

## AN EXPERIMENTAL INVESTIGATION OF STATIC PRESSURE DISTRIBUTIONS ON A GROUP OF SQUARE OR RECTANGULAR CYLINDERS WITH ROUNDED CORNERS

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**Abstract:** The static pressure distributions on a group of cylinders with either square or rectangular cross-section having rounded corners are presented. The test is conducted at the exit end of an open circuit wind tunnel with uniform velocity of 14.2 m/s across the cylinder with Reynolds number of  $2.87 \times 10^4$  and  $4.20 \times 10^4$  based on the side dimension of the cylinder normal to the direction of the approach flow. The experiment is performed for a group consisting of two cylinders one behind the other along the flow direction with different side dimensions at zero angle of attack for various interspacing between the cylinders. It is observed from the experimental results that there is appreciable effect of the side dimension and interspacing on the drag coefficient of the cylinders. The results are applicable to a group consisting of two tall buildings one behind the other along the wind velocity direction and each building of either square or rectangular cross-section having rounded corners. The wind load on the downstream cylinder decreases remarkably due to the presence of the cylinder in the upstream side.

**Keywords:** Wind load, Group of buildings.

### INTRODUCTION

It is the great challenge of the engineers and architects to reduce the wind load on the tall buildings. Now a day due to huge population pressure, emphasis on design and construction of the tall buildings is being given in many places. Especially the design of the group of tall buildings is the most important consideration to take care of the housing problem of the huge population. As the building becomes tall it is necessary to take into consideration the effect of wind load on its design. Keeping this in mind the study on the group of square and rectangular cylinders has been conducted, which will be applicable to obtain the wind load on the group of tall buildings.

When the flow occurs over a tall building there will be wind shear at the bottom and the flow will be of three dimensional one at the top. While at the middle of the building the flow may be treated as two dimensional one. Neglecting the pattern of flow at the bottom and top ends of a tall building, the entire flow may be considered approximately as the two dimensional one. Again it is well known fact that there will be turbulence in the actual wind flow and it will have the effect on the wind load of the building. However, in the study the flow has been chosen as the two dimensional uniform flow with negligible turbulence to determine the wind load.

Till now usually the different researchers have conducted experiment to determine the wind load on the square and rectangular cylinders with sharp corners both in a group and in a stand alone

condition. They have measured the static pressure distributions mainly, from where they have calculated the wind load. Barriga et al (1975) carried out a study of flow on a single square cylinder. They measured the mean pressure distribution on the same at small angle of attack in a turbulent cross flow. They showed the effect of angle of attack, turbulence intensity and scale on their results.

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### Nomenclature

- $C_d$  Drag coefficient  
 $C_p$  Mean pressure coefficient  
 $D$  Width of cylinder normal to approach flow  
 $F_D$  Drag force per unit length of the cylinder  
 $H$  Width of cylinder parallel to approach flow  
 $H/D$  Side ratio  
 $\Delta P$  Difference of ambient and local static pressure  
 $r/D$  Non-dimensional corner radius  
 $s/D$  Interspacing  
 $U_o$  Free stream velocity

### Greek Letters

- $\alpha$  Angle of attack  
 $\rho$  Density of air
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Lee (1975) performed study on the effect of turbulence on the surface pressure field on a square prism. In his study measurements were presented of the mean and fluctuating pressure field acting on a two dimensional square cylinder in uniform and turbulent flows. In his investigation he showed that the addition of turbulence reduces the drag on the cylinder.

Mandal and Farok (2005) 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. The experimental results reveal that the corner radius of the cylinder has significant effect while the side dimension has some effect on the drag coefficient.

Mandal and Islam (1980) made an experimental investigation of mean pressure coefficients on square cylinders. They measured the pressure coefficients on single square cylinder at various angles of attack and on a group of square cylinders with sharp edge at zero angle of attack.

Islam and Mandal (1992) 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.

**EXPERIMENTAL SET-UP**

The test was conducted at the exit end of an open circuit subsonic wind tunnel. In Fig. 1 the schematic diagram of the wind tunnel is presented showing the position of the cylinders at the exit end of the wind tunnel. One cylinder was located at the upstream side called front cylinder and the other one was located at the downstream side called rear cylinder. The wind tunnel was 6 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.

