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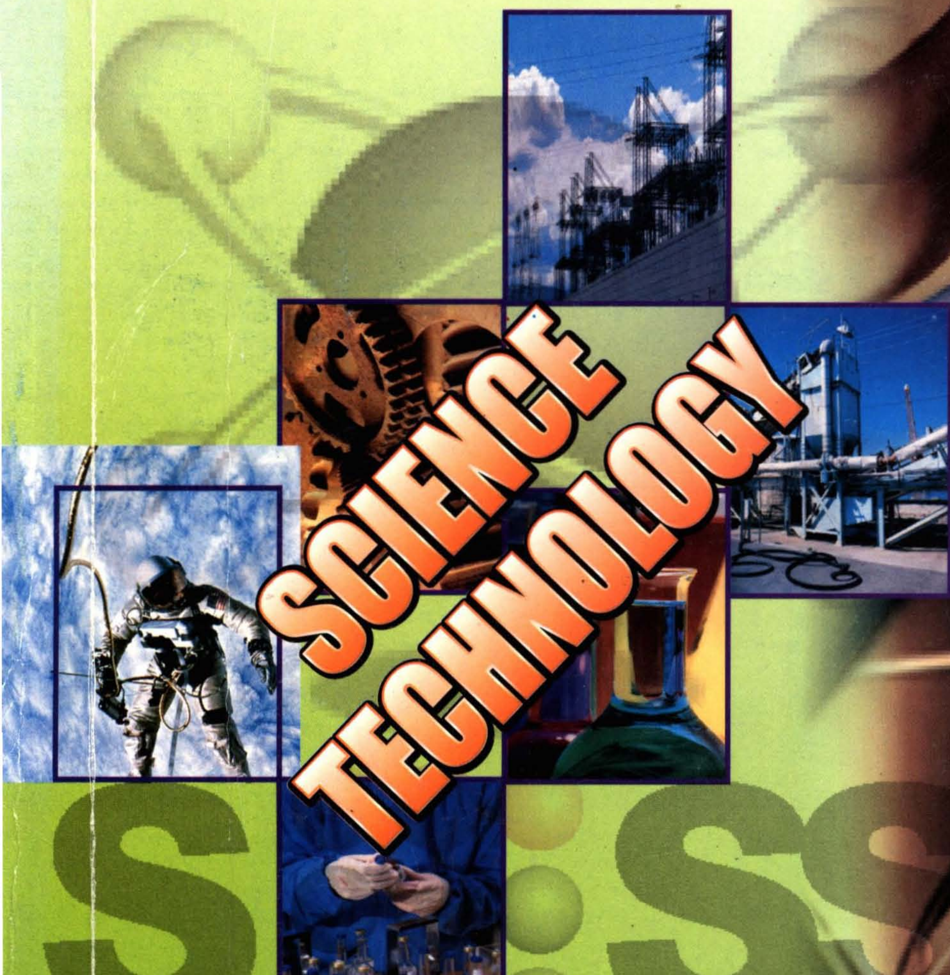

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Aerodynamic Studies on Multi-Storied Building

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ABSTRACT

Wind tunnel tests on structural models are needed when the full-scale structures cannot be tested or analysed. Very few industrial structures can be analysed accurately, particularly when they have solid and not lattice faces. Objects of tunnel tests include bridges, chimneys, vehicles, buildings, and radars. The model under investigation is non-aerodynamic building model. The wind tunnels tests on the building model are carried out to include flow visualization, pressure and velocities distributions on the various faces of the building. Flow visualization tests are carried out by using the woollen tuft technique at three different speeds, i.e., 22 ms^{-1}, 30 ms^{-1} and 38 ms^{-1}. In addition, for each speed, the building's yaw angle was varied from -15° to +15°. Flow visualization by wool tuft technique is able to show the characteristic of the flow around the building. Pressure distribution tests on the building model are carried out by using the wind tunnel technique and Bernoulli Principle. Around 164 static pressure ports available on all faces of the building are connected to a water tube manometer. Results showed high pressure along the centre line of the front surface of the building. CFD analyses of the flow are carried out by using Cosmosflowork 2004. The computational results are compared with the experimental results.

