AERODYNAMIC FORCES AROUND A TAPERED SQUARE CYLINDER

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ABSTRACT

An experimental investigation of the pressure distribution around a tapered square cylinder placed in uniform flow with three Reynolds numbers i.e. 5.49 X 10^4, 6.88 X 10^4 and 1.38 X 10^5 is presented. Mean pressure was measured for 0 and 45 angle of attack at different planes of the tapered square cylinder in an open circuit wind tunnel. The drag co-efficient was calculated by numerical integration. The pressure co-efficient around the cylinder at different planes has been obtained by measuring the static pressure head on the surfaces of the cylinder.

INTRODUCTION

In fluid mechanics the flow around a cylinder is a very important problem from fundamental and applied points of view. The investigation of mean pressure distribution and drag are very important for designing aircraft, windmill, buildings and structure that have to face wind load. While designing square tapered cylindrical type object, towers, buildings, vehicles, missiles and other structures the designer should keep in mind the effect of wind loading. Flow past a cylinder is always associated with the separation of flow from the cylinder incurring large energy losses. Specially in the case of flow past square cylinders the separation of flow occurs at the corner of the frontal face and a complex wake is created behind it. Although studies with both the models and full-scale structures are being carried out now a days, it is easier and simpler to study with a model rather than the full-scale object. So, a wind tunnel study is the only means to investigate the flow phenomena past such cylinders. Till now extensive research works have been carried out on isolated bluff bodies. Even then, very little information is available concerning the flow around tapered square cylinder although this is a problem of considerable practical significance. The knowledge of wind loading on tall buildings and the windmill towers is essential for sound planning and design.

One approach to the problem of predicting the flow around an object or structure is to develop an understanding of the nature of flows on relatively simple arrangement of bluff bodies by wind tunnel experiments. With this end in view, the present investigation of pressure distributions around a tapered square cylinder was carried out. Tapered square cylinder represents the general shape of the windmill towers and sometimes high-rise buildings. Thus the study on the tapered square cylinder would be helpful in the analysis of wind effects on windmill towers or high-rise buildings. The present study is an attempt to give an understanding about the variation of wind load pattern imposed on a square tapered structure at different planes.

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OBJECTIVES

The prime objectives of the study were:

- To measure the pressure around the tapered square cylinder at different planes and to observe the effects of varying angle of attack.
- To determine the effect of Reynolds number.
- To calculate the drag and lift co-efficients from the measured pressures.

3. MATERIALS AND METHODS

The investigation of flow characteristics around a tapered square cylinder was carried out in a subsonic wind tunnel. Mean pressure distribution around the tapered square cylinder placed normal to the approaching uniform flow was measured with the help of inclined manometer. The following sections describe in detail regarding the experimental set-up and techniques adopted for the present investigation.

3.1 The Wind Tunnel

The experiment was carried out in an open circuit low velocity wind tunnel, which was 5.265 m long with a test section of 0.49 m X 0.49 m in cross- section. Figure 1 depicts a schematic diagram of the wind tunnel used for the experiment. The successive sections of the wind tunnel comprised of a bell mouth entry, a flow straightener with the honeycomb section, the motor assembly with the fan section, flow controlling valve, converging diverging section, silencer and test section. The setup of the wind tunnel was situated at a constant height from the floor with its central longitudinal axis.

The wind tunnel and all its associated control measuring equipment were supported in a single bench. The axial flow fan was a Wooden Aerofoil type 15BJG of 381 mm in diameter. The blades had a pitch angle of 16 degree. The maximum speed at which the fan could be run was 3600 rev/min. A thyristor controlled DC swinging field motor of 0.7 kW; through a 1:1 ratio toothed belt ran the fan. A proximity sensor and electronic digital counter was used to measure the speed of the fan. The fan was mounted in a circular air way or duct of 381.5 ± 0.5 mm in diameter and the flow was discharged to the atmosphere through a variable area damper and silencer. The variable area damper or butterfly valve was used to control the flow. A screw thread mechanism was used to actuate the valve. The silencer was fitted to reduce the noise of the system. The air entered the duct via a standard conical inlet.

1.Standard conical inlet. 2. Honeycomb section. 3. Pitot tube section. 4. Fan section 5. Butterfly section. 6. Diverging-Converging section 7. Silencer. 8. Square section. 9. Tapered Square Cylinder

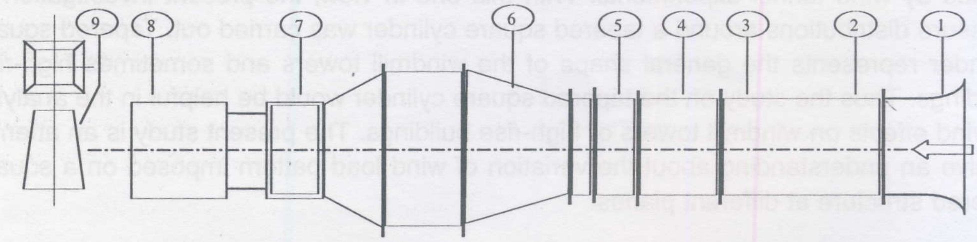


Figure 1: The Schematic diagram of the Wind Tunnel.

3.2 The Square Section

The square section was made by 24 SWG galvanized sheet. The construction detail of the section has been shown in the Figure 2. The test section mainly consisted of two parts. One part was circular and another part was square in section. The main function of the circular section was to make the flow straight. The circular section was filled up with plastic pipes. A piece of wire net was set at the end of the circular section so that the plastic pipes could not come out. At one end of the circular section flange made of 16 SWG M.S. sheet was welded and at the other end the square section was welded. After setting the test section it was found that the wind velocity at the exit reduced slightly (by 10%).

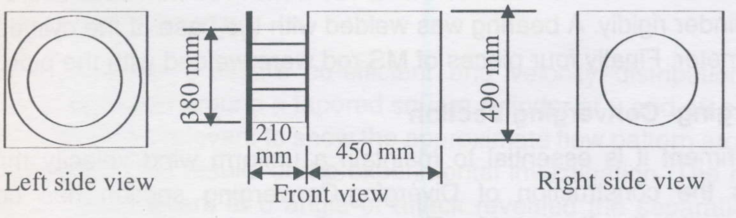
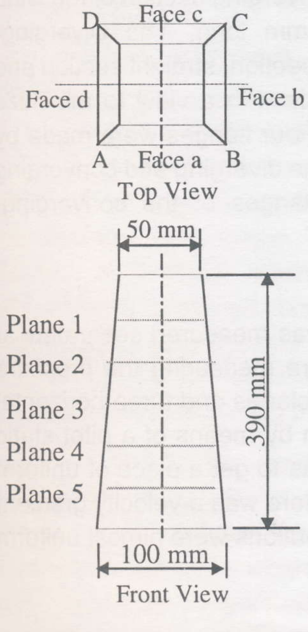


Figure 2: The Test Section.



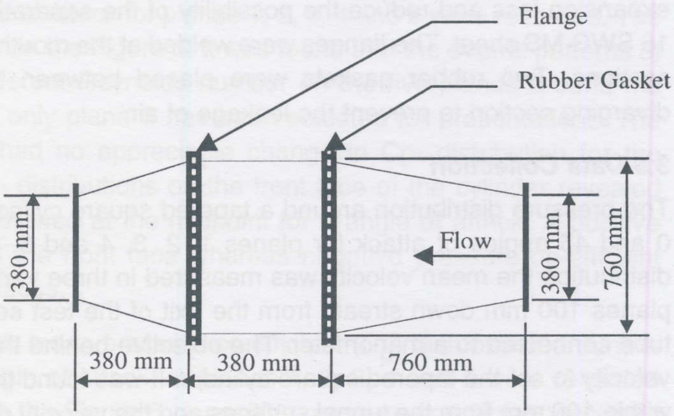


Figure 3: Tapered Square Cylinder

Figure 4: Diverging -Converging Section

3.3 The Cylinder

The Tapered Square Cylinder or the model (Body with trapezoidal face) was made of Perspex sheet of 4 mm in thickness. The height of the cylinder was 390 mm. The construction details have been shown in the Figure 3. The total height of the cylinder was divided into six equal vertical height so that five planes could be obtained. A total of 60 pressure tapings were made on those five planes in two adjacent surfaces of the model. To make the pressure tapings 2 mm holes (through pass) were made on each of the surfaces of the cylinder. Then 14 mm long copper tubes of 2 mm diameter were press fitted to the holes from inside, keeping the outer surface smooth as far as possible. The exposed ends of the copper tubes were connected with transparent and flexible plastic tubes which were passed through the bottom end of the model. The transparent and flexible plastic tubes were marked to identify its location for the plane, face and position.

The base of the cylinder was made of MS sheet. The dimension of the sheet was 120 mm x 120 mm. A hole of 30 mm in diameter was made at the center of the sheet. Then 10 mm from each of the four sides was bent so that a 100 mm X 100 mm base could be produced to hold the cylinder rigidly. A bearing was welded with the base of the cylinder and a pipe of 50 mm diameter. Finally four pieces of MS rod were welded with the pipe.

3.4 The Diverging- Converging Section

For this experiment it is essential to maintain a uniform wind velocity throughout the section. Thus the construction of Diverging-Converging section has been realized essentially to make the flow stable. The construction detail of Diverging-Converging section has been shown in the Figure 4. The diverging and converging section of the wind tunnel, made of 24 SWG galvanized sheet, was 1520 mm long. The Diverging-Converging section mainly consisted of three parts: diverging section, straight section and converging section. The angle of divergence of 20 was made with a view to minimize expansion loss and reduce the possibility of the separation. Four flanges were made by 16 SWG MS sheet. The flanges were welded at the mouth of the diverging and converging sections. Two rubber gaskets were placed between the flanges of the converging-diverging section to prevent the leakage of air.

3.5 Data Collection

The pressure distribution around a tapered square cylinder was measured separately at 0 and 45 angles of attack for planes 1, 2, 3, 4 and 5. Before measuring the pressure distribution the mean velocity was measured in three vertical planes and three horizontal planes 100 mm down stream from the exit of the test section by means of a pitot static tube connected to a manometer. The objective behind this was to get a place of uniform velocity to set the tapered square cylinder. It was found that there was a velocity gradient within 100 mm from the tunnel surfaces and the velocity distributions were almost uniform with 7% fluctuation.

3.5.1 Mean Pressure Distribution

The tapered square cylinder was placed 80 mm downstream from the exit of the jet. The cylinder was attached to the base and a weight of 4 kg was placed at the top of the cylinder so that the cylinder stood rigidly. Transparent and flexible plastic tubes of the cylinder passed through the pipe at the base and were fitted with a manometer. For each angle of attack three sets of measurements were taken for three different Reynolds number namely 5.49 X 10^4, 6.88 X 10^4 and 1.38 X 10^5. The mean flow velocities in the test section for these three sets were 10.7 m/sec, 13.4 m/sec and 26.8 m/sec

For 0 angle of attack, baseline AB of the cylinder was oriented normal to the flow symmetrical to center lie of the wind tunnel. For 45 angle of attack baseline AB of the cylinder was placed at 45 symmetrical to center lie of the wind tunnel. The mean pressure distribution on the cylinder was recorded by means of a manometer. A pitot static tube for indicating the free stream velocity and pressure was placed centrally. Since pressure-tapping points were made only on two perpendicular surfaces of the cylinder, two-fold readings were taken for a complete record of pressure distributions on four surfaces by alternately placing the front surface towards the upstream and downstream direction.

4. RESULTS AND DISCUSSIONS

The distributions of mean pressure co-efficient and velocity distribution at different positions in the wake region around a tapered square cylinder at 0 and 45 angle of attack were analyzed. It would be relevant to show the approximate flow pattern around a square prism before discussing the results of the experimental investigation. The nature of flow pattern around a square prism at 0 angle of attack revealed the separation points are always occur at the leading edges and the shear layers originating from the leading corners curved outwards and a wake region was formed behind the body.

4.1 Pressure Distribution

The effect of Reynolds number on mean pressure co-efficient (C_p) distribution around a tapered square cylinder at 0 angle of attack for planes 1, 2, 3, 4 and 5 were recorded. The result for plane 3 has been shown in the Figure 5. It was found that the overall patterns of the Cp-distribution curves for different Reynolds number on the five planes around the four surfaces were similar. Thus only plane 3 has been selected for presentation. The variation of Reynolds numbers had no appreciable change in Cp- distribution for the tapered square cylinder. The Cp- distributions on the front face of the cylinder revealed that a stagnation point was established at the midpoint for 0 angle of attack. A positive pressure co-efficient occurred at the front face whereas negative pressure co-efficient prevailed at the remaining three faces.

The effect of Reynolds number on mean pressure co-efficient (C_p) distribution around a tapered square cylinder at 45 angle of attack for planes 1, 2, 3, 4 and 5 were recorded and the result has been shown in the Figure 6. A positive pressure co-efficient occurred at the front two faces whereas negative pressure co-efficient prevailed at the rear two faces. The pressure gradually fell near the rear corner starting from the front corner. The negative pressure co-efficient of the rear two faces were almost uniform throughout the whole surface. The positive pressure in the front two faces and the negative pressure in the rear two faces became symmetric.

Figure 7 represents the comparison of C_p distribution around the tapered square cylinder at 0 and 45 angle of attack at Reynolds number 1.38 X 10^5. Plane 3 has been selected for this comparison. Figure 8 represents the variation of drag coefficient (C_D) with Reynolds number (Re) for tapered square cylinder. It can be seen from the figure that the drag coefficients (C_D) were not changing much for both 0 and 45 angles of attack with varying Reynolds number from 5.49 X 10^4 to 1.38 X 10^5. The standard values of drag co-efficient for square and circular cylinder are 2.0 and 1.2 respectively. In the present study tapered square cylinder was used. Theoretically, the value of drag co-efficient for tapered square cylinder should be in between the value of square and circular cylinder. Practically, the values of drag co-efficients (C_D) were found to be 1.36, 1.39 and 1.37 for Reynolds number 5.49 X 10^4, 6.88 X 10^4 and 1.38 X 10^5 respectively with 0 angle of attack, which values are acceptable.

The result of the present experiment is compared with that of Lee [2] and Hossain [7] as shown in Figure 9. The parameter turbulence intensity has a great influence on the surface pressure distribution as may be seen from the figure, except at the front face. The Cp distribution at the front face shows that it is nearly independent of turbulence intensity and a stagnation point was established at middle of the face. At other faces the values of pressure coefficients decrease as the turbulence intensity increases. The figure shows that the value of pressure coefficient for tapered square cylinder is less than that of straight cylinder.

In the case of a sharp edged body like a tapered square cylinder the separation points are fixed at the leading edges (corners of the front face) and thus the shear layers originating at the front corners curved outwards and these resulted the formation of familiar vortex shedding in the wake region behind the cylinder. The free shear layers were basically unstable and rolled up to form discrete vortices. The growing vortices drew in fluid from the base region and it is suggested that it is this continual entrainment process that sustained the low back pressure. In fact the magnitude of the back pressure was determined almost solely by the manner in which the shear layers leaved the body and rolled up to form discrete vortices. Thus a low base pressure was associated with vortex formation close to the body while a high base pressure (less negative value) was caused by vortex formation further.

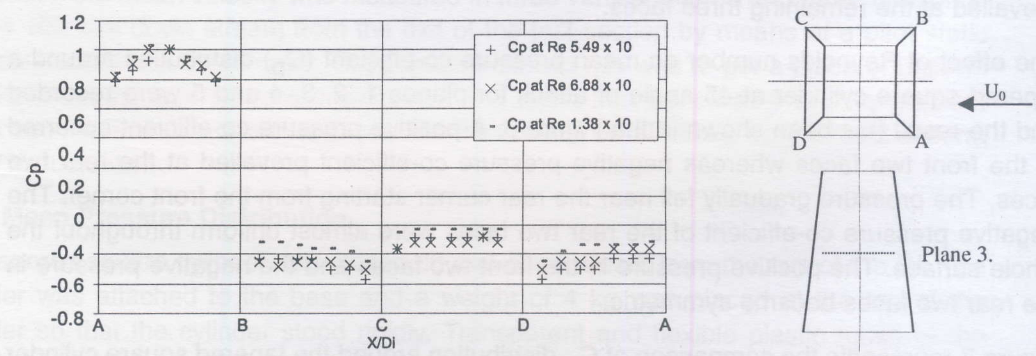


Figure 5: Effect of Reynolds number on mean pressure co-efficient (Cp) distribution around a tapered square cylinder at 0° angle of attack for plane 3.

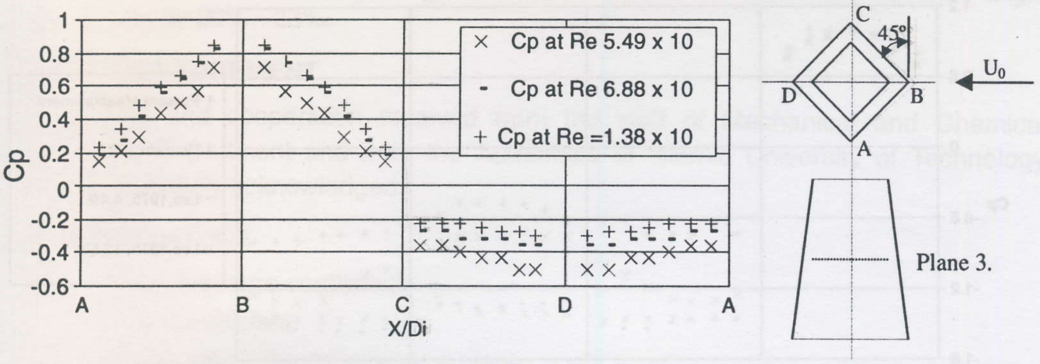


Figure 6: Effect of Reynolds number on mean pressure co-efficient (Cp) distribution around a tapered square cylinder at 45° angle of attack for plane 3.

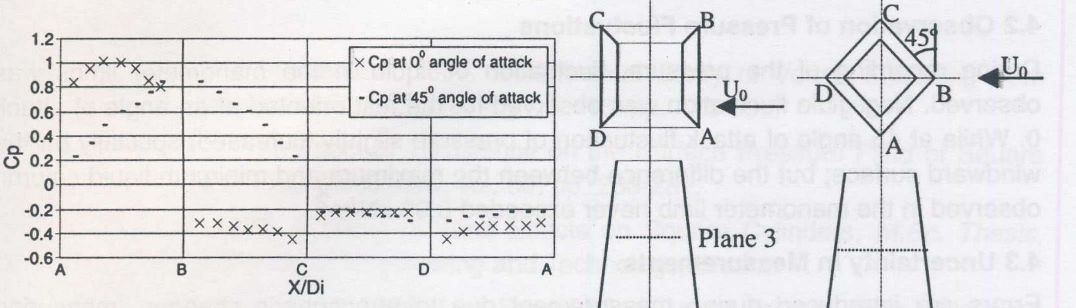


Figure 7: Comparison of Cp - distribution around a tapered square cylinder at 0° and 45° angles of attack at Reynolds number 1.38 X 105.

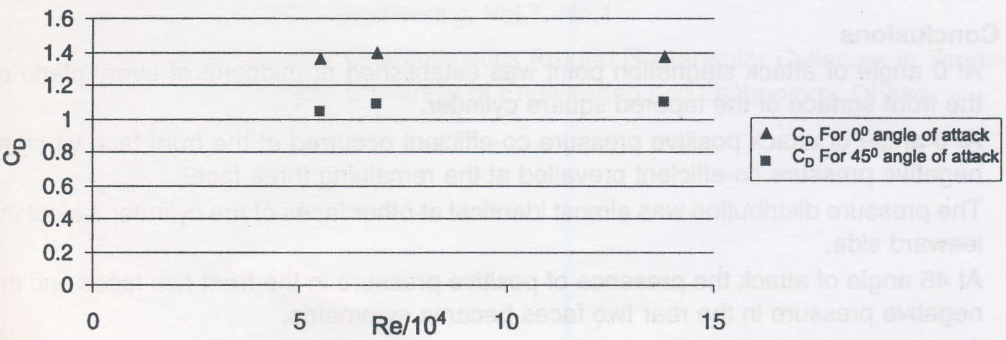


Figure 8: Variation of drag coefficient (CD) with Reynolds number (Re) at 0° and 45° angles of attack for tapered square cylinder

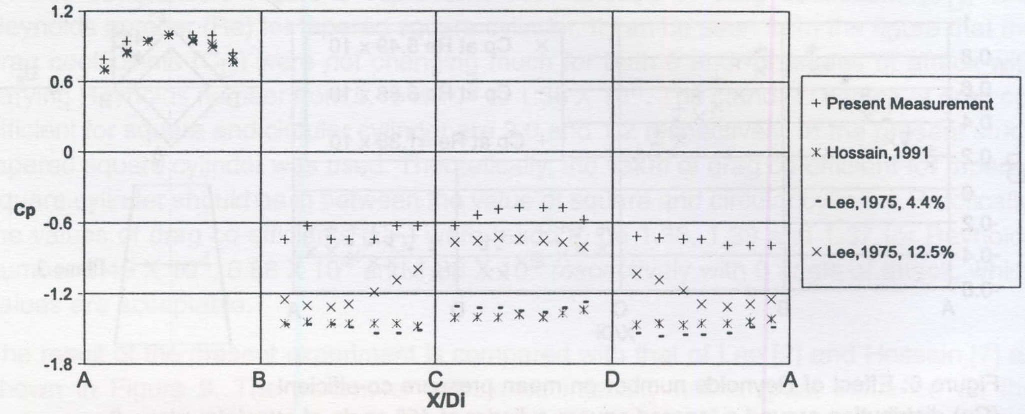


Figure 9: Comparison of Cp - distribution between tapered square cylinder and straight cylinder.

4.2 Observation of Pressure Fluctuations

During recording of the pressure, fluctuation of liquid in the manometer limbs was observed. Negligible fluctuation was observed for the test oriented at an angle of attack 0. While at 45 angle of attack fluctuation of pressure slightly increased, specially on the windward surface; but the difference between the maximum and minimum liquid column observed in the manometer limb never exceeded 0.03 kN/m^2.

4.3 Uncertainty in Measurements

Errors are introduced during measurement due to atmospheric changes, measuring instruments, probe setting etc. An uncertainty analysis has been made for different measured parameter that is illustrated. It has been found that the uncertainty in surface static pressure measurements is 0.00098 % for Re = 6.5 X 10^4. For different Reynolds number the uncertainties in velocity measurements are different. It was found that for Reynold's number 5.04 X 10^4 uncertainty in velocity measurements were 2.28 %.

5. Conclusions

- At 0 angle of attack stagnation point was established at midpoint of every plane on the front surface of the tapered square cylinder.
- At 0 angle of attack positive pressure co-efficient occurred at the front face whereas negative pressure co-efficient prevailed at the remaining three faces.
- The pressure distribution was almost identical at other faces of the cylinder except the leeward side.
- At 45 angle of attack the presence of positive pressure in the front two faces and the negative pressure in the rear two faces became symmetric.
- At an angle of attack of 0º and 45º, no flow reattachment occurred on the surfaces of the square tapered cylinder.
- The change of Reynolds number had no appreciable change in the Cp-distribution for the tapered square cylinder.

- The value of drag co-efficient (C_D) at 0 angle of attack was more than that of 45 angle of attack by 20% - 23%.

6. ACKNOWLEDGEMENT

All the help and cooperation received from the staff of Mechanical and Chemical Engineering Department and from the Authorities of Islamic University of Technology (IUT) are gratefully acknowledged.

7. NOMENCLATURE

C_P Mean pressure coefficient.

C_D Drag Co-efficient.

D_i Side length of the cylinder at a plane.

X Distance from edge of a face.

U_O Free stream velocity

8. REFERENCES

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