In the side wall the cylinder was fastened rigidly at one end and through the other end of the cylinder the plastic tubes from the tapping were taken out and were connected with the inclined manometer, which contained water as the manometer liquid. The cylinder was leveled in such a way that the flow direction was parallel to its top and bottom sides and perpendicular to the front side. The axis of the cylinder was at the same level to that of the wind tunnel. The top and the bottom of the extended portion of the wind tunnel were open.

In Fig. 2, the cross-section of a cylinder with pressure tapping position has been shown. The section has been divided both vertically and horizontally with equal inter-space. The cylinders were made of side dimensions 45 mm x 30 mm ( $D = 45\text{ mm}$  and  $H = 30\text{ mm}$ ) for side ratio of 0.67, 30 mm x 30 mm ( $D = 30\text{ mm}$  and  $H = 30\text{ mm}$ ) for side ratio of 1.0 and 30 mm x 45 mm ( $D = 30\text{ mm}$  and  $H = 45\text{ mm}$ ) for side ratio of 1.5.

**COEFFICIENTS**

The coefficients of pressure ( $C_p$ ) is defined as,

$$C_p = \frac{\Delta P}{\frac{1}{2} \rho U_o^2} \tag{1}$$

and the coefficient of drag ( $C_d$ ) is defined as,

$$C_d = \frac{F_D}{\frac{1}{2} \rho U_o^2} \tag{2}$$

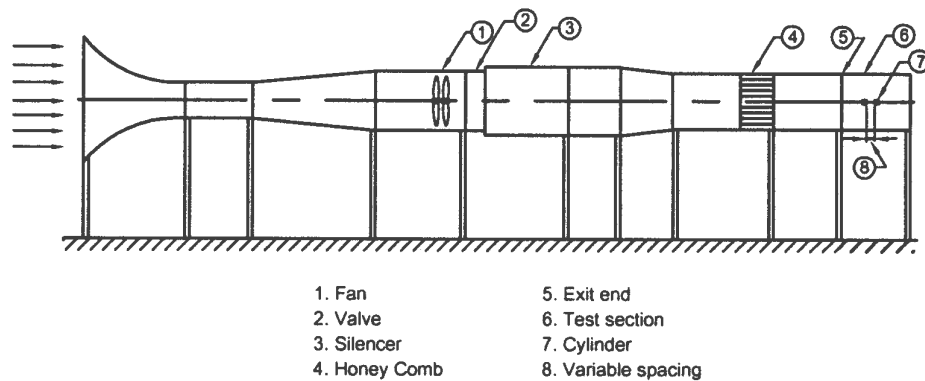


Figure 1. Schematic Diagram of Wind Tunnel.

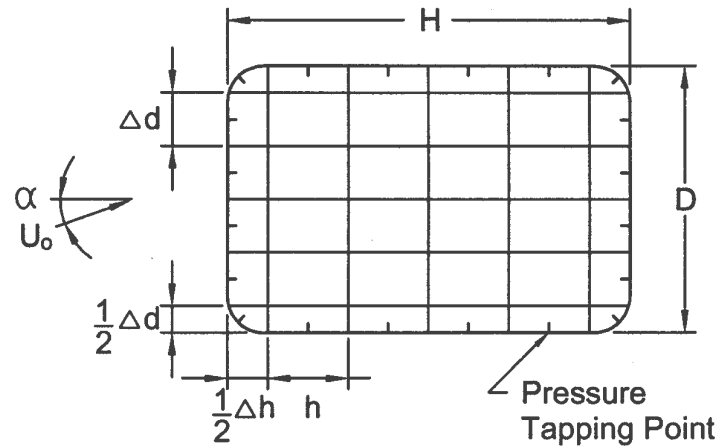


Figure 2. Section of a Cylinder Showing Pressure Tapping Position.

### EXPERIMENTAL RESULTS AND DISCUSSIONS

The distributions of static pressure coefficients on the front cylinder with rounded corner are shown in Fig. 3 to 5 for side ratios ( $H/D$ ) of 0.67, 1.00 and 1.50 and the corresponding nose radii ( $r/D$ ) of 0.167, 0.167 and 0.188 respectively. The pressure coefficients are presented for the various non-dimensional interspacing ( $s/D$ ) of 1, 2, 4, 6 and 8 between the front and the rear cylinders. Based on the front side dimension of the cylinder, Reynolds number for side ratio of 0.67 was  $4.30 \times 10^4$  and for side ratios of 1.0 and 1.5 was  $2.87 \times 10^4$ . The angle of attack was zero in each case.

