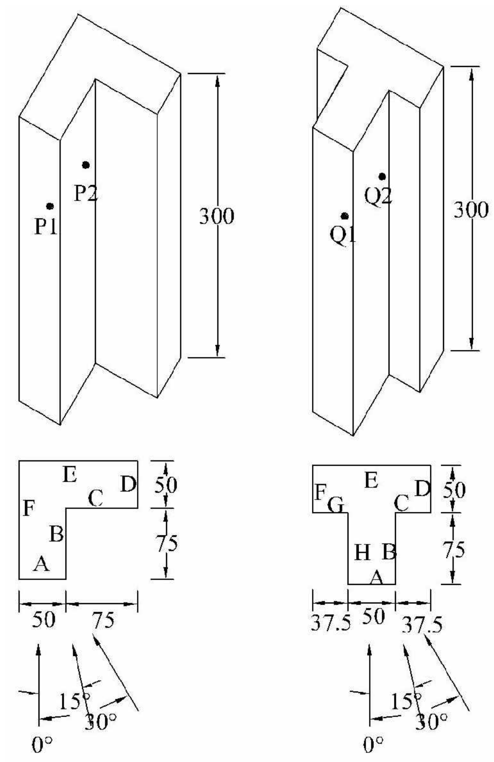
2 EXPERIMENTAL PROGRAMME

2.1 Details of models

The models used for the experiments are made of transparent perspect sheets (6 mm thickness) at a geometrical model scale of 1:500. Plan area (10,000 mm^2) and height (300 mm) of both the models having “L” and “T” plan shape are kept same for comparison purpose. The plan and isometric view of the building models are shown in Fig. (1). Both the models are instrumented with more than 150 numbers of pressure taps at six different height levels 25, 75,125,175, 225 and 275 mm from bottom to obtain a good distribution of pressures on all the faces of building models. These pressure taps are placed as near as possible to the edges of the faces to capture the high pressure variation at the edges of the faces.

2.2 Wind flow characteristics

The experiments are carried out in closed circuit wind tunnel at Indian Institute of Technology Roorkee (India) under boundary layer flow. The wind tunnel has a test section of 8.2 m length with a cross sectional dimensions of 1.15 m (width) x 0.85 m (height). Models are placed at a distance of 6.1 m from the upstream edge of the test section. A reference pitot tube is located at a distance of 3.5 m from the grid and 500 mm above the floor of wind tunnel to measure the free stream velocity during experiments. The variation of mean wind velocity with height at the test section is shown in Fig. (2). Velocity profile inside the tunnel has a power-law index (α) of 0.133.



Model-1 (L-shape) Model-2 (T-shape)

Fig. 1 Plan and isometric view of building models

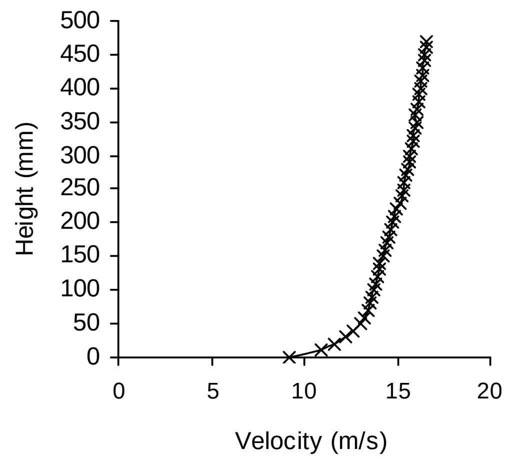


Fig. 2 Velocity profile at the test suction

3 RESULTS AND DISCUSSIONS

Mean, r.m.s., maximum and minimum pressure coefficients on all the surfaces of L-and T-shape building model are evaluated from the fluctuating wind pressure records at all pressure points over an extended range of wind incidence angle namely 0^0 to 180^0 at an interval of 15^0. This information is much useful while designing claddings and structural systems of this type of high-rise building for lateral load.

