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# Combined Effect of Surface Roughness and Wake Splitter Plate on the Aerodynamic Characteristics of a Circular Cylinder

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**Abstract.** This paper is focussed on numerical investigation of flow around a stationary circular cylinder (diameter,  $D$ ) with selectively applied surface roughness (roughness strips with thickness ' $k$ ') in the presence of a wake splitter plate (length,  $L$ ). The plate leading edge is at a distance of ' $G$ ' from the cylinder base. For this study, the commercial software ANSYS Fluent is used. Fluid considered is water. Study was conducted the following cases (a) plain cylinder (b) cylinder with surface roughness (without splitter plate) (c) Cylinder with splitter plate (without surface roughness) and (d) cylinder with both roughness and splitter plate employed. The study Reynolds number (based on  $D$ ) is 17,000 and  $k/\delta = 1.25$  (in all cases). Results indicate that, for cylinder with splitter plate (no roughness), lift coefficient gradually drops till  $G/D=1.5$  further to which it sharply increases. Whereas, drag coefficient and Strouhal number undergoes slight reduction till  $G/D=1.0$  and thereafter, gradually increase. Circumferential location of strip ( $\alpha$ ) does not influence the aerodynamic parameters significantly. With roughness alone, drag is magnified by about 1.5 times and lift, by about 2.7 times that of the respective values of the smooth cylinder. With splitter plate, for roughness applied at all ' $\alpha$ ' values, drag and lift undergoes substantial reduction with the lowest value attained at  $G/D=1.0$ .

## 1. Introduction

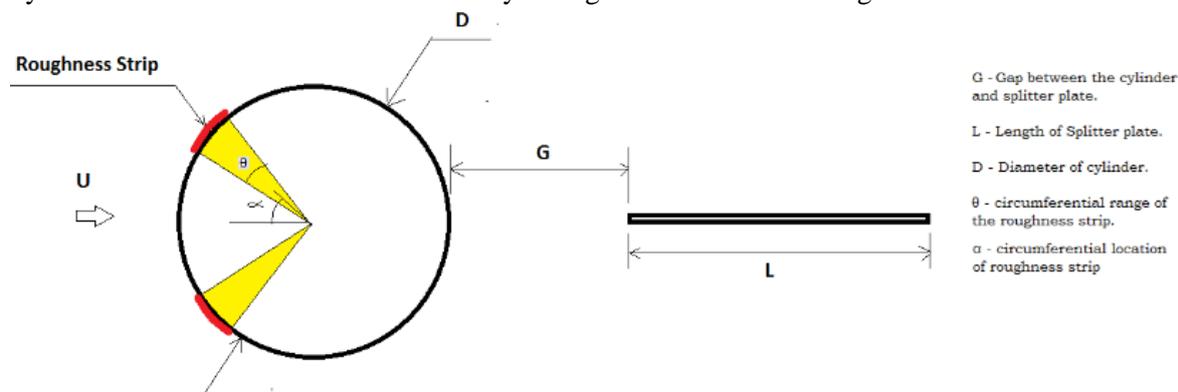
Flow around circular cylinder has been extensively studied due to its application in a wide variety of engineering structures such as chimney stacks, heat exchangers, cooling towers and so on. Due to space limitation, only few selected past studies are reviewed here. Bishop & Hassan [1] have reported measurements on lift and drag forces on a stationary circular cylinder in the Reynolds number range between 3600 and 11,000. Further, some of the early works carried out are cited in the review paper



by Niemann & Holscher [2]. In the 1966, Gerrad [3] has proposed the underlying mechanism of vortex shedding behind a circular cylinder. Further to this, Achenback [4] has revealed results on the effect of surface roughness (applied on the entire surface) on the cross flow over a circular cylinder by measuring the local surface pressures and wall shear stresses. He found that, higher the surface roughness, earlier will be the transition of flow from laminar to turbulent. Dalton & Xu [5] found that placement of a control cylinder has notable influence on the drag and lift of the primary cylinder. Norberg [6] found that between Reynolds number value of 1600 and 20000, lift (rms) increases 10 times. Li-Chen et al [7] have proposed a new passive jet control method to manipulate the wake vortex shedding process.