For height diameter ratios of 0.67, 1.00 and 1.50 and the corresponding nose radii of 0.167, 0.167 and 0.188 respectively, the distributions of static pressure coefficients on the rear cylinder with rounded corner have been presented in Fig. 6 to 8. The pressure coefficients are presented for the various non-dimensional interspacing ( $s/D$ ) of 1, 2, 4, 6 and 8 between the front and the rear cylinders. Reynolds number and angle of attack were identical to those for the front cylinder.

It can be noticed from Fig. 3 to 5 that the pressure coefficients are almost identical at the top and bottom faces of the front cylinder, which is due to the symmetry of flow. From the top, bottom and rear faces of the front cylinder it is observed that there is small effect of interspacing on the distribution of pressure coefficients. However, in general the pressure coefficient on the back surface is relatively higher at the higher interspacing.

If the distributions of pressure coefficients on the front cylinder are compared with those of the single cylinder as presented by Mandal and Farok (2005), it will be seen that due to the presence of the rear cylinder, the back pressure of the front cylinder has increased. The flow at the

downstream side of the front cylinder becomes more turbulent due to the presence of the rear cylinder creating relatively more mass and momentum transfer, which makes the pressure recovery.

It is observed from Fig. 6 to 8 that the variation of pressure distributions on the top, bottom and rear faces are not prominent for different interspacing. However, there is wide variation of the pressure distributions with interspacing on the front face of the rear cylinder. On the front face at the small interspacing the pressure coefficients become negative while at the higher interspacing pressure coefficients become slightly positive in general. The front face of the downstream cylinder remains in the wake region produced by the upstream cylinder.

The front face of the downstream cylinder never sees the free stream flow pattern as the single cylinder for the interspacing considered in the test. Of course at the very large interspacing the front face of the downstream cylinder will ultimately see the free stream pattern of flow. At the small interspacing, relatively larger wakes are generated while at the large interspacing relatively smaller wakes are generated. The mean velocity in the wake is much lower than the free stream velocity. This mean wake velocity is relatively smaller for the larger wakes and vice versa. For this reason at the smaller interspacing the pressure coefficients on the front face of the downstream cylinder are smaller and negative while at the larger interspacing the pressure coefficients are higher and positive.

The variation of drag coefficient with interspacing for different side ratios on the front and rear cylinders are shown in Fig. 9 and 10 respectively.

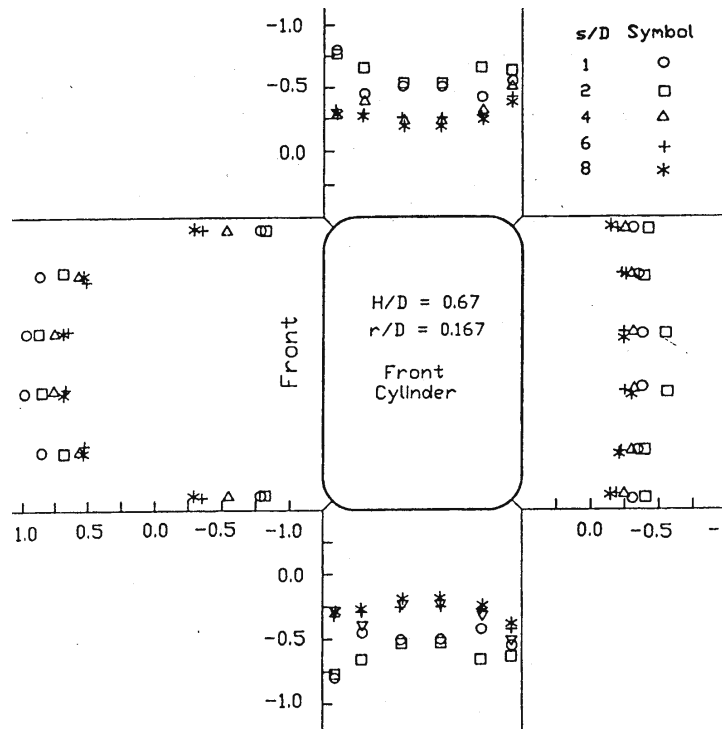


Figure 3. Static Pressure distribution on Front Cylinder for Different Interspacing Having Side Ratio of 0.67.