Keywords: *Wind tunnel test, tall building, flow visualization, pressure coefficient, CFD*

Introduction

Wind loads have become particularly significant because of the increasing number of high-rise buildings. Other factors have also contributed to the importance of wind in design: light-weight low-slope roofs, curtain wall construction and the appearance of special structure having aerodynamic shapes.

Some tall buildings that extend into regions of high wind velocity have swayed excessively in strong winds. Improperly anchored light-weight roofs have been sucked off bodily by wind forces, and roofing materials have been lifted by high local suctions and eventually peeled from large areas of roofs. These and many other problems have emphasized the importance of the clearer understanding of winds and its effects.

With the old simplified approach, the total effect of wind was often represented merely by a uniform lateral pressure on the windward side of a building and suction on the leeward wall. Wind loads present a challenge when designing very tall structures. Even in relatively light winds, a building behaves as a very large sail, and is subjected to large aerodynamic loads that push the building to one side.

Wind loads vary around the world. Meteorological data collected by the national weather services are one of the most reliable sources of wind data. Factors that affect the wind loads include building height and size, direction of prevailing winds, velocity of prevailing winds and the positive or negative pressure due to the architectural design features. All of these factors are taken into account when the lateral loads on the facades are calculated.

Wind Tunnel

It is well known that conducting experiments on the building model to establish flow and performance characteristics is going to be both time consuming and expensive. Wind tunnel measurements have thus served as an effective alternative for determining all the performance characteristics of the building model for the present aerodynamics study. The wind tunnel provides great benefits for aerodynamic tests. Specified flow condition such as Mach number and incidence can be achieved and sustained much easier in a wind tunnel. Dangerous, uncontrollable flight condition may safely be investigated in wind tunnel. Data acquisition and processing are simpler with direct connection to ground-based equipment (Pope and Harper 1996).

Flow Visualization

Flow visualization is used for obtaining a qualitative local or global picture of the flow. It may also be employed for acquiring qualitative measurements without introducing probes. Some techniques are confined to the visualization of surface flow as pattern, others provide visual information about the flow in a cross section, but there are also techniques yielding a global picture of the flow structure.

By visualization, one can find the location of transition region and the point of separation as well as the pattern of flow itself when it passes through the model. These data are important not only for predicting the effect of air flow and its interaction to the model but also for improving the aerodynamics characteristics of the building model (Pope and Harper 1996).

Wool Tuft Technique

The wool tuft technique is a very simple and adequate mean to obtain information about local condition on aerodynamic surfaces. The length of tuft depends on the size of the building model. The tufts are fixed on the building model by a gum. When the fluid flows over the body, the tufts are aligned in the local flow direction. Separated flow and high turbulence are indicated by more or less pronounced oscillation of the tuft. (Pope and Harper 1996)

Pressure Distribution

Pressure distributions are measured on the building model in wind tunnels tests by relatively insensitive manometers, so that the variations in suction due to vortex separation are smoothed out. All pressures are related to a static (velocity) pressure measured in the wind tunnel wall. On full-sized structures the static pressure is more difficult to measure. It is difficult to find a zero-velocity point on a lattice structure, and on a solid building any zero-velocity point inside the building may be at a different pressure due to open windows or air-conditioning. (Peter Sachs 1972)

Pressure Coefficient

Pressure coefficients used in practice have usually been obtained experimentally by testing models of different types of structures in wind tunnels. Commonly used coefficients refer to the average pressure or suction over a surface. Tangential forces are considered insignificant, so that the forces referred to act at right angles to the surfaces in question (Dalgliesh and Schriever 1962).

Drag Coefficient

Drag coefficients (C_d) in aerodynamics are drag forces normalized with a reference area, usually the frontal area, another projection area or the wetted area. Sometimes the reference area is not given, so the drag coefficient is a misleading figure. The actual values of C_d of particular devices are confidential by nature. The drag force, instead, is more clearly identified (Macdonald 1975).