3.1 L-shape building model

Fig. (3a) and (3b) show the pressure coefficient contours on L-shape building model for wind incidence angle of 0^0 and 30^0 respectively. The general characteristics and observed pressure distribution on different faces of L-shape building model are summarized as follows:

For wind incidence angle of 0^0, it is observed that the frontal face-A is subjected to positive pressure. However, wind pressure coefficients distribution does not remain symmetrical about the vertical centerline as in the case of rectangular/square bluff body. It increases from left edge to right edge (towards the re-entrant corner) of face-A. It is also observed that the positive mean pressure coefficient increases along the height on face-A of the building model due to increase in wind velocity with height and it varies from 0.35 to 1. Inner faces B and C are also subjected to pressure of almost uniform intensity. Although face-B is parallel to face-F, which is a side face, it is subjected to pressure and not suction due to blockage of flow by face-C, which causes stagnation of flow in that re-entrant corner. It is the peculiar characteristics of L-shape building. Side faces D and F are subjected to negative pressure, which increases slightly from windward to leeward edge due to separation of flow. The leeward face-E is subjected to suction but the variation of suction along the height as well as along the width is almost negligible. Value of mean wind pressure coefficient near the base is around -0.55 and its value near the top is around -0.7.

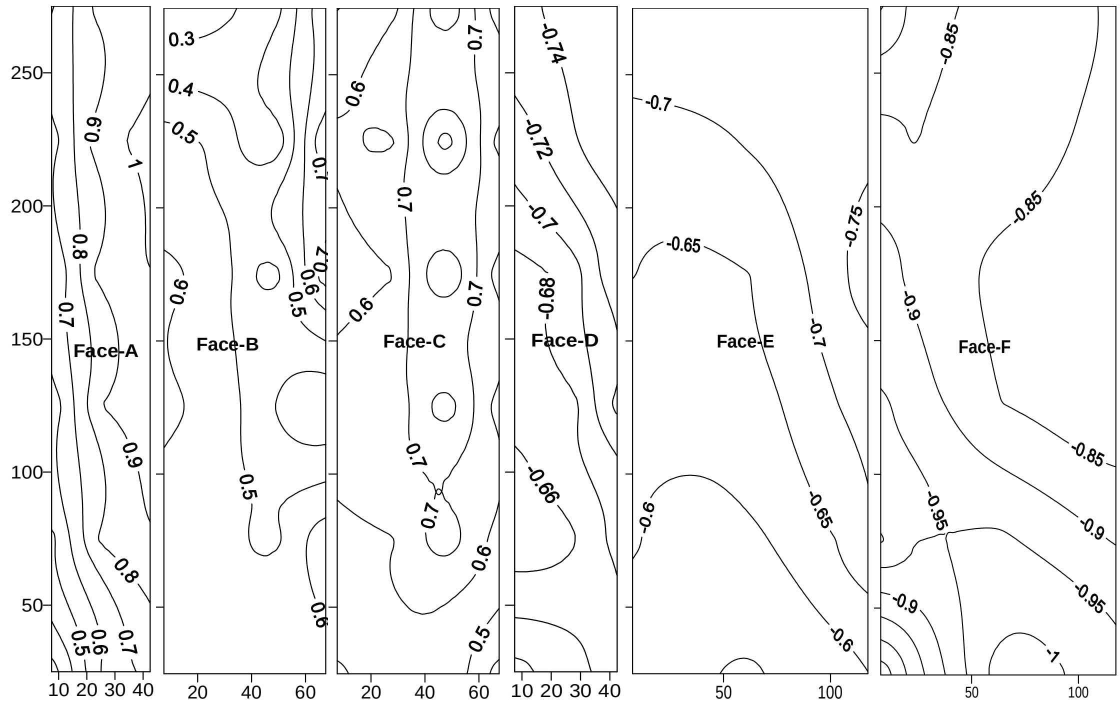


Fig. 3a Mean surface pressure coefficient distribution- Model-1 (Angle-0^0)

As the angle of incident wind increases, a positive pressure on the frontal wall (face-A) reduces. However, higher positive pressure still exists on the re-entrant corner. At the skew wind incidence angles between 30^0 and 60^0, portion of inner faces B and C towards the re-entrant corners attracts more wind pressures (Fig. (3b)). Wind incidence angle in the range of 30^0 and 60^0, depending up on the width of the inner faces, governs the cladding design of faces B and C. The face-D is subjected to a maximum negative pressure coefficient of the order of -1.2 at wind incidence angle of 30^0. Beyond the wind incidence angle of 45^0, the face-A is subjected to a negative pressure and a maximum negative pressure coefficient of -1.6 is noticed at wind incidence angle of 60^0. The faces E and F are subjected to negative pressures up to wind incidence angle 90^0 and the values of mean wind pressure coefficients are in the range of -0.7 and -1.0. Contours for other wind incidence angle are not shown here due to paucity of space.