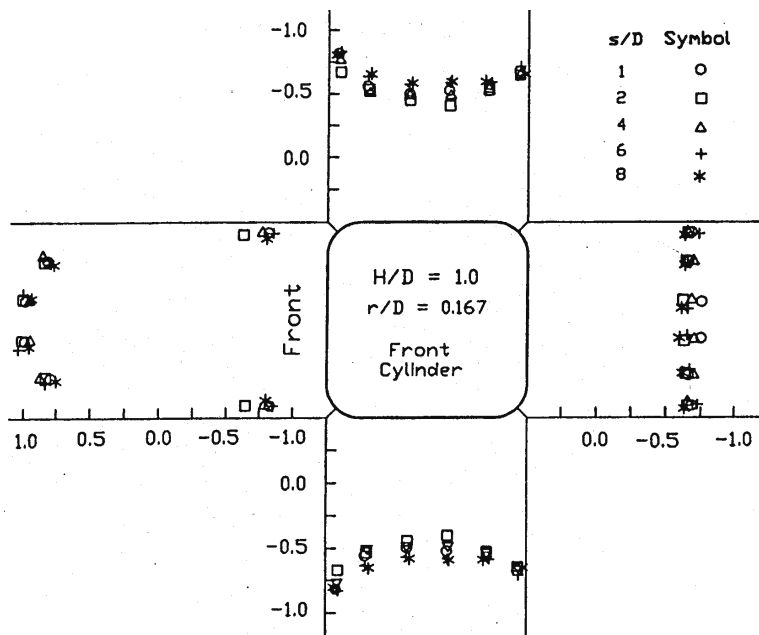


Figure 4. Static Pressure Distribution on Front Cylinder with Different Interspacing Having Side Ratio of 1.00

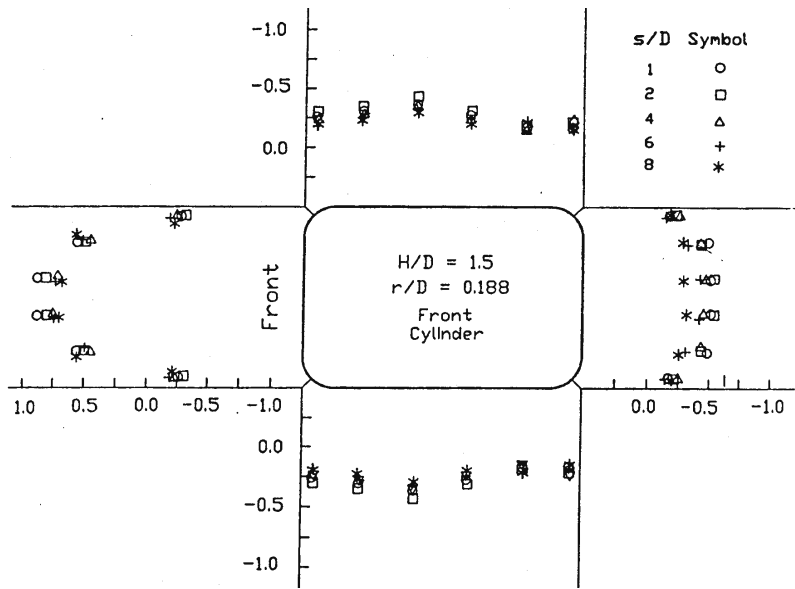


Figure 5. Static Pressure Distribution on Front Cylinder with Different Interspacing Having Side Ratio of 1.50.