Experimental Setup

As accurate model (scale 1:904) of the typical twin tower is used for this present investigation. The model is painted in black to prevent radiation emmissivity. The dimensions of the building model are 500 mm x 150 mm x 200 mm. The dimensions of the middle section of the building model are 150 mm x 150 mm x 99 mm. The middle section of the building model is 50 mm from the base. The details are shown in Figure 1.

164 static pressure holes each 1 mm in diameter are bored on every surface of the building model. 16, 5, 22, 29 pressure ports are available on the front surface, top surface, back surface, out side surface and inside surface respectively. For the mid section, 9, 4, 6, 4 pressure ports are available on the front surface, top surface, back surface and bottom surface respectively.

All the experiments of the present investigation are carried out in the SKTM wind tunnel lab. The wind tunnel of SKTM is open loop low speed wind tunnel. The dimension of the test section is 1000 mm x 1000 mm x 2500 mm. The overall length and overall height of wind tunnel are 14500 mm and 4000 mm respectively. The maximum air speed is 50 m/s at 75 hp. 4 sheets are set in the settling chamber of the wind tunnel to reduce the inlet free stream turbulence. Wind tunnel speed is calculated via the manometer reading.

The method used to carry out the flow visualization is a wool tuft technique. The wool tuft technique is a very simple and adequate mean to obtain information about local condition on aerodynamic surfaces. The suitable length of tuft depends on the size of the building model. Thus, the length of wool tuft is cut to 35 mm. Building model is black in colour, so the contrasting colour of wool tuft is needed. Hence, the colour of wool tuft selected is blue in colour. The tufts are pasted on the building model by a gum.

The building model is mounted on the tested area by screw mounting. The flow visualization around the building model at the different wind velocities and at different yaw angles are photographed with a high resolution digital camera. The picture of the building model with the wool tufts is showed in Figure 1.

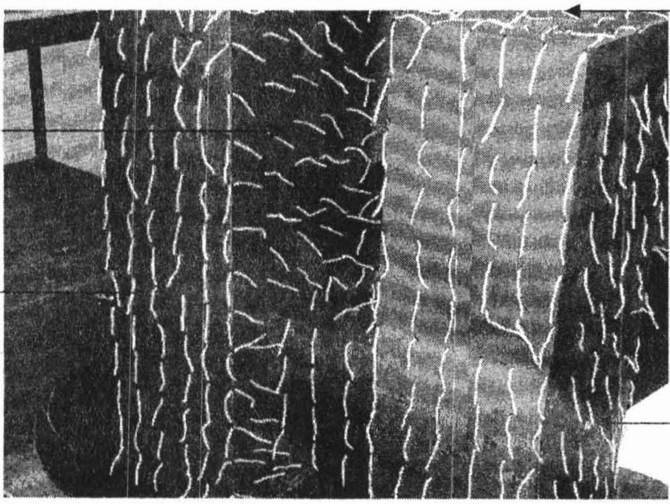


Fig. 1: Isometric View of Building Model

Static pressure tests are carried out by connecting the small plastic tubes to the bottom of the building model. Then, they are connected to the multi-tube water manometers. The static pressure data is obtained at three different speeds. At each speed, the static pressure was obtained at the yaw angles of 0^0, $+6^0$, $+12^0$, -6^0, -12^0 respectively. From the obtained static pressure, the static pressure coefficient is calculated as follows