At wind incidence angle of 105^0, the positive pressure increases near the outer side of inner face-B. This can be attributed to the direct incidence of flow on that small area, after skipping over the opposing wing, with a consequent increase of the values.

For wind incidence angles between 120^0 and 180^0, the inner faces of the L-shaped model are not directly exposed to the flow, being rather under the wake region influence. As a consequence, the pressure coefficient distribution is negative (suction) and almost uniform. When the wind incidence angle is 180^0 i.e. normal to face-E, positive pressures are developed on the frontal face-E similar to the square/rectangular bluff body with a parabolic variation across the width. The central portions of the face-E are subjected to more pressure as compared to the edge portion with values of maximum mean wind pressure coefficient as 1.07. All the remaining five faces of the model are subjected to negative pressure in the range of -0.69 to -1.08 without any significant changes across the section.

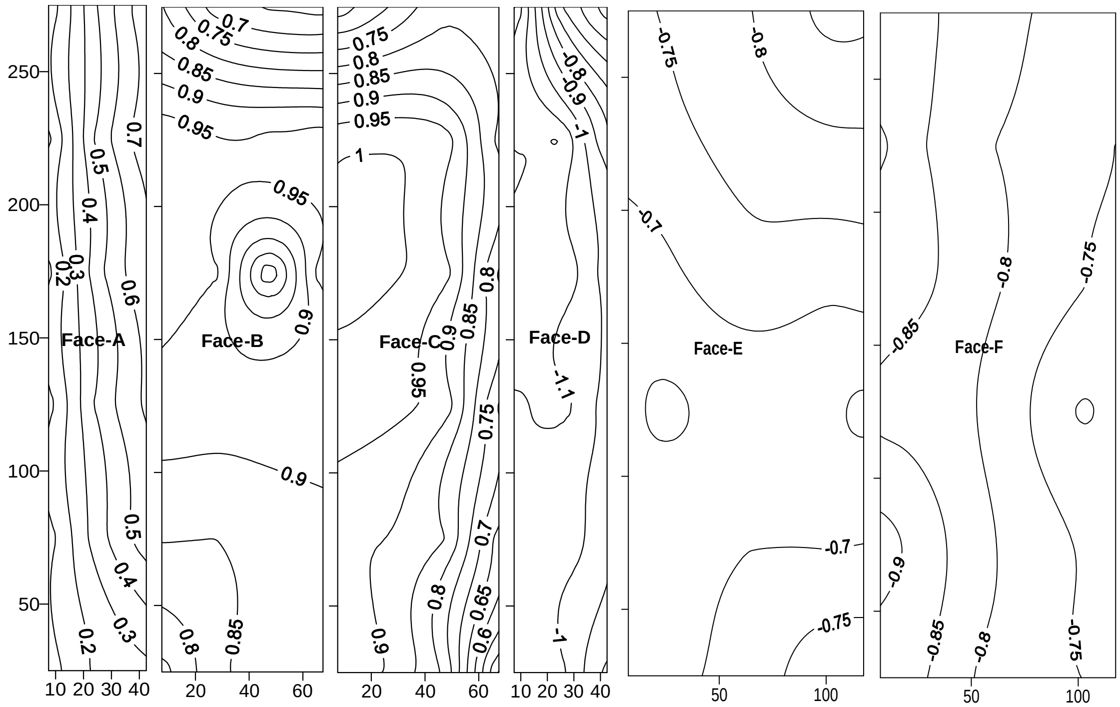


Fig. 3b Mean surface pressure coefficient distribution- Model-1 (Angle-30^{0})

Influence of wind incidence angle on wind pressure values on different surfaces of L-shape building model are shown in Figs. (4a) and (4b). It is observed from Figs. (4a) and (4b) that the wind incidence angle has great influence on the pressure values. At the same section on the model, pressure varies from –1.0 to 1.0 approximately, when wind incidence angle changes from 0° to 180°. Further it is noticed that, whereas suction does not vary with height appreciably, pressure values increase with height of the building.