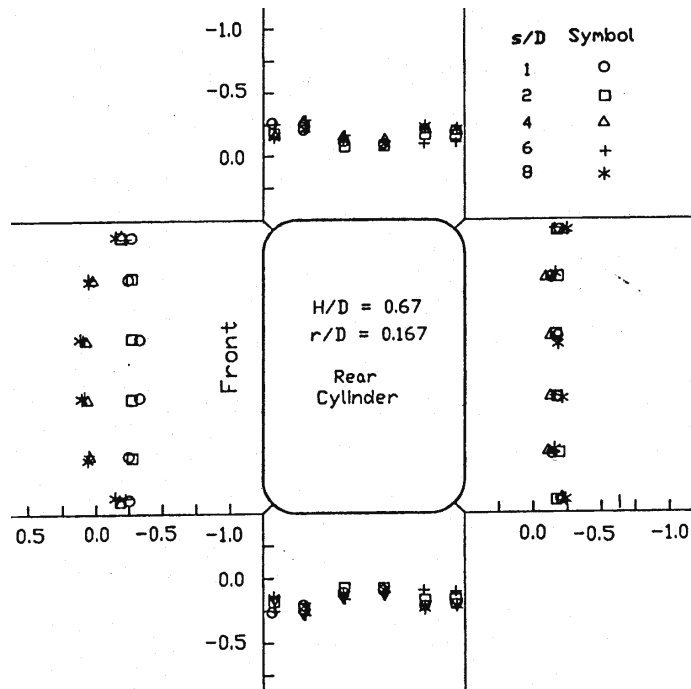


Figure 6. Static Pressure Distribution on Rear Cylinder with Different Interspacing Having Side Ratio of 0.67.

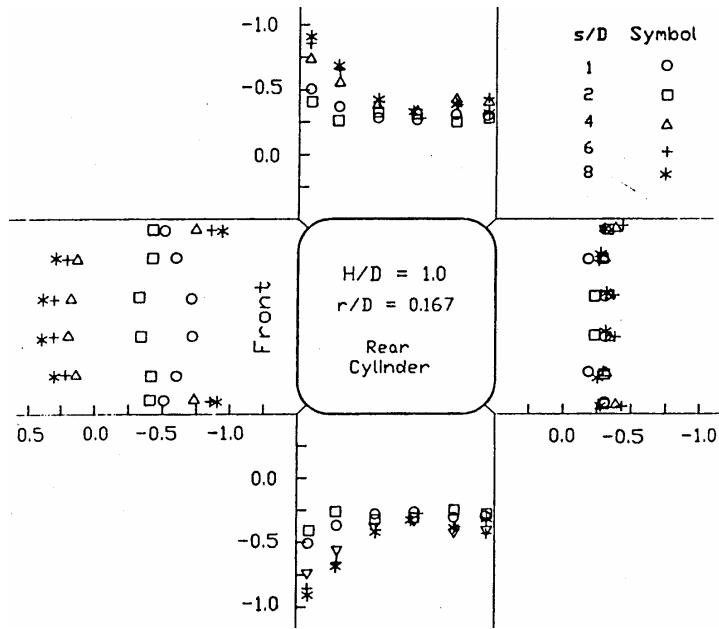


Figure 7. Static Pressure Distribution on Rear Cylinder with Different Interspacing Having Side Ratio of 1.00

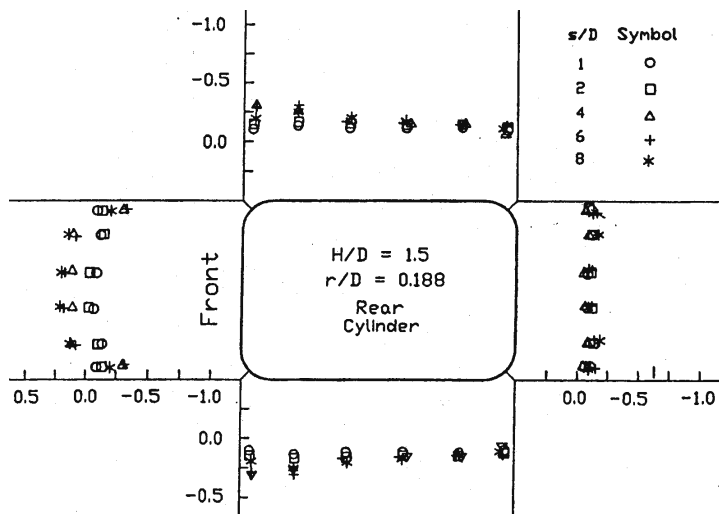


Figure 8. Static Pressure Distribution on Rear Cylinder with Different Interspacing Having Side Ratio of 1.50