$$C_p = \frac{p - p_s}{p_0 - p_s}$$

Where

p_o is stagnation pressure in test section of the wind tunnel

P_s is the static pressure in the test section of the wind tunnel

P is static pressure from any port

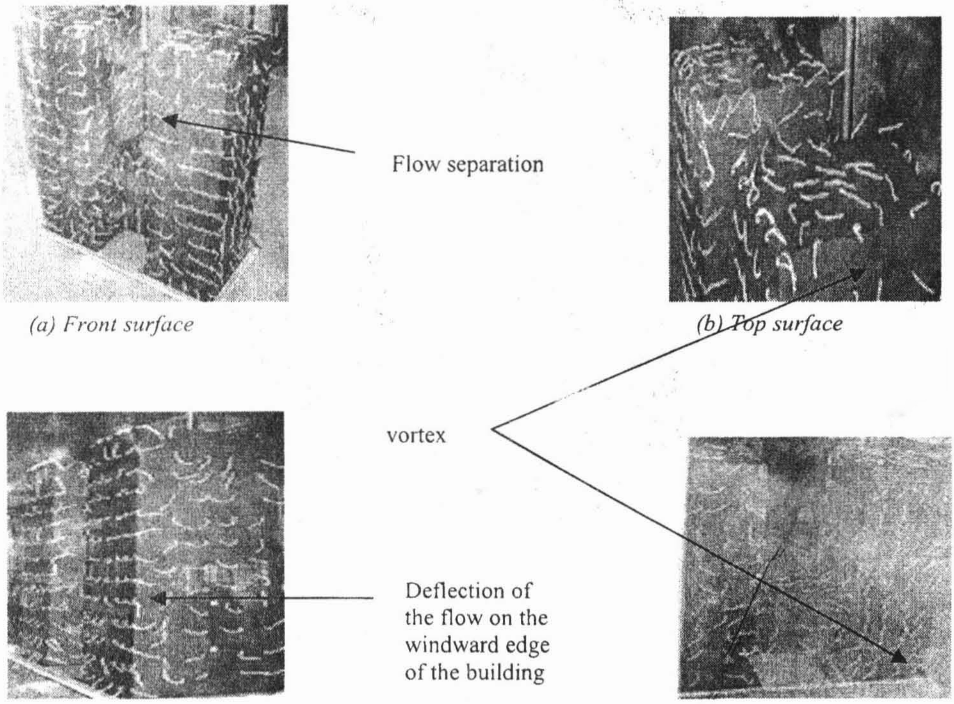
Computational Model

CFD investigations are carried out to obtain some additional results to be compared with the experimental results. The CFD software used is COSMOSFLOWORK 2004 and SOLIDWORK 2004. The building model is created by using SOLIDWORK 2004 and it was tested by COSMOSFLOWRK 2004. The three dimensional grid had about 350,000 cells. Structured mesh was employed. The steady, incompressible, viscous turbulent flow was solved by COSMOS as an external flow. A velocity inlet of 80 kmph was specified. This velocity is a typical of seasonal storms. The walls of the building were assumed smooth as well as adiabatic.

Results and Discussion

For building with the flat roof, the windward wall is the only surface subjected to the pressure; all other surfaces are located in the wake where pressures are below the ambient. The building model is bluff body and is not a streamlined body. The separation occurs between the wind and the building on all of the surfaces of the building model according to the Figure 2. The reason for this is again that the flow lines deflected around the windward edges are unable to "cling" to the building surfaces as they pass around the sharp corners.

Flow visualization in CFD results are showed in Figures 3 to 5.



(a) Front surface *(b) Top surface*

(c) Side surface *(d) Back surface*

Fig. 2: Wool Tuft Testing of Building Model at Speed 22 m/s, yaw angle 0^0

According to Figure 3, when wind strikes the front face of the building, the streamlines are forced to diverge and pass around the edges. Stagnation pressure is produced near the centre of the wall, but there is an increasingly steep pressure gradient towards the edges where the flow, diverted by the wall, regains its velocity in a direction parallel instead of perpendicular to it. According to the Figure 4, the vortex of the flow is created at the back of the building.

When the fluid passes over bluff bodies like a building with sharp corners, the separation points are fixed. Flow separation from these bodies is independent of Reynolds number. With the result, wakes are formed behind the building. The viscous shear layer rolls into vortex with static pressures less than the ambient pressures. With front face having a static pressure equivalent to stagnation pressure and the back surface having pressures less than the ambient pressure creates drag force in the direction of the building. The formation of the vortices is indicated in Figure 4.

