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An experimental investigation of wind effect on pentagonal and hexagonal staggered cylinders

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Abstract

In this research work, an experimental investigation of wind effect on pentagonal and hexagonal staggered cylinders was carried out. The study was performed on the group consisting of three cylinders, arranged in staggered form, one pentagonal cylinder in the upstream and another two hexagonal cylinder in the downstream side. The test was conducted in an open circuit wind tunnel at a Reynolds number of 4.22×10^4 based on the face width of the cylinder across the flow direction in a uniform flow velocity of 13.5 m/s. The group of three cylinders was taken into consideration for the study and the surface static pressures were measured for various transverse spacing of 2D, 3D, 5D and longitudinal spacing of 1D, 2D, 4D, 6D, 8D, where D is the width of the cylinder across the flow direction. The surface static pressures at the different locations of the cylinder were measured with the help of inclined multi-manometers.The pressure coefficients were calculated from the measured values of the surface static pressure distribution on the cylinder. Later the drag and lift coefficients were obtained from the pressure coefficients by the numerical integration method. The results will enable the engineers and architects to design buildings more efficiently. Since the results will be expressed in the non-dimensional form they may be applied for the prototype building.

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Keywords: Drag coefficient; Lift coefficient; Hexagonal cylinder; Pentagonal cylinder; Static pressure distribution; Wind load.

1. Introduction

The subjects of wind load on buildings and structures are not a new one. In the 17th century, Galileo and Newton have considered the effect of wind loading on buildings, but during that period, it did not gain popularity. In recent years, much emphasis has been given on “The study of wind effect on buildings and structures” in the different corners of the world. Even researchers in Bangladesh have taken much interest in this field. The pioneer researcher in this field is Lawson [1] of the University of Bristol. A number of works of the environmental aspects of wind was being studied at the Building Research Establishment at Garson and the University of Bristol, UK. It is true that researchers from all over the world have contributed greatly to the knowledge of flow over bluff bodies as published by Mchuri [2] but the major part of the reported works are of fundamental nature involving the flow over single body of different profiles. Mandal and Farok [3] measured the static pressure distributions on the single cylinder with square and rectangular cross-section having rounded corners in a uniform cross flow. The experiment was conducted for different corner radii and side dimensions of the cylinders at zero angle of attack. Islam and Mandal

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[4] performed an experimental investigation of static pressure distributions on a group of rectangular cylinders in a uniform cross flow. The effect of longitudinal spacing as well as the side dimension of the cylinder was taken into consideration in the study. Sultana [5] performed an experimental investigation of wind load on tall buildings with hexagonal cross-section. Most of the researchers have conducted works either on single cylinder with circular, square, octagonal, hexagonal or rectangular sections etc. or in a group with them for various flow parameters. However, the flow over a combination of pentagonal and hexagonal cylinders has not been studied extensively especially in-groups to date, although this is a problem of practical significance. It is believed that the study on the cylinder with pentagonal and hexagonal section will contribute to find the wind load on the group of pentagonal and hexagonal buildings and the results will be useful to the relevant engineers and architects. The flow around a combination of pentagonal and hexagonal model cylinder can be ideally considered analogous to that of the flow around a combination of tall pentagonal and hexagonal-shaped building. Therefore, a study of wind flow around groups of pentagonal and hexagonal cylinders would be helpful in this respect.

Nomenclature

A	Frontal area of the Cylinder
F_D	Drag force
F_L	Lift force
C_L	Coefficient of lift
C_D	Coefficient of drag
C_p	Coefficient of pressure
ρ	Density of the air
U_∞	Free stream velocity
ΔP	Pressure difference
Δh_w	Manometer reading
γ_w	Specific weight of manometer liquid (water)
α	Angle of attack

2. Experimental set-up

2.1. Wind tunnel

The test was conducted at the exit end of an open circuit subsonic wind tunnel. In Figure 1 the schematic diagram of the wind tunnel is presented showing the position of the cylinders at the exit end of the wind tunnel. The wind tunnel was 5.93 m long with a test section of 460 *mm* x 460 *mm* cross section. The cylinders were fixed to the side walls of the extended portion at the exit end. The cylinder was leveled in such a way that the top and bottom faces of the hexagonal cylinder and top face of the pentagonal cylinder were parallel to the flow direction. The axis of the cylinder was at the same level to that of the wind tunnel. To generate the wind velocity, two axial flow fans are used. In each case of the tests, wind velocity is measured directly with the help of a digital anemometer. The flow velocity in the test section was maintained at 13.5m/s approximately. The Reynolds number was 4.22×10^4 based on the projected width of the cylinder across the flow direction.