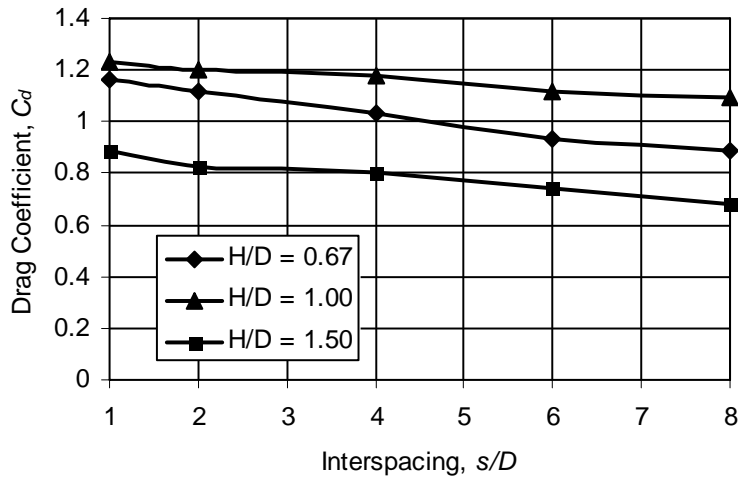


Figure 9. Variation of Drag Coefficient with Interspacing on Front Cylinder for Different Side Ratios.

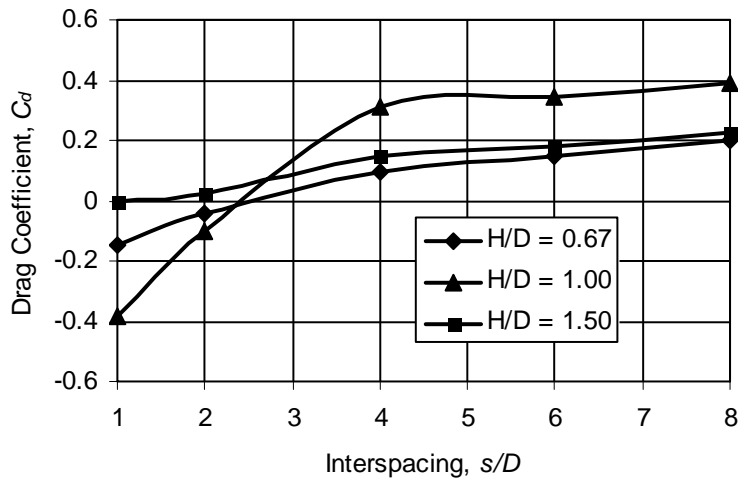


Figure 10. Variation of Drag Coefficient with Interspacing on Rear Cylinder for Different Side Ratios.

The drag coefficient for a single cylinder with sharp edge having side ratio of 1.0 is about 2.1 as found by Lee (1975). On the other hand according to Mandal and Farok (2005) the drag coefficient for a single cylinder with nose radius of 0.167 is about 1.0 and there is some effect of side ratio on this value. It can be seen from Fig. 9 that there is some effect of interspacing and side ratio on the drag coefficient of front cylinder; however the effect is not very significant. The nose radius of the cylinder with side ratio of 1.5 is 0.188 and that with side ratios of 0.67 and 1.0 is 0.167; however, since the

difference of the nose radius values are small, so their effect has been neglected here.

From Fig.10, it can be observed that there is remarkable effect of interspacing on the drag coefficient of rear cylinder. For side ratio of 0.67 and 1.50 the drag coefficients are close to each other at all interspacing while that for the side ratio of 1.0 there is wide variation. In general the drag coefficient on the rear cylinder at all interspacing is small compared to that on the single cylinder. Addition of turbulence will reduce the drag further as mentioned by Lee (1975). Since on the front face of the rear cylinder the pressure coefficient is

small and close to zero, as a result the drag coefficient on this cylinder is small. As the interspacing increases the pressure on the back surface of the cylinder increases; the drag coefficient decreases.

### **CONCLUSIONS**

The drag coefficient on the rear cylinder with either square or rectangular cross section having rounded corner decreases significantly compared to that on the single cylinder. There is small change of drag coefficient on the front cylinder compared to that on the single cylinder. The effect of interspacing and side ratio on the drag coefficient of the rear cylinder is appreciable. There is small effect of interspacing and side ratio on the drag coefficient of front cylinder.

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