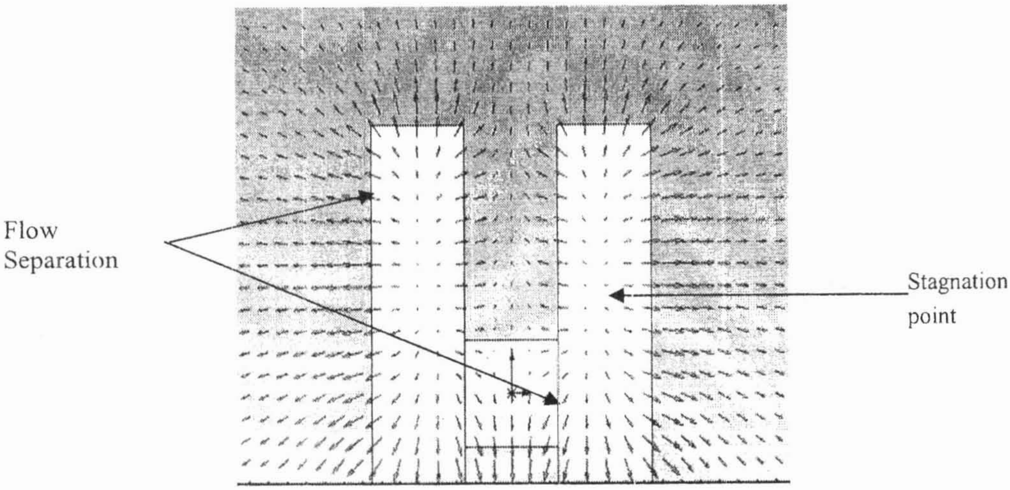


Fig. 3: Velocity Vectors (front view)

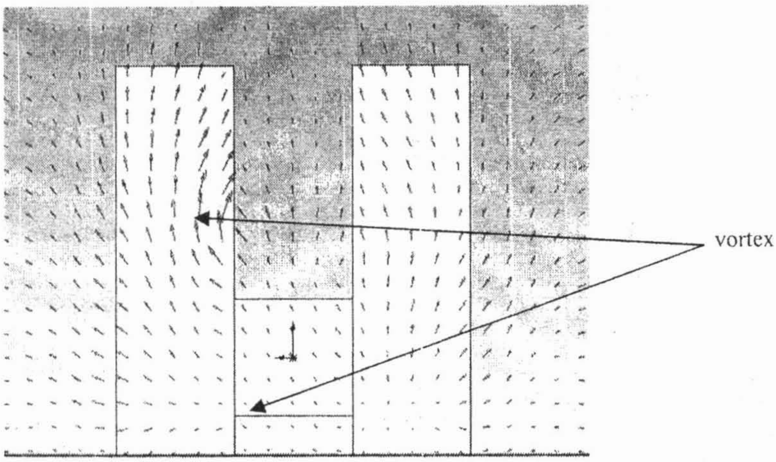


Fig. 4: Velocity Vectors (back view)

Figure 5 illustrates a more complicated shape and the flow lines associated with it. The flow is deflected by the edge of the wall and it is hard to cling together. It will cause a vortex and create suction at the back of the building. According to Dalgliesh and Schriever (1962), the roof is usually the critical area in the wind design of low buildings, particularly residential structures. Where it is made up of light-weight components, particular attention must be paid to anchorage details because of the suction condition prevailing over most, if not all, of it.

The distributions of negative and positive pressures over a building depend largely on how it disturbs the air flow. The datum from which all pressures and suctions are measured is the ambient pressure in the undisturbed air flow. When wind strikes a simple structure such as a free standing wall, the streamlines in line with the wall are forced to diverge and pass around the edges. The direction and magnitude of the original wind velocity are therefore altered by the encounter and cause changes in pressure. The stagnation pressure is uniform over the entire surface ($C_p \approx 1$, Fig. 6). There is an increasingly steep pressure gradient towards the edges where the flow, diverted by the wall, regains its velocity in a direction parallel instead of perpendicular to it as before. Behind the wall a different situation prevails. The streamlines of flow are unable to come together immediately because of the inertia of the air and a wake is left where they are separated from the wall. Air from the wake region is "entrained" by the fast-moving flow lines, thus reducing the pressure below the ambient pressure of the undisturbed flow and creating "suction.", Figure 7.