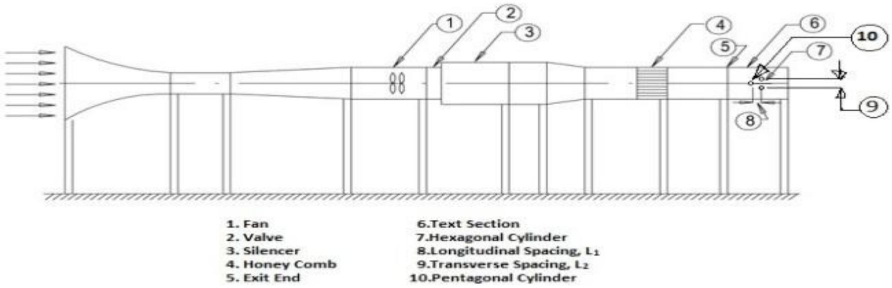

Fig. 1. Schematic diagram of wind tunnel.

2.2. Constructional details of cylinders

The tapping positions on the longitudinal section of the cylinder is shownin Figure 2. There were five tappings on each face of the cylinder. The distance between the consecutive tapping points was equal (Δd). However, the location of the corner tapping was at a distance of $(1/2)\Delta d$. Each tapping was identified by a numerical number. It can be seen from the longitudinal section that the tappings were not made along the cross-section of the cylinder.They were located within some span of the cylinder as shown in Figure 2. On one side of the cylinder a steel plate was attached through which there was a bolt for fixing the cylinder with the side wall of the extended tunnel as shown in Figure 2. The other side of the cylinder was hollow through which the plastic tubes were allowed to pass. The plastic tubes were connected with the copper capillary tubes at one side and at the other side with the inclined multi-manometer. The manometer liquid was water. The tappings were made of copper tubes of 1.71 mm outside diameter. Each tapping was of 10mm length approximately. From the end of the copper tube flexible plastic tube of 1.70 mm inner diameter was press fitted.

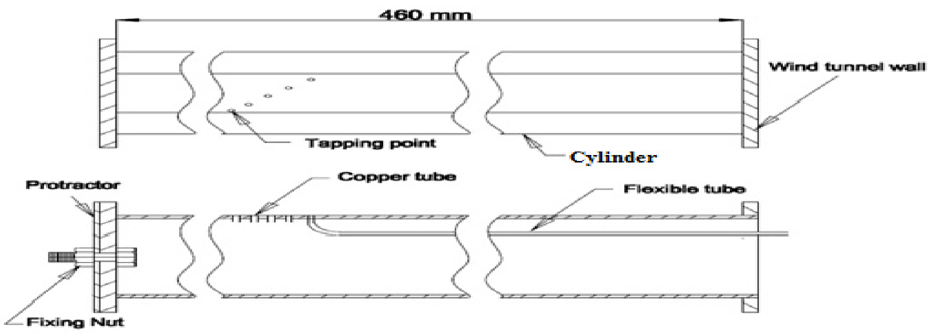

Fig. 2. Tapping positions shown on longitudinal section of cylinder.

2.3. Group of cylinders

In Figure 3, the group of cylinders is shown at zero angle of attack. One pentagonal cylinder is positioned in the upstream side designated as the front cylinder and another two hexagonal cylinders is positioned in the downstream side designated as the rear cylinders.