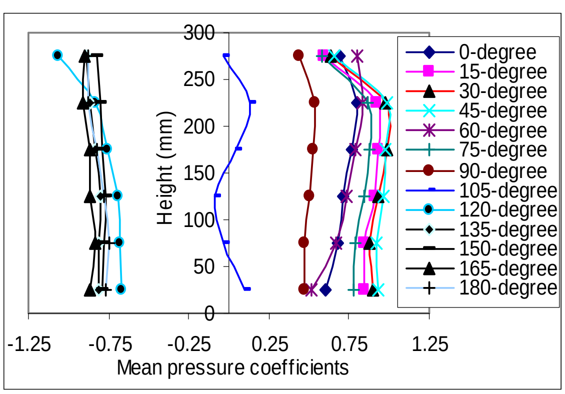


Fig. 4a Variation of mean pressure coefficients with height at 7.5 mm from re-entrant corner on Face-B (model-1)

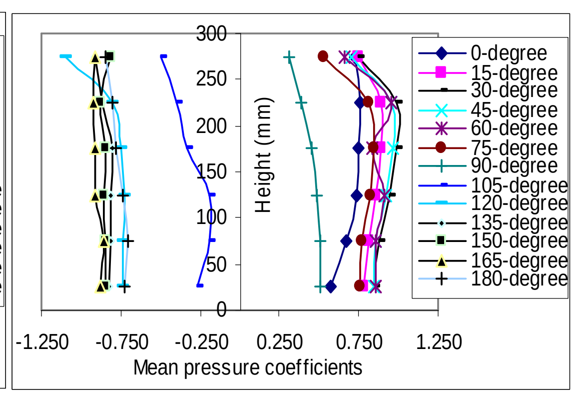


Fig. 4b Variation of Mean pressure coefficients along the vertical centerline of Face-C (model-1)

Fig. (5a) and (5b) show the variation of wind pressure coefficient values with wind incidence angle at two typical points, one on face-A and another on face-B. It is seen from Fig. (5a) that point P1 on face-A experiences pressure for wind incidence angle of 0^0 to 40^0, after which it experiences suction, where as positive pressure is maximum at 0^0 wind incidence angle, i.e.1.0, suction is maximum i.e. -1.35 at 60^0. Variations of $C_{p,\ max}$, $C_{p,\ min}$, $C_{p,\ mean}$ and $C_{p,rms}$ with wind direction are also identical. Pont "P2" on face-B is subjected to pressure for wind direction 0^0 to 105^0, after which it experiences suction. Pressure remains almost constant (0.75 to 1.0) for wind direction 0^0 to 75^0. Similarly suction remains almost constant (-0.75 to -0.9) for wind direction 120^0 to 180^0.

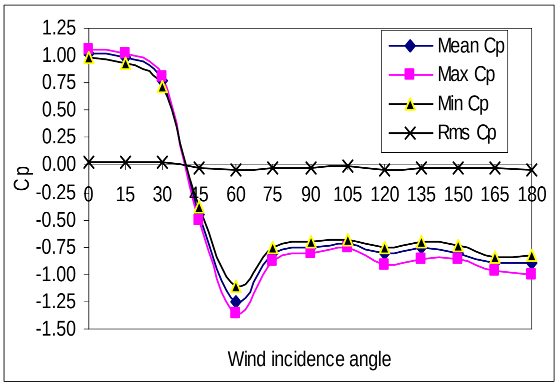


Fig. 5a Variation of wind pressure coefficients at point P1 (x=42.5 & y=225 mm) on Face-A (model-1)

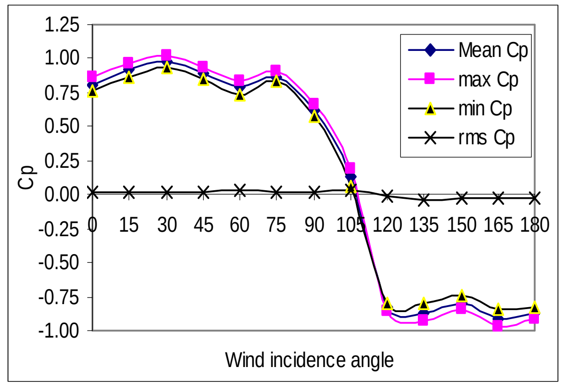


Fig. 5b Variation of wind pressure coefficients at point P2 (x=67.5 & y=225 mm) on Face-B (model-1)

3.2 T-shape building model

Fig. (6a) and (6b) show the pressure coefficient contours on T-shape building model for wind incidence angle of 0^0 and 30^0 respectively. The general characteristics and observed pressure distribution on different faces of T-shape building model are summarized as follows:

Since the flow is symmetrical about the central axis when the wind incidence angle is 0^0, the stagnation point is in the middle of the front face-A. It is observed that the frontal face-A is subjected to a positive pressure and value of mean pressure coefficients is observed to be increasing with height in the range of 0.6 to 1.0. It is also noticed that face-B and face-H of the T-shape model are subjected to negative pressures, where as face-B of the L-shape model is subjected to positive pressures. The exterior edge of face-C is subjected to a positive wind pressures due to direct incidence of flow on that small area, where as the portion towards the re-entrant corner of the face-C and G is partially submerged by the shear layers emanating from the upstream edge/block, thus subjected to suction. The pressure variation and magnitude of pressure coefficients on face-B is, thus largely affected by the length of face-C. The side face-D, face-F and leeward face-E are subjected to negative pressures, whereas the negative pressure coefficients on side face-D increases from windward to leeward edge. The variation of suction on leeward face-E along the height as well as along the width is almost negligible. The suction on the leeward and side faces of the building model is significantly affected by the ratio of the width of face-B and face-C.

At wind incidence angle of 15^0, inner faces-B and C are subjected to positive pressures and attract more pressure as compared to the 0^0 wind incidence angle. It is observed that as wind incidence angle increases the mean pressure coefficients on faces-B and C increase up to 45^0. The pressure coefficients at this wind incidence angle govern the cladding design of face B and C. For the wind incidence angle of 30^0, face-D is subjected large suction with a maximum value of mean wind pressure coefficients as -1.35. Similarly face-A of the model is subjected to a maximum suction at a wind incidence angle of 60^0.

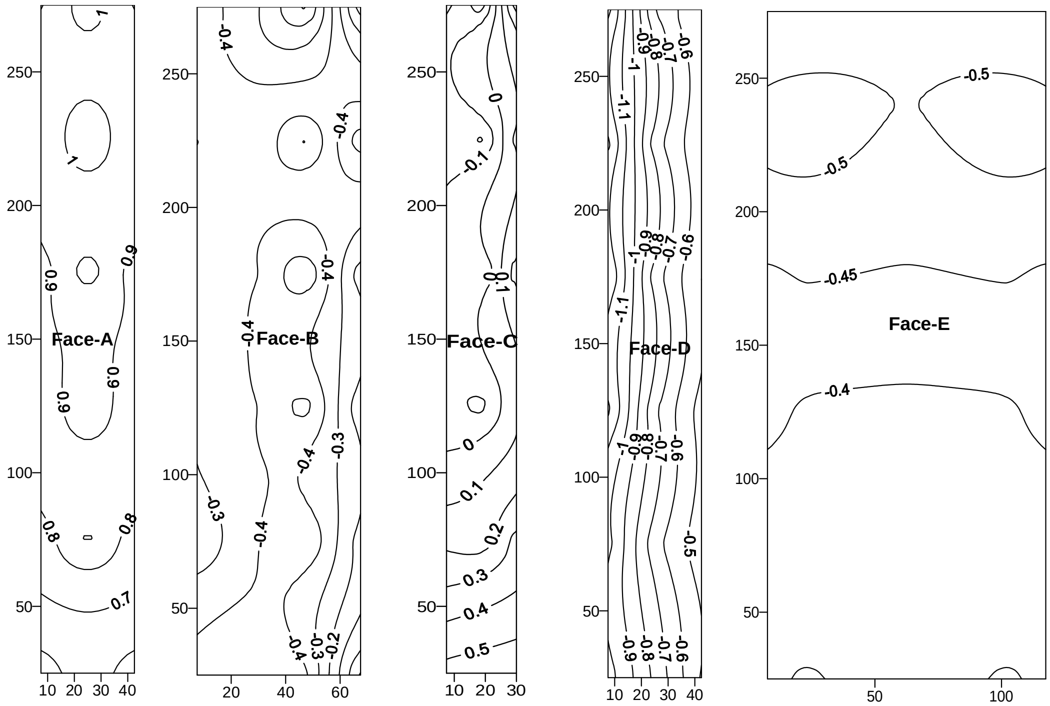


Fig. 6a Mean surface pressure coefficient distribution- Model-2 (Angle-0^0)