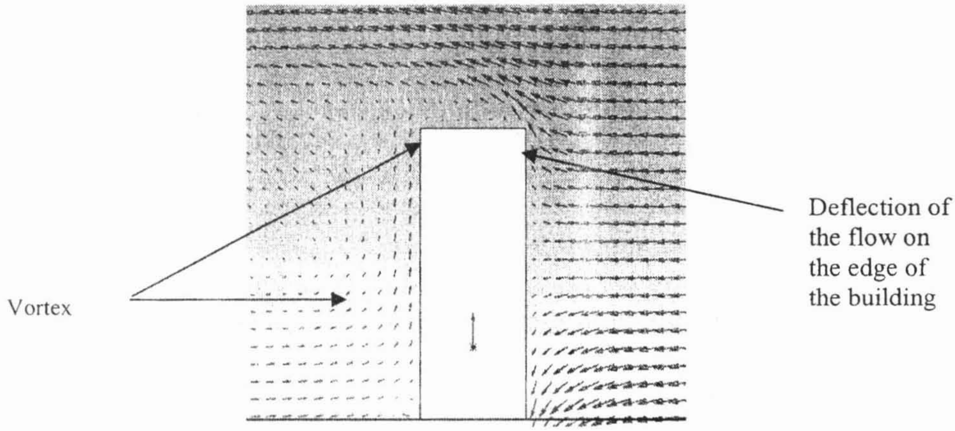


Fig. 5: Velocity Vectors (side view)

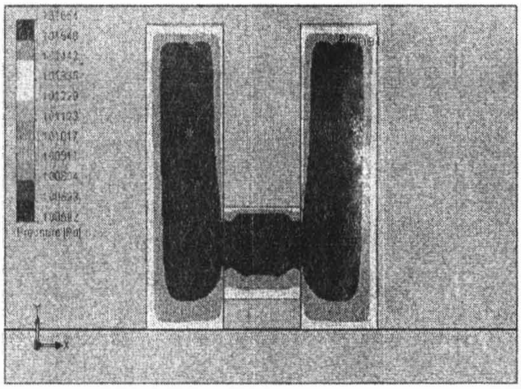


Fig. 6: Variation of Pressure (front surface)

Pressure is not usually constant over a wall or roof surface; but to simplify design procedures an average coefficient is specified for a given surface; when multiplied by the area and the basic pressure it gives the total force on the surface. The net force on the free standing wall would of course be the result of both the pressure on the windward side and the suction on the leeward side (back surface).

The outer side and the top surfaces exhibit pressures which are below the atmospheric values, Figure 8 to 9. The inner side surface has high pressure region due to the impact of the fluid on the connecting wall (Figure 10).

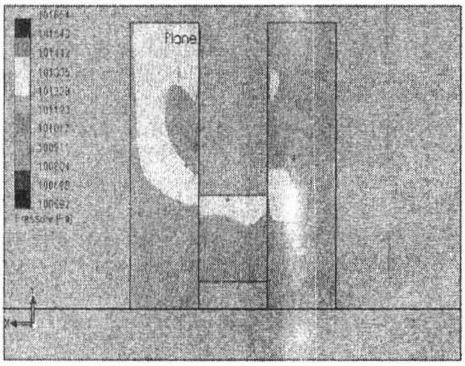


Fig. 7: Variation of Pressure (Back surface)

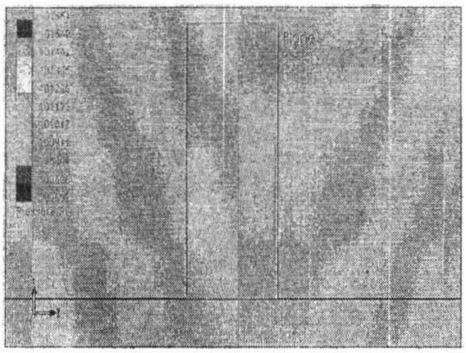


Fig. 8; Variation of Pressure (outer side surface)

Figure 11 shows the static pressure distribution on all faces of the building. The data presented in the above graph is obtained from the wind tunnel testing. The data from the wind tunnel corroborates the data presented from the CFD analysis. The origin of the graph in the x-axis represents the base of the building and the increasing pressure point indicates the distance along the length of the building. The C_p has a value almost close to 1, indicating the stagnation region on most part of the front surface. At both edges the static pressure gradient due to the regaining of the velocity very near to the corners of the building. On outer and top surfaces, the C_p values are negative but less than that of the back surface. On the inner side surface, the maximum C_p point corresponds to the red and orange region of Figure 10.