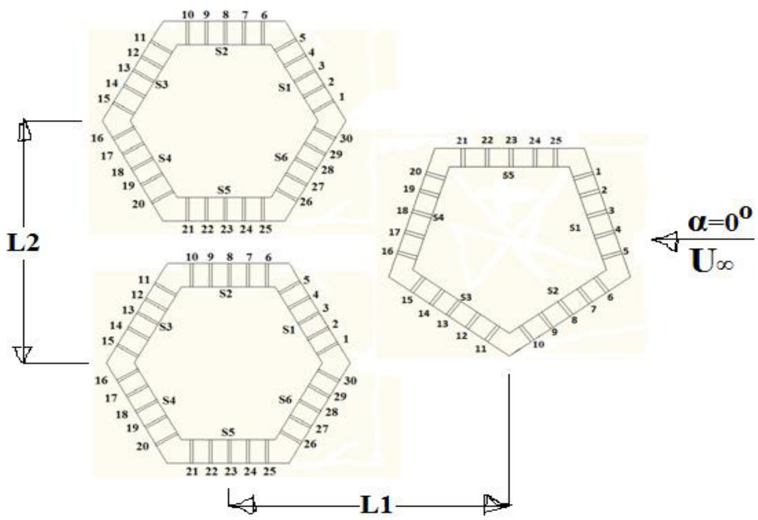

Fig.3. Flow over cylinder in group at zero angle of attack.

3.Mathematical Model

The pressure coefficient is defined as

$$C_P = \frac{\Delta P}{\frac{1}{2}\rho U_\infty^2} \quad (1)$$

Drag and lift coefficients are defined as follows $C_D = \frac{F_d}{\frac{1}{2}\rho A U_\infty^2}$ (2)

and $C_L = \frac{F_L}{\frac{1}{2}\rho A U_\infty^2}$ (3)

4. Results and Discussion

4.1. Distribution of Pressure Coefficients on hexagonal Cylinder

The Cp-distribution on the hexagonal cylinder of the group at L_1=8D, L_2=2D is shown in Figure 4. It can be seen from this figure that the C_p-distribution is symmetric. There is little effect on the Cp-distribution of the hexagonal cylinder due the presence of the pentagonal cylinder. In Figure 5, the C_p-distribution on the hexagonal cylinder at L_1=6D, L_2=2D has been presented. It can be observed from this figure that there has been appreciable increase in the back pressure due to presence of the pentagonal cylinder. The average C_p values on the surfaces S_2 to S_5 is approximately -1 compared that of-1.50 in case of the inter-spacing L_1=8D, L_2=2D. However, C_p-distribution on the surfaces S_2 to S_5 is of uniform nature approximately. About same pattern of C_p-distribution is seen in Figure 6 at L_1=4D, L_2=2D on the hexagonal cylinder. There is remarkable effect on the Cp-distribution at both the inter-spacing L_1 of 4D and 6D due to the presence of the pentagonal cylinder. The Cp-distribution on the hexagonal cylinder of the group at inter-spacing L_2 of 3D and 5D with in each case of inter-spacing L_1 of 1D,2D, 4D, 6D and 8D are more or similar to inter-spacing L_2 of 2D.

4.2. Distribution of Pressure Coefficient on pentagonal Cylinder

The Cp-distribution on the pentagonal Cylinder of the group at L_1=8D, L_2=2D is shown in Figure 7. It can be observed from this figure that there is remarkable effect on C_p-distribution due the presence of the hexagonal cylinder. From S_2 to S_5, the C_p-distribution is symmetric and the C_p-distribution is more uniform on the surfaces S_3 to S_4.It is observed from Figure 8 that on the pentagonal Cylinder of the group at L_1=6D, L_2=2D, the pattern of the C_p-distribution is similar as that of the L_1=8D, L_2=2D but the values increases. The C_p-distribution is more uniform on the surfaces S_3 to S_5. However, a picture is seen in Figure 9 for the C_p-distribution on the pentagonal Cylinder of the group at L_1=4D, L_2=2D, the pattern of the C_p-distribution is similar as that of the L_1=6D, L_2=2D but the values increases for the surfaces S_3 to S_5 and C_p-distribution is more uniform. The Cp-distribution on the pentagonal cylinder of the group at inter-spacing L_2 of 3D and 5D with in each case of inter-spacing L_1 of 1D, 2D, 4D, 6D and 8D are more or similar to inter-spacing L_2 of 2D.

4.3. Variation of Drag and Lift Coefficient on pentagonal and hexagonal cylinder

The variation of drag coefficients on the hexagonal and pentagonal cylinders of the group with L_1 for different values of L_2 at zero degree angle of attack has been presented in Figure 10 and 11 respectively. It can be seen from figure 10 that, as the inter-spacing L_2 increasedragcoefficient also increase for the all values of inter-spacing L_1 except L_1=2D,where drug coefficient is near to 1 for L_2 for hexagonal cylinder. It can be seen from figure 11 that, for L_2= 2D, at L_1=4D drag coefficient is equal to 1 and for higher L_1 drag coefficient is more than 1 and for lower L_1 drag coefficient is less than 1. For L_2= 5D, drag coefficient is higher than L_2= 2D for the all values of inter-spacing L_1. For L_2= 3D, drag coefficient is lower than L_2= 2D for the all values of inter-spacing L_1 except L_1=1D and 8D.