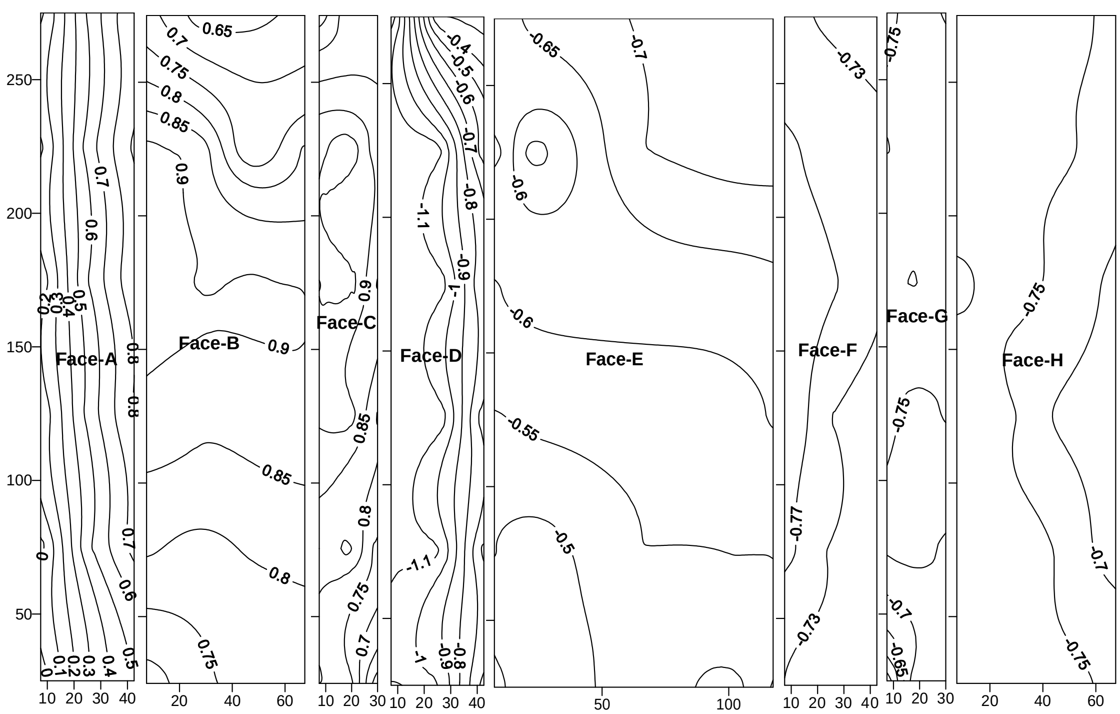


Fig. 6b Mean surface pressure coefficient distribution- Model-2 (Angle-30^0)

At wind incidence angle of 90^0, the inner faces B and C are subjected to a positive pressure as in the case of L-shape building model. The highest positive pressures on front wall-D are no longer in the middle of the faces as in the case of square/rectangular building models but are moved to position near the re-entrant corner. This is due to the effect of flow separation that leaves stagnant flow in that re-entrant corner.

For wind incidence angle of 105^0 and 120^0, the positive pressure still exists on face-B and face-C. This can be attributed to the direct incidence of flow on the face-B, after skipping over the opposing wing, with a consequent increase of the values.

For wind incidence angle between 135^0 and 180^0, the inner faces of the T-shape model are not directly exposed to the flow, being rather under the wake region influence. As a consequence, the pressure coefficient distribution is negative (suction) and almost uniform.

For wind incidence angle of 180^0 (i.e. normal to face-E), the wind flow is very similar to that of rectangular block in the upwind region. Two symmetrical vortices are formed on the either side of central portion of T-shaped model in the cavity on downwind side. The pressure coefficient on face-E along the height is increases due to boundary layer wind profile. The face-E subjected to maximum mean wind pressure coefficients of 1.02. All the remaining faces are subjected to a negative pressure in the range of 0.68 to 1.0 without any significant changes across the section

Fig. (7a) shows the variation of mean wind pressure coefficients along the height at a distance of 7.5 mm from the re-entrant corner on face-B. Fig. (7b) shows the variation of centerline mean wind pressure coefficients along the height on face-C of T-shape model. Great influence of wind incidence angle on mean wind pressure coefficient is observed.