Past studies show that introducing a splitter plate in to the near wake of a circular cylinder brings significant changes in the aerodynamic characteristics around it (Dehkordi and Jafari [8]; Assi and Bearman [9]). Furthermore, application of selective roughness on a circular cylinder is found to considerably modify the flow-induced vibration response of an elastically mounted cylinder (Chang et al [10]; Hongrae et al [11]; Hongrae et al [12]). This has naturally aroused a curiosity as to how the flow field and the resultant fluid forces change if they are together employed. The present study is an outcome of this inquisitiveness to investigate the combined influence of splitter plate and selectively applied roughness on a circular cylinder in water flow. To point out further, such a study has not been reported so far in the literature.

In the present study, selective roughness is applied on a circular cylinder using a roughness strip having a width 'b' (circumferential coverage=10 deg) and roughness height (k). Besides this, a splitter plate is introduced in to the body wake. Thus, the combined influence of surface roughness and splitter plate on the aerodynamic/hydrodynamic characteristics of a circular cylinder is investigated at a Reynolds number value of 17000. The study configuration is shown in Fig.1.



**Figure.1:** Model geometry

## 2. Nomenclature

St - Strouhal number

Cpb - Base pressure coefficient

G/D - Gap to diameter ratio

L/D - Length to diameter ratio

$\alpha$  - Roughness location

Cl\* - Non dimensional lift coefficient

$\delta$  - Boundary layer thickness

k - Roughness height

Cd\* - Non dimensional drag coefficient

## 3. Computational Model and Validation

Numerical simulations in the present study were carried out using ANSYS FLUENT, a finite volume-based commercial CFD tool. Transient formulations of the governing equations for incompressible flow are as follows:

$$\text{Continuity equation: } \partial \rho / \partial t + \nabla \cdot (\rho V) = 0 \quad (1)$$

$$\text{Momentum equation: } \rho (\partial V / \partial t) + \rho V \nabla \cdot V = -\nabla P + \mu \nabla^2 V + \rho g \quad (2)$$

The SST  $k-\omega$  approach was used for turbulence particularly because of its capability to model flows dominated by separation and recirculation. The domain is discretized using a quadrilateral mesh with adequate resolution of the near-wall regions. A mesh size of 210748 cells was found to be sufficient for a grid-independent solution. The wall  $y^+$  is in the range of 2-10. Second order upwind scheme is used for convective and diffusive terms. In order to validate the computational model, the predicted Strouhal number, base pressure coefficient and rms value of lift coefficient were compared with the experimental data reported in the literature at the same Reynolds number. Comparison between the experimental and the present CFD results is summarized in Table 1. The simulation results comply fairly well with the experimentally reported values for the respective parameters.

**Table.1:** Validation of simulation data with experimental results for smooth cylinder and cylinder with splitter plate

Para-meter	Experiment (Ozono, [13]) -Smooth Cylinder with splitter plate	CFD (Present study)- Smooth cylinder with splitter plate	Experiment (Norberg [6])Smooth Cylinder	CFD (Present study)- Smooth Cylinder
<b>St</b>	0.148	0.1464	0.198	0.196
<b>C<sub>pb</sub></b>	0.77	0.75	-----	-----
<b>C<sub>l</sub>(rms)</b>	-----	-----	0.446	0.424

The present study is carried out at a Reynolds number (based on D) value of 17,000. The freestream turbulence intensity is 1%. Referring to Fig.1, the roughness strip locations are  $\alpha = 0^\circ, 9^\circ, 31^\circ, 65^\circ$  and  $75^\circ$ . Moreover, for a boundary layer thickness  $\delta$ ,  $k/\delta$  is kept constant at 1.25 at all strip locations ( $\alpha$ ). It is pointed out that, the boundary layer thickness vary at each circumferential location and the values calculated at each location is given in Table.2. Boundary layer thickness is calculated based on the modified Pohlhausen method described in Khan et al [14]. The study configurations considered in this series of simulations are as follows (a) stand-alone smooth circular cylinder (b) Circular cylinder with roughness strip at ' $\alpha$ ' locations mentioned above (without splitter plate) (c) Cylinder with splitter plate at  $G/D=0.5, 0.75, 1.0, 1.5$  and  $2.0$ ,  $L/D$  being fixed at  $1.0$  (without roughness) (d) cylinder with both roughness and splitter employed.