The variation of lift coefficients on the hexagonal and pentagonal cylinders of the group with L_1 for different values of L_2 at zero degree angle of attack has been presented in Figure 12 and 13 respectively. It can be seen from figure 12 that, for L_2=3D and 5D, the pattern of lift coefficient for hexagonal cylinder is similar. For L_2=2D, lift coefficient is negative for the all values of inter-spacing L_1 except L_1=4D and 8D. It can be seen from figure 13 that, for L_2=2D and 3D, lift coefficient is decrease with increase of L_1 andfor L_2=5D, firstly lift coefficient is decrease with increase of L_1 up to 4D then increase for pentagonal cylinder.

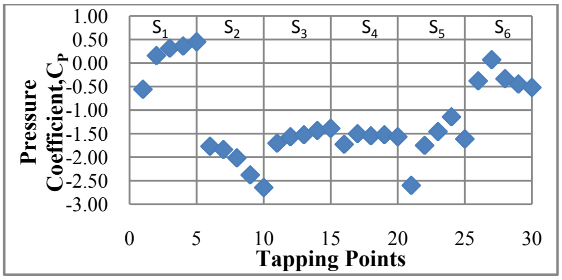

Fig. 4. Distribution of Pressure Coefficient on Hexagonal Cylinder at L_1=8D, L_2=2D.

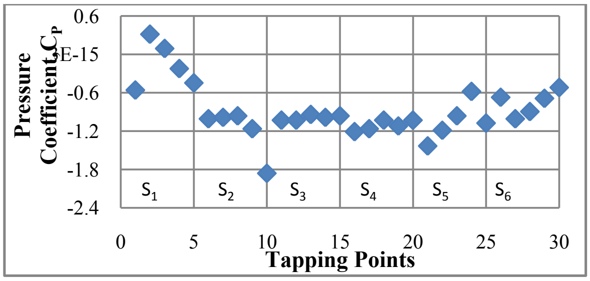

Fig. **5**. Distribution of Pressure Coefficient on Hexagonal Cylinder at L_1=6D, L_2=2D.

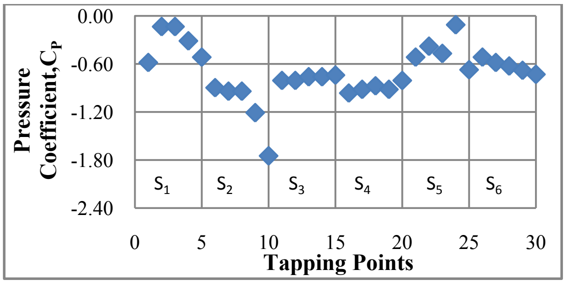

Fig. 6. Distribution of Pressure Coefficient on Hexagonal Cylinder at L_1=4D, L_2=2D.

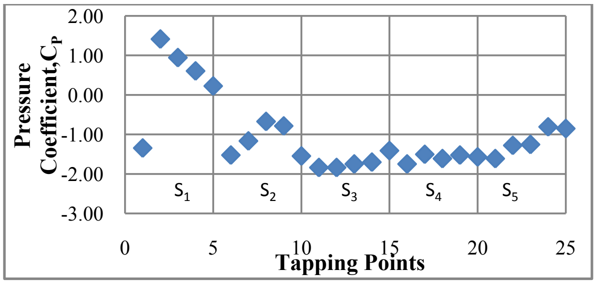

Fig. 7. Distribution of Pressure Coefficient on Pentagonal Cylinder at L_1=8D, L_2=2D.

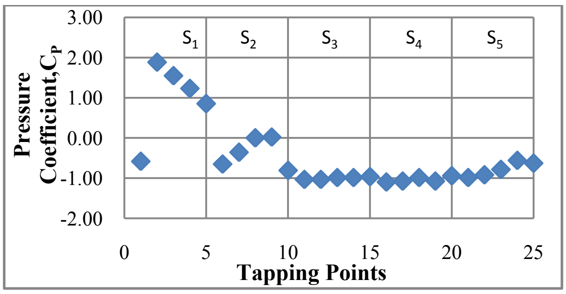

Fig. 8. Distribution of Pressure Coefficient on Pentagonal Cylinder at L_1=6D, L_2=2D.