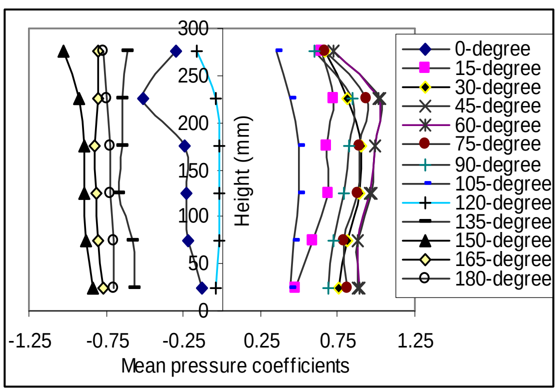


Fig. 7a Mean pressure coefficients variation at a distance of 7.5 mm from re-entrant corner on Face-B (model-2)

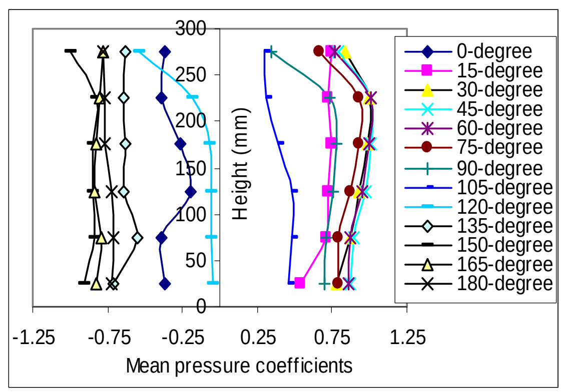


Fig. 7b Mean pressure coefficients variation along the vertical centerline of Face-C (model-2)

Fig. (8a) and (8b) show the variation of wind pressure coefficients at point Q1 having a co-ordinate of x = 42.5 mm and y = 225 mm on face-A and at point Q2, having a co-ordinate of x = 67.5 mm and y = 225 mm on face-B respectively. The origin of the each face is assumed at lower most left corner of each face to represent the co-ordinate of different points on the building models. It is observed from Fig. (8a) that face-A is subjected to a positive pressure up to wind incidence angle of 45^0 and there after is subjected to suction with maximum suction at 60^0. Beyond the angle of 90^0, the pressure coefficients on face-A do not change significantly. In case of point-B of face-B, positive pressure is maximum at 45^0 angle; where as absolute value of negative pressure is maximum at 150^0 angle.

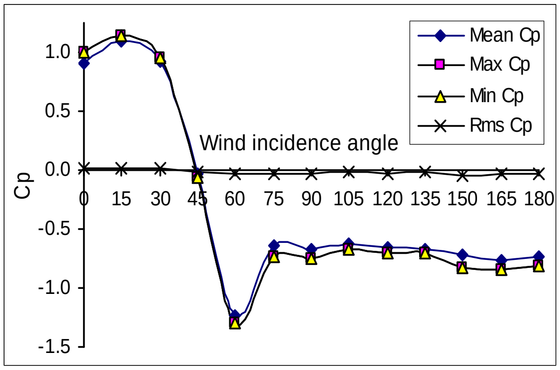


Fig. 8a Variation of wind pressure coefficients at point Q1 (x=42.5 & y=225 mm) on Face-A (model-2)

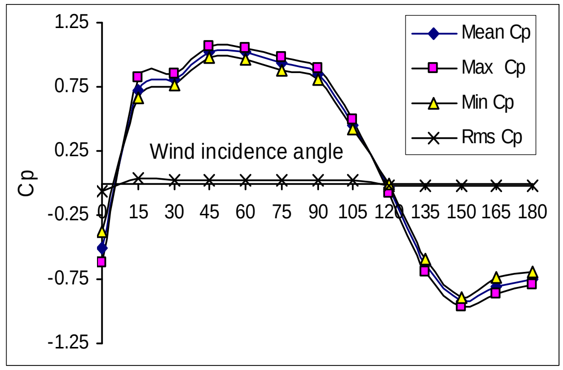


Fig. 8b Variation of wind pressure coefficients at point Q2 (x=67.5 & y=225 mm) on Face-B (model-2)

4 CONCLUSIONS

The following conclusions are drawn from the study reported in this paper.

(i) The wind pressure distribution on the frontal face-A of the L-shape building is not symmetrical about centre line of face as in case of T-shape building.

(ii) As the angle of incidence wind increases beyond 120^0, the pressure field in the inner faces of the L-shape building turns out to be negative and almost uniformly distributed.

(iii) The wind pressure coefficients distribution on inner faces-B and C of both buildings largely depend on the plan-shape and dimension of the inner faces of the buildings.

(iv) Change in the plan-shape of buildings considerably affects the suction on side faces and leeward faces.

(v) The results presented in the present paper can be incorporated in Indian Code IS: 875 (part-3)-1987 for the design of claddings and structural systems of typical plan shape buildings.

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