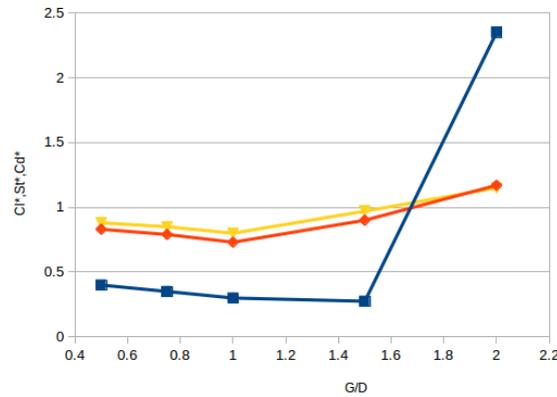
**Table. 2:** Boundary layer thickness values at various circumferential locations

<b><math>\alpha</math></b>	<b><math>\delta</math> (mm)</b>
$0^\circ$	0.299215
$9^\circ$	0.300321
$31^\circ$	0.312966
$65^\circ$	0.370096
$75^\circ$	0.401496

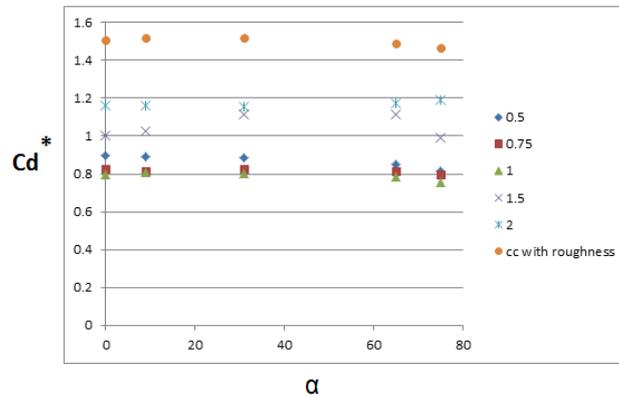
#### 4. Results and Discussion

Results for the study configurations comprise of drag coefficient, lift coefficient (root mean square value), and the Strouhal number. All these parameters are non-dimensionalized with respect to the respective values for the smooth cylinder and are presented in Figs. 2-4. As seen in Fig.2, the non-dimensional lift coefficient undergoes a reduction as  $G/D$  increases from 0.5 to 1.5 further to which it drastically increases to a high value. Non-dimensional Strouhal no. and drag coefficient slightly reduce when  $G/D$  is increased from 0.5 to 1.0 and it registers an increasing trend for  $G/D > 1.0$  (Fig.2).

With splitter plate alone, at  $G/D=1.5$ , lift reduces substantially to value of about 25% that of the smooth cylinder whereas drag reduces to about 75% that of the smooth cylinder at  $G/D=1.0$ .

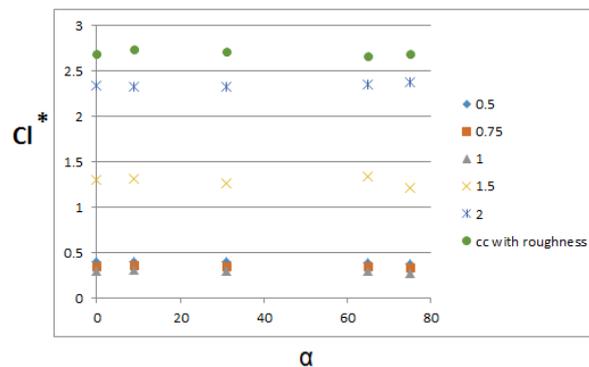


**Figure.2:** Variation of Cl, Cd and St with G/D ratio (Plain cylinder)



**Figure.3:** Variation of non-dimensional drag coefficient with roughness location

Fig.3 gives the non-dimensional drag coefficients for the study configuration (d) mentioned earlier (with both roughness and splitter plate). As could be seen, compared to the case with roughness alone, all the cases with splitter plate show a reduction in drag values. As  $G/D$  decreases, drag reduces in general. Quite interestingly, as  $G/D$  is further reduced from 1.0, drag slightly increases indicating that, there is an optimum  $G/D$  where drag is a minimum. This trend reversal is particularly evident at  $\alpha = 0$  (stagnation point). At a given  $G/D$  value, change of strip locations does not bring any notable variation in the drag values. But, with roughness alone (no splitter plate), as Fig.3 shows, drag gets multiplied by a factor of about 1.5 compared to a smooth cylinder. Furthermore, Fig.3 also reveals that, a magnificent reduction of about 50% could be achieved by employing both roughness and splitter plate.



**Figure.4:** Variation of non-dimensional lift coefficient with roughness location

Non-dimensional lift coefficient (Fig.4) also shows a similar trend to that of the drag when both roughness and splitter plate are introduced. It could be seen that, with roughness (no splitter plate), lift is magnified by about 2.7 times that of smooth cylinder. Quite interestingly, as these results show, with the introduction of splitter plate along with roughness, lift coefficient drops to a substantially lower value equal to the value obtained in splitter plate alone configuration, i.e., 25% that of the smooth cylinder. Similarly, hike in drag coefficient obtained by roughness application (1.5 times that of smooth cylinder; Fig.3) is neutralised by the splitter plate resulting in a very low drag value equal (75% that of smooth cylinder). That is, selectively applied roughness tends to enhance both drag and lift whereas splitter tends to subdue both of them thus inducing mutually opposite effects. Therefore, it is thought that, by suitably employing roughness and splitter plate, the aerodynamic/hydrodynamic characteristics could be suitably manipulated or controlled. This meets the objective of the present study.

With splitter plate, lift drops down to lower values at lower G/D ratios; the drop is almost 75% (compared to smooth cylinder) at G/D=1.0. Similar to drag, a trend reversal occurs for lift also whereby reduction of G/D below 1.0 slightly increases the lift at all roughness locations tested. It is pointed out that, the Reynolds number of the current study (=17000) falls in the TrSL 2 regime where fluctuating lift shows notable magnification (Zdravkovich [15]) but it is lower than the magnification of the same compared to the TrSL 3 regime.

It is quite interesting to note that, at high Reynolds numbers (order of magnitude the same as that in the present study), selectively applied surface roughness induces high amplitude galloping oscillations in a flexibly mounted circular cylinder in water flow at majority of the circumferential locations considered by Chang et al [10] except at 64 deg (near the separation point). This seems to sensibly comply with the substantial hike in the lift coefficient obtained at almost all circumferential locations in the present study.

The observed features in the trends of drag, lift and Strouhal number characteristics of the test circular cylinder could be attributed to the structure of separated shear layers and its interaction with the roughness element and splitter plate. This has direct consequence on the wake dynamics and is reflected in Figs 2-4. However, to pinpoint the exact reasons, further experimental or numerical studies are required which is planned for the future.

## 5. Conclusions:

From the results obtained, the following conclusions are drawn:

- (1) Roughness strip application is found to significantly alter the lift and drag forces acting on a circular cylinder. Lift coefficient is found to magnify about 2.7 times and the drag coefficient by about 1.5 times compared to a smooth cylinder. But, the circumferential location of the strip is found to have only a negligibly small influence on these parameters.
- (2) With splitter plate, lift and drag coefficients reduce to lower values particularly at closer splitter plate positions (smaller G/D ratios). At G/D=1.0, lift and drag coefficients become the lowest.
- (3) Present study reveals that surface roughness and splitter plate could be suitably employed to control the wake characteristics of a circular cylinder.

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