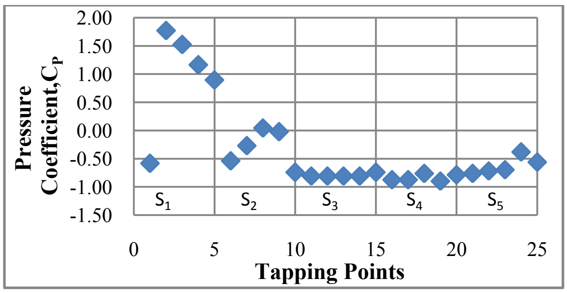

Fig. 9. Distribution of Pressure Coefficient on Pentagonal Cylinder at L_1=4D, L_2=2D.

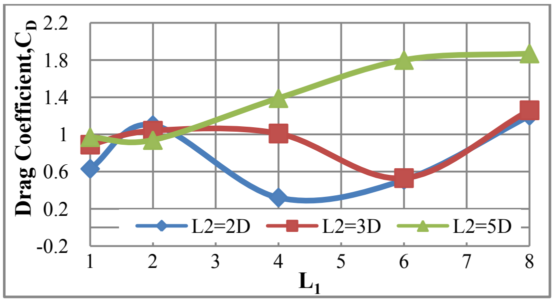

Fig. 10. Variation of Drag Coefficients on Hexagonal Cylinder with L_1 for different values of L_2.

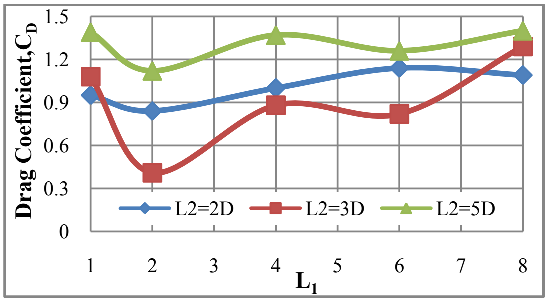

Fig. 11. Variation of Drag Coefficients on Pentagonal Cylinder with L_1 for different values of L_2.

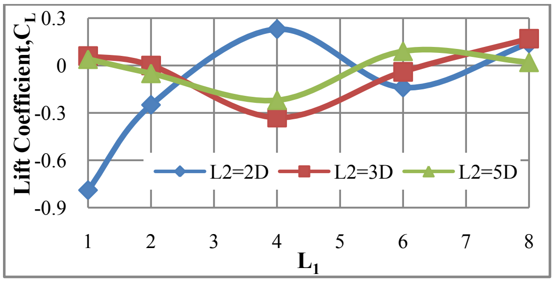

Fig. 12. Variation of Lift Coefficients on Hexagonal Cylinder with L_1 for different values of L_2.

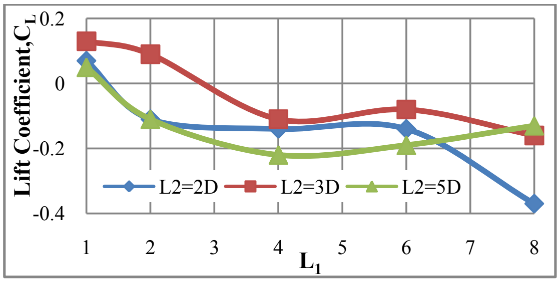

Fig. 13. Variation of Lift Coefficients on Pentagonal Cylinder with L_1 for different values of L_2.

5. Conclusion

The following conclusions are drawn in regard to the wind effect on the two hexagonal cylinders and one pentagonal cylinder in a group. The stagnation point is found on the front face of the hexagonal cylinder in the group, however no such stagnation point is found in the pentagonal cylinder of the group.As the inter-spacing L_2 increasedragcoefficient also increase for the all values of inter-spacing L_1 except L_1=2D for hexagonal cylinder. While wind load is to be used for the design of the group of building having hexagonal and pentagonal cross-section, the outcome of the present results may be applied.

Acknowledgements

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