Wind Analysis on Pentagonal Cylinder by Using Low Speed Subsonic Wind Tunnel

Mohanraj .N

Abstract: ***In this present work experimental investigation of wind effect on a pentagonal cylinder was carried out. The test was performed on the single pentagonal cylinder in a open circuit wind tunnel at different cases of Reynolds numbers from 57300 to 133700 or different inlet velocity of air from 15m/sec to 35m/sec. The surface static pressure head at different locations of the cylinder were measured with the help of multitube manometer. The pressure coefficients were calculated from the measured values of surface static pressure head on the cylinder. The drag coefficient and drag force are obtained from the pressure coefficients by the numerical integration method. These results will help the engineers to design the building in conservative way. The results obtained in this present work can be adopted for real life structure by multiplying with the scale factor if the conditions were well suited with the experiments.***

Keywords: drag coefficient, drag force, pentagonalcylinder, pressure distribution.

Nomenclature

D Drag force component of resultant aerodynamic force parallel to the free stream velocity.
N Normal force component of resultant aerodynamic force perpendicular to the chord length of the body.
A Axial force component of resultant aerodynamic force perpendicular to the chord length of the body.
A Angle of attack i.e.) angle between the chord length and free stream velocity.
P_u,τ_u The pressure and shear stress on the upper surface of the body.
P_l,τ_l The pressure and shear stress on the lower surface of the body.
θ Pressure will be acting normal to the surface and is oriented at an angle θ relative to the perpendicular.
Ds Elemental surface area of the body.
$N^{'}, A^{'}$ Total normal and axial force due to the pressure and shear stress on the elemental area ds(prime denotes force per unit span)
q_∞ Dynamic pressure.
C Chord length.
C_d Drag coefficient.
C_p Pressure coefficient.
P Pressure acting on the cylinder.
p_∞ Pressure on the free stream air.
V_{inlet} Inlet velocity of air.
L Length of the building model.
γ_{air} Kinematic viscosity of air.

1. Introduction

The fundamental of aerodynamics was evolved from the work initiated by the Issac newton in 16^{th} century. He obtained an expression which says that hydrodynamic force on the surface varies as $\sin^2\theta$. The results showed that, the rule that for oblique plane resistance varies with the sine square of the angle of incidence holds good only for angles between 50^0 and 90^0 must be abandoned for lesser angles. Later in 17^{th} Century Leonhard Euler came with the concept that, fluid moving towards the body "before reaching the latter bends its direction and its velocity so that when it reaches the body it flows past along the surface and exercise no other forces on the body except the pressure corresponding to the single points of contact.

Euler went on to present a formula for resistance that attempted to take into account the shear stress distribution along the surface as well as the pressure distribution. Later this expression became proportional to $\sin^2\theta$ for larger incidence angles, where as it was proportional to $\sin\theta$ for small incidence angles. Such variation was in reasonable agreement with the ship hull experiments carried out by d'alembert. Now the latest trend in the study of aerodynamics of building was by using wind tunnel. In the early planning stages, careful attention to the effects of wind, snow, ventilation, vibration and related micro climate environmental issues on buildings and structural are proven to save time, money and reduce risk.

RWDI consultancy says that, Wind tunnel testing is advisable on buildings higher than 22 stories (10 stories in hurricane areas) or where the building or structure is an unusual shape or construction methodology, Unusual terrain or surrounding structures in the area also make the wind tunnel testing an important step to optimize cost efficiencies generate accurate results to enhanced safety of the project, minimize assumptions and allow for maximum design freedom. Wind tunnel testing can be used for the projects like skyscrapers and tall buildings, group of buildings, long span roofs, tunnels, industrial and institutional facilities, long span pedestrian or automotive bridges, sporting stadiums, casinos, other tall or wind sensitive structures. Also construction of tall structures will be one of the best solutions for the problem of inadequate housing with respect to the rapid growth of population.

The researcher kapilghosh[1] says that flow over a pentagonal cylinder has not been studied extensively, although this is a problem of practical significance. It is believed that the study on the cylinder with pentagonal section will contribute to find the wind load on the single pentagonal building and the results will be useful to relevant engineers and architects. He showed that there is significant drop in the drag coefficient values for the single pentagonal cylinder in comparison to that of square cylinder. The variation of lift coefficient on the single pentagonal cylinder is shifted 9^0 and the pattern is more or less similar with the variation of lift coefficient for the single square cylinder except at 0^0 angle of attack.

Author'sk.s priyanga[2] and p.harikrishna[2]have been combinedly showed that, the average of the mean C_d values along the height of the building model for θ of 0^0 and 90^0 are observed to be 1.37 and 1.45 respectively. These values are well comparable to the corresponding mean C_d values 1.27 and 1.36 respectively. As per IS875(Part 3) with percentage of difference about 7%.Researcher s.selvirajan[3] showed that, standard deviation or RMS drag coefficients gave higher values for their study this can be attributed to the fact that suburban terrain has higher turbulence intensities as compared to the open terrain on which their literature is based. the evaluated mean drag coefficient value of 0.93 for 0^0 is comparable to the value of 1.1 provided in IS875(Part3)-1987.In the above both research they used rectangle shaped cylinder.

2. Experimental Setup

The test was carried out at the test section of the suction type subsonic wind tunnel. The image of the wind tunnel shown below is available at MVJ College of engineering situated at Bangalore. The wind tunnel was 6m long with a test section of 600mm x 600mm cross section. Length of the test section is 2000mm. The pentagonal cylinder was fixed to the base of the test section at its center with help of fasteners. The plastic tubes from the tapping's were taken out and connected with multitube manometer, which contained water as the manometer liquid.

Figure 1: Lowspeed subsonic wind tunnel

The pentagonal cylinder was leveled in such a way that top surface of the cylinder was parallel to the flow direction. The axis of the cylinder was at the same level to that of the wind tunnel. To generate wind velocity axial flow fan is used which is having capacity of producing maximum of 1300rpm. Wind velocity inside the tunnel can be directly recorded from the calibrated chart between the rpm of the fan and the inlet velocity of air inside the tunnel. There was a provision for rotation of the test cylinder at various angles to obtain the wind load at different angle of attack. The Reynolds number used here was based on the projected width of the cylinder across the flow direction.

3. Details of Pentagonal Cylinder

The tapping position on the surface of the cylinder is shown in the figure below. The width of the pentagonal cylinder was 60mm. Each face of the cylinder contains six numbers of tappings. The distance between the consecutive tapping points was equal as shown in fig2.1. Each tapping was identified by a numerical number from 1 to 30 for pentagonal cylinder. All the tappings were located within some span of the cylinder as shown in figure. The pentagonal cylinder was fixed to the base of the test section with help of fasteners. From the bottom portion of the pentagonal cylinder there will be a small hollow cylinderlike projection through which plastic tubes were allowed to pass out from the cylinder to the multitube manometer. The plastic tubes were connected with copper capillary tubes behind the tapping points at one side and other side with the multitube manometer. The manometer liquid was water. The tappings were made of copper tubes of 1.82mm outside diameter. Each tapping point on cylinder was 20mm in horizontal direction and 75mm in the vertical direction. From the end of the copper tube flexible plastic tube of 1.8mm inner dia**meter was pressfitted.**

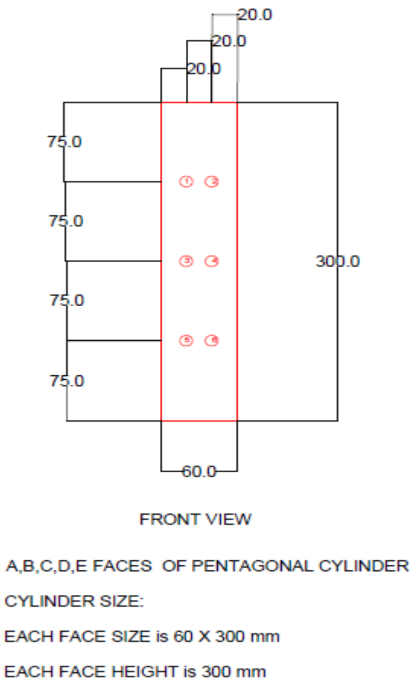


Figure 2.1: Schematic diagram of the pentagonal cylinder

Pressure Tapping nos

A FACE nos 1 - 6

B FACE nos 7 - 12

D FACE nos 13 - 18

E FACE nos 19 - 24

C FACE nos 25 - 30

Figure 2.2: Details of pressure tappings

The upstream velocity was assumed to be uniform and the flow occurred across the cylinder. In figure the position of the single cylinder at zero degree angle of attack is shown in fig2.3. The surface static pressure distributions on each faces of the cylinder were measured in this position. The same test procedure was repeated to measure the surface static pressure distribution of the cylinder with different Reynolds number case 57300, 95500, 133700 or with different inlet velocity of air at 15, 25, 35 m/sec.

4. Mathematical Formulation

The drag component is given by,
D = N sinα + A cosα
The total normal and axial forces per unit span is given by,

$$N' = (-)\int_{LE}^{TE} (P_u \cos\theta + \tau_u \sin\theta)\, dS_u + \int_{LE}^{TE} (P_l \cos\theta - \tau_l \sin\theta)\, dS_l$$

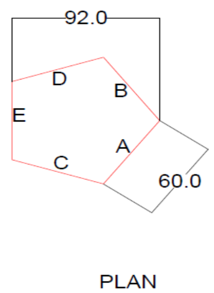
$$A' = \int_{LE}^{TE} (-P_u \sin\theta + \tau_u \cos\theta)\, dS_u + \int_{LE}^{TE} (P_l \sin\theta + \tau_l \cos\theta)\, dS_l$$

For a two dimensional body drag coefficient per unitspan is given by, $C_d = \frac{D'}{q_\infty C}$

Pressure coefficient is defined as, $C_p = \frac{\Delta P}{\frac{1}{2}(\rho_\infty)(V_\infty)^2}$

Reynolds number based on the width of the pentagonal cylinder across the air flow is given by, $Re = \frac{V_{inlet} \times L}{\gamma_{air}}$

5. Results and Discussion



DETAILS OF PENTAGON MODEL:

CYLINDER SIZE:

SIDE is 60 mm

CHORD LENGTH is 92 mm

Figure 2.3: Schematic diagram of pentagonal model plan

In this section the distribution of pressure coefficient, drag coefficient, drag force for a single pentagonal cylinder at 0 degree angle of attack with different Reynolds number have been discussed. Pressure coefficients have been calculated from the measured values of the surface static pressure head. Then finally drag force have been obtained from the pressure coefficient by the numerical integration method. From drag force required drag coefficient can be calculated. All the coefficients were determined for the uniform cross flow on the cylinder at different Reynolds number of 57300, 95500, 133700 based on the width of the cylinder across the flow direction at zero angle of attack. That is experiment is conducted on three different inlet velocity of air at 15, 25, 35 m/sec which corresponds to different Reynolds number.

6. Distribution of Pressure Coefficient

The single pentagonal cylinder with 30 number of tappings six numbers on each surface of the cylinder at 0 degree angle of attack has been shown in figure below. The five surface of the pentagonal cylinder have identified with A,B,C,D,E alphabetical letters for avoiding confusion. Pressure coefficients for each tapping point have determined from the measured surface static pressure head. In the following figures the distributions of static pressure coefficients for 0 degree angle of attack with different inlet velocity of air has given in schematic diagrams. From fig.3 it was observed that on surface of pentagonal cylinder at 0 degree angle of attack, pressure coefficients are positive at all the points of A surface. One interesting point seen from the fig.3 is that pressure coefficients are nearly uniform for odd number of points on A face namely1,3,5 and also uniform for even number of points on A face namely 2,4,6.

The same types of pressure distribution have been occurred on B surface also. That too magnitudes of pressure coefficients are equal in A and B surface of the pentagonal cylinder. In fig.3 pressure coefficients are negative at all the points of C and E surfaces. Like A surface pressure coefficients of odd number and even number of pressure tappings on C and E surfaces are not uniform. Along the D surface of the pentagonal cylinder pressure coefficients are mixed with positive and negative values. Among that number of positive pressure coefficient was higher than number of negative pressure coefficient. This same kind of pressure coefficient distribution we got for other two different inlet velocities of air which is shown in the fig.4 and fig.5, except for inlet velocity of air at 15m/sec in which C surface of the pentagonal cylinder it is observed that uniformity in pressure coefficient at all the points. But the magnitude of pressure coefficient gets increased with respect to the increase in the inlet velocity of air.

7. Variation of Drag Coefficient

Variation of drag coefficient at 0 degree angle of attack with different Reynolds number on a single pentagonal cylinder is shown in the fig.6.The drag coefficient for single pentagonal cylinder having width of 50mm at 0 degree angle of attack with Reynolds of 42200, at uniform flow of velocity of air 13.5m/sec was obtained by researcher kapil ghosh as 1.5 which we are using for verification purpose. In this present paper drag coefficient for single pentagonal cylinder having a width of 60mm at 0 degree angle of attack with Reynolds number from the range 57300 to 133700 , at uniform inlet velocity of air from 15m/sec to 35m/sec is obtained here as from 2.45 to 2.7 .

8. Variation of Drag Force

Variation of drag force at 0 degree angle of attack with different inlet velocity of air on a single pentagonal cylinder is shown in the fig.7.It can be observed that there exists a linear relationship between inlet velocity of air and drag force. It is observed that for different inlet velocity of air from 15m/sec to 35m/sec we got drag forcein the range from 170N to 190N for the taken pentagonal cylinder.

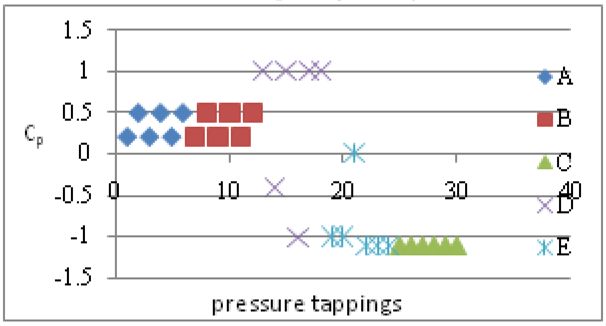


Figure 3: C_p distribution vs pressure tapping numbers for 0 degree angle of attack with inlet velocity of air at 15m/sec or at 57300 Reynolds number

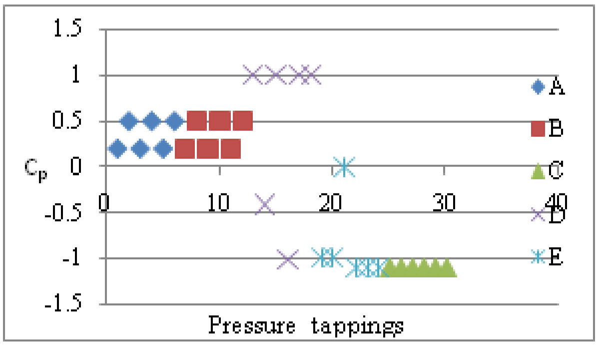


Figure 4: C_p distribution vs pressure tapping numbers for 0 degree angle of attack with inlet velocity of air at 25m/sec or at 95500 Reynolds number

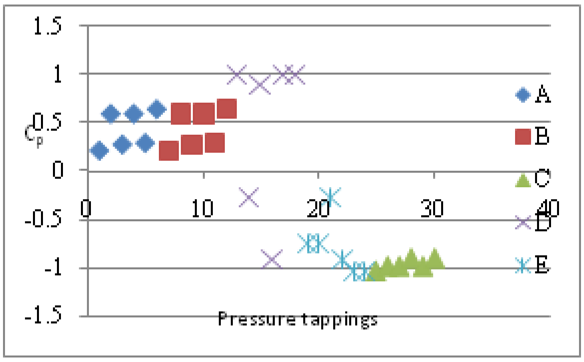


Figure 5: C_p distribution vs pressure tapping numbers for 0 degree angle of attack with inlet velocity of air at 35m/sec or at 133700 Reynolds number

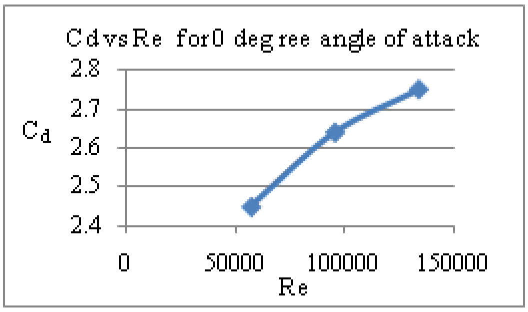


Figure 6: Drag coefficient vs Reynolds number for 0 degree angle of attack.

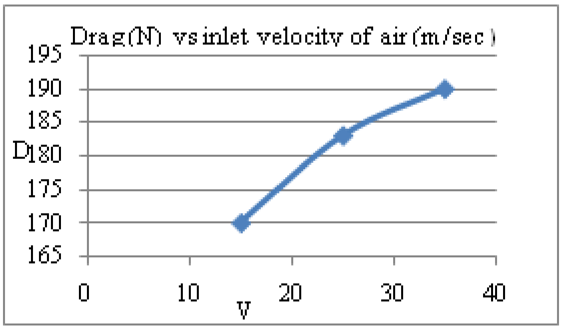


Figure 7: Drag force vs inlet velocity of air for 0 degree angle of attack

9. Conclusions

In statistics theory it was given that, regression was a mathematical measure showing the average relationship between two or more variables in terms of the original units of the data. Regression line describes the average relationship between x and y variables i.e.) it is a line which displays the mean value of y for the given values of x. Using minitab software regression line between drag coefficient and Reynolds number for this present condition it was found out to be y = 2.284 + 0.000003x for the curve shown in fig.6. Similarly regression line between drag force and inlet velocity of air for this present condition it wss found out to be y =156 + x for the curve shown in fig.7.

References

[1] Kapilghosh, "An experimental investigation of flow over pentagonal cylinder ", BUET, Bangladesh, vol. ME 44, No.1, June 2014.
[2] Anila jayakrishnan, "Pressure measurement studies on a rectangular building model under boundary layer flow condition", VIT university, Vellore, volme1-issue No.1-jun 2014.
[3] k.s priyanga and P.harikrishna, "Wind tunnel pressure measurement studies on 1: 2: 7 rectangular building model under uniform flow", MCET, pollachi, RAISE'2014.
[4] Text book," Fundamentals of aerodynamics" by john D Anderson jr.
[5] Text book."Reinforced concrete design of tall buildings" by Bungale.s and Taranath.
[6] Text book," Low speed wind tunnel testing" by Jewel Barlow, William H.Rae, Jr. Alan pope.
[7] Text book," Statistics theory and practice" by R.S.N Pillai , Bagavathi.