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# Local Scour Reduction At Bridge Pier Using Sleeve

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***Abstract*** — *Sleeve as a protection device that is used around a bridge pier in the laboratory. The sleeve is an axisymmetric, open-ended pipe-like cylindrical enclosure placed concentric to the circular bridge pier. The underlying scour reduction mechanism with the sleeve is to confine the scouring vortex in annular space amid the pier and sleeve. Experiments were carried out on four sizes of sleeves at different vertical locations. After experimentation, it was concluded that as the diameter of the sleeve is smaller than performance potential of the sleeve becomes higher. The sleeve may be able to reduce scour by 56% with reference to an unprotected circular bridge pier. This axisymmetric device is sufficient for huge changes at the angle of flow attack and also workable during floods. Hence, this device provides a scour-free arrangement.*

**Keywords —** *Sleeve, Bridge Pier, Vortices, Dimensional analysis.*

## I. INTRODUCTION

Bridges across rivers are important structures for the physical communication of people. Bridge pier and abutments are the integrated part of bridges. Bridge piers are transferring dead and live a load of the bridge through the foundation at the river bed. Bridge piers are creating an obstruction to the flow as they are constructed into the river. This river flow generates vortices around the bridge pier. The vortex revolves around the pier and dislodges sediment from the bed and releasing it downstream. These vortices are taking out the sediment from the scour hole around the bridge pier. To protect the bridge pier, a count of protection devices was used around the bridge pier by the researchers. Keeping in mind scour protection around a bridge pier, a Sleeve is installed around the bridge pier. Under such situations, scour reduction devices are necessary to reduce the frontal pier area from getting excessively exposed.

The genesis of using a sleeve as a scour protection device has been taken from the caisson foundation of the pier. Normally, the vortex formed due to the pier will be retained on the projected portion of the caisson foundation. However, as the size of the horseshoe vortex increases, it forms on the erodible bed. Due to the formation of a horseshoe vortex on the erodible bed, the caisson gets exposed, and larger scouring results around the bridge pier. This situation is worse than the pier exposed alone because the scour depth is proportional to the size of the obstruction facing the flow ($H_s = 1.4D$, Breusers, 1977). To improve the situation, a sleeve is suggested to be provided around the bridge pier by replacing the caisson. The main difference between the caisson and sleeve is that caisson is a closed-ended structure around the bridge pier forming the foundation, while the sleeve is an axisymmetric open-ended pipe-like enclosure placed concentric to the pier. In the case of the sleeve, vortices are restricted in between bridge pier and sleeve.

The basic principle for the protection of bridge foundations is to be able to resist the impact of vortices (Garde, Raju, 1978; Julien, 2002). By providing protection device around bridge pier in the form of collar plate (Chiew, 1992; Kumar et al., 1999; Melville, Coleman, 2000; Singh et al., 2001; Zarrati et al., 2004; Garg et al., 2005; Heidarpour, Zarrati 2010, Garg et al. 2021), sleeve or foundation extended up to the bed level in the form of caisson (Singh et al. 1995; Parola et al. 1996; Setia et al. 2001; Gangarudraiah V.et al., 2011; Qiqi Xiang et al. 2020).

Singh et al. worked on the different sizes of sleeves provided around the bridge pier. (1995) Parola et al. (1996) worked on foundation pier geometry which affects local scour depth. As the elevation of the foundation changes, then scour depth also varied. Scour depth is sensitive with the change of foundation level and with its geometry. Setia et al. (2001) worked on the sleeve as well as collared sleeve about bridge pier. They varied sleeve size and sleeve position with respect to average bed level. They concluded that a collared sleeve of size 2D with a collar plate of 3D could lessen the scour around the bridge pier.

Gangarudraiah V. et al.[12] conducted test for 3 pier types of scour depth: cylindrical, cylindrical along caisson, nose piers. They did work on different sizes of caisson below and above the level of the bed. They studied primary vortex categorizes involving its size and rotational speed corresponding to scour and flow depth with caisson diameter. San-Shyan et al. [14] worked on the Caisson foundation utilized to cross-river bridges in Taiwan. Qiqi Xiang et al. [13] developed local scour around caissons under unidirectional tidal currents. Figure 1 and 2 represents the definition sketch indicating sleeve details along with its parameters.

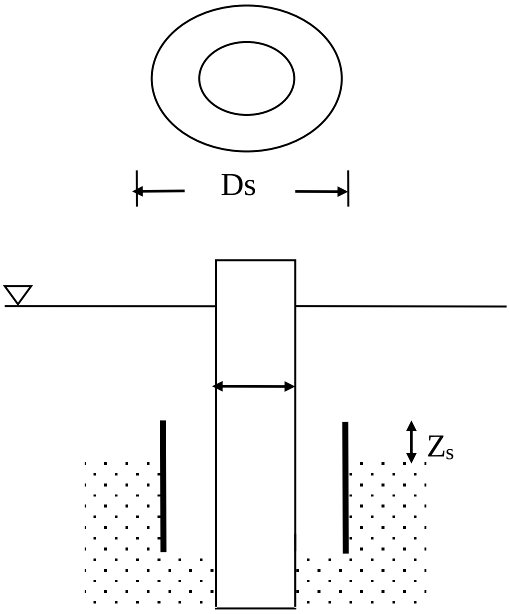

**Figure 1: Sleeve around a circular bridge pier**

The basic principle for the protection of bridge foundations is to be able to resist the impact of vortices [1,2]. By providing protection device around bridge pier in the form of collar plate [3, 4,5,6,7, 8,9] sleeve or foundation extended up to the bed level in the form of caisson [6,10,11,12,13] worked on the different sizes of sleeves provided around bridge pier. [11]Parola et al.worked on foundation pier geometry which affects local scour depth. As the elevation of the foundation changes, then scour depth also varied. Scour depth is sensitive with the change of foundation level and with its geometry. Setia et al. [10] worked on the sleeve as well as the collared sleeve about the bridge pier. They varied sleeve size and sleeve position with respect to average bed level. They concluded that a collared sleeve of size 2D with a collar plate of 3D could lessen the scour around the bridge pier.

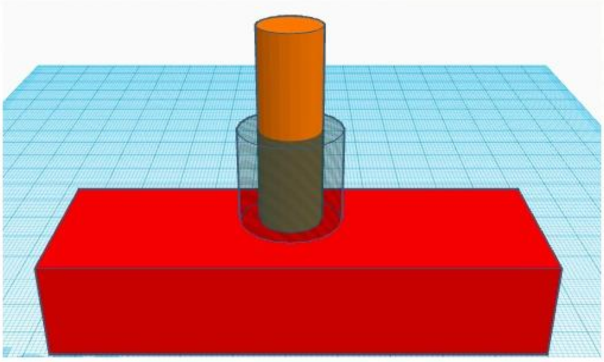

**Figure 2: Circular Sleeve around a circular bridge pier in 3-Dimensional form**

## II. EXPERIMENTAL SETUP

Experiments are conducted using 12 m length, 0.6 m width, and 0.75 m deep flume in Hydraulics Lab of Civil Engineering Field. For performing experiment on scouring, sufficient depth of sand bed($d_{50}$ = 0.28 mm; $\sigma_g$ = 2.51) was kept. All the experiments were done for clear water scour on incipient velocity. For determining equilibrium scour depth, the experimental run is taken 300mins for every experiment. To lessen the effect of flow depth in scouring, the depth of flow ratio is pier diameter, h/D keep more than 2.5 depending on the recommendation of Ettema (1980), Chiew (1984). To avoid the wall effect of the flume, the width of the flume was maintained 8 to 10 times the diameter of the pier, as mentioned by Shen et al. [14]. Here, this ratio of bridge pier and sediment size of the particle is 221 ($D/d_{50} > 50$), which causes a small reduction in equilibrium to scour depth for the higher ratio of $D/d_{50}$ [15]. For studies on scouring surround circular bridge pier, the pier model comprising of a Plexiglas cylinder of 0.062 m diameter (D).

During experimentation, sediment bed level was levelled with steel scale from the upstream to the downstream if any undulation is formed due to previous experiments. After leveling the sediment bed, the flow was released into the flume. This flow depth was measured with the help of a pointer gauge at different points. After maintaining uniform flow depth, the sleeve model was inserted into the sediment bed approximately 5 m from the inlet section. Bridge pier model inserted inside the sleeve around bridge pier. The sleeve and bridge pier both are concentric with each other. The rate of flow is measured by an orifice meter. Critical velocity(u*) was taken 0.9 times the velocity of flow with the help of the Shields diagram. Shear stress is the key factor for the scouring, which was calculated with the help of shear velocity.

Scouring can take place around the bridge pier and sleeve as flow takes place. Six sizes of circular sleeves of diameters 1.25D, 1.5D, 1.75D, 2.0D, 2.25D, and 2.5D have been employed in the flume around the bridge pier. In this device, the sleeve provides protection around the bridge pier against scour. But at the same time, scour occurs around the sleeve also. It is also known as a sacrificial sleeve that protects the bridge pier but is damaged due to scouring. The scour protection device performance is deemed by performance potential [10], determined as $(1- H_s / H_u) \times 100$,

Here, $H_s$= Maximal scour depth below average bed level with the device

$H_u$ = Maximal scour depth around the non-protected pier.

### *A. Dimensional Analysis*

During dimension analysis, various parameters like hydraulic, structural, and sedimentological have been studied, which govern the scour depth around the bridge piers that influence the scour phenomena, such as categorizing the fluid, bed material, flow, and bridge pier. For the purpose of analysis, it may be assumed that the sediment is non-cohesive and has a uniform size of $D_{50}$. To avoid the effect of contraction on the bridge pier, the channel width is taken sufficiently wide. The bridge pier is taken as cylindrical (Circular), having a smooth surface so as not to affect change of flow direction.

The parameters are:

a) Fluid: density ($\rho$), kinematic viscosity ($\nu$), acceleration due to gravity (g);
b) Bed material: diameter of sediment ($d_{50}$) with its density($\rho_s$);
c) Flow: the depth (h) as well as mean velocity of flow (V);
d) Pier: its diameter (D)
e) Sleeve: its diameter ($D_s$) and its location ($Z_s$).

Therefore, the local scouring $H_s$ may be taken to be dependent on the following eight quantifiable parameters:

$H_s = f_1 (\rho, \nu, g, d_{50}, \rho_s, h, V, D, D_s, Z_s)$

The following ones may replace these parameters:

$H_s = f_2 (\rho, \nu, g, d_{50}, \Delta, h, V_c, D, D_s, Z_s)$

$\Delta = (\rho_s - \rho)/\rho$, the relative submerged density

$$V_c = \sqrt{gdI}$$

With the help of the theorem of Vaschay-Buckhingam, we can write as:

$$\frac{H_s}{D} = f_3\left(\frac{V_c d_{50}}{\nu}, \frac{{V_c}^2}{\Delta g d_{50}}, \Delta, \frac{h}{D}, \frac{D_s}{D}, \frac{Z_s}{D}, \frac{d_{50}}{D}\right)$$

## III. RESULTS AND DISCUSSION

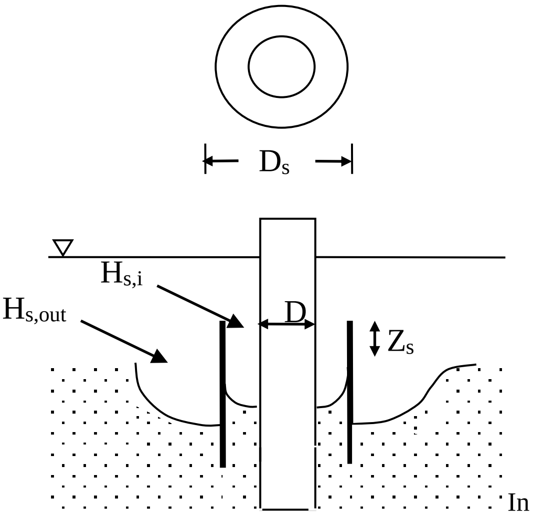

**Figure 3: Sleeve around bridge pier shows scouring inside and outside sleeve**

These experimental work experiments were conducted around the bridge pier with a circular sleeve. It was observed that scour depth completely depends upon the size of sleeve Ds and the vertical location of sleeve Zs. These are the most significant parameters of a sleeve that affects scour depth. There are 2 different deep scour locations: (i) inside the sleeve (ii) outside the sleeve. The maximum scours inside the sleeve has been denoted as $H_{s, in}$, while maximum scours outside the sleeve is denoted by $H_{s, out.}$ Shown in Figure 3.

### *A. Effect of the size of sleeve*

Six sizes of sleeves $D_s/D$ = 1.25, 1.5, 1.75, 2.0, 2.25 and 2.5 were investigated around a circular pier. These sleeves kept along its tops flush and level of the bed. Figure 3 shows the results of variation of maximum scour depth, $H_{s,}$ with the size of the sleeve $D_s$. The results are un-dimensional with pier diameter. Initially, the sleeve of size $D_s$=1.25D was placed at ambient bed level for experimentation. The inside and outside scour of sleeve $D_s$ = 1.25D is found to be 0.47D and 0.92D. For this size of sleeve, it was observed that very soon, scouring takes place outside the sleeve but at the same time scouring inside the sleeve is less. From observing the Figure, the size of the sleeve is diminished from $D_s$=1.25D to $D_s$=2.5D; inside scour, $H_{sin}$ reduces 57.48% to 10.91% in terms of performance potential.

However, figure 4 presents the reverse trend for maximum outside scour ($H_{sout}$) in which the sleeve size decreases from Ds=2.5D to Ds=1.25D, outside scour, $H_{sout}$ decreases 1.12D to 0.96D. Lesser inside scour in the case of the sleeve of size $D_s$ = 1.25D could be attributed to its ability to confine the horse-shoe vortex inside the sleeve. The larger size sleeve, i.e., $D_s$ = 2.5 D, is not confined to the vortex inside it, causing in larger inside scour.