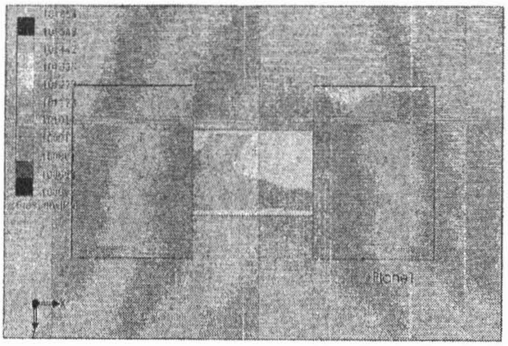


Fig. 9: Variation of Pressure (top surface)

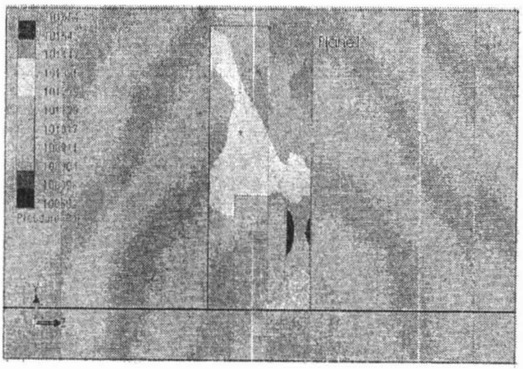


Fig. 10: Variation of Pressure (inner side surface)

Based on the Figure 8 and Figure 9, pressure coefficient of rear section of the building is lower than the side section. It is because of high value of length of the building.

Conclusion

This project successfully investigated the common aerodynamic characteristics of the multi-storeyed building by using the experimental and computational methods. Flow visualization indicated the characteristic of flow around the building. Separated flows at the corners, vortex formation on the back and side surfaces were clearly revealed by the flow visualisation and CFD results. Higher C_p values on the front surface and lower values at the back surface indicate the large drag force the building is subjected. The qualitative agreement between CFD results and static pressure distribution is quite good.

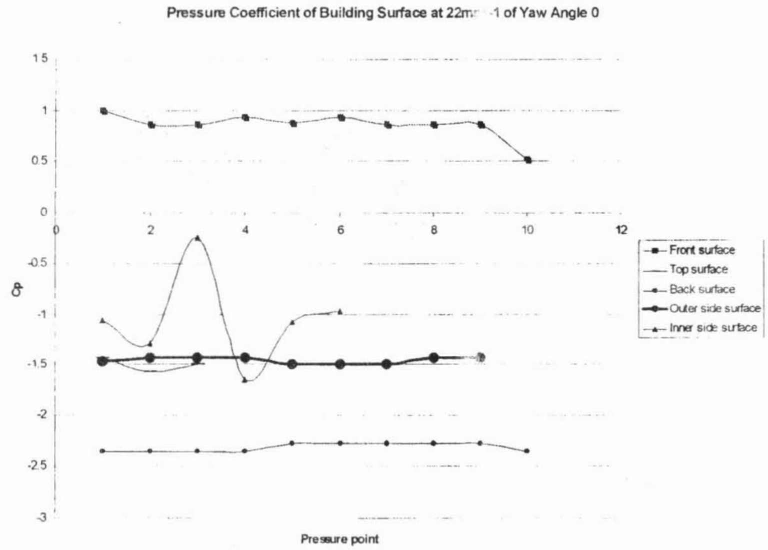


Fig. 11: Pressure Coefficient on all Surfaces of the Building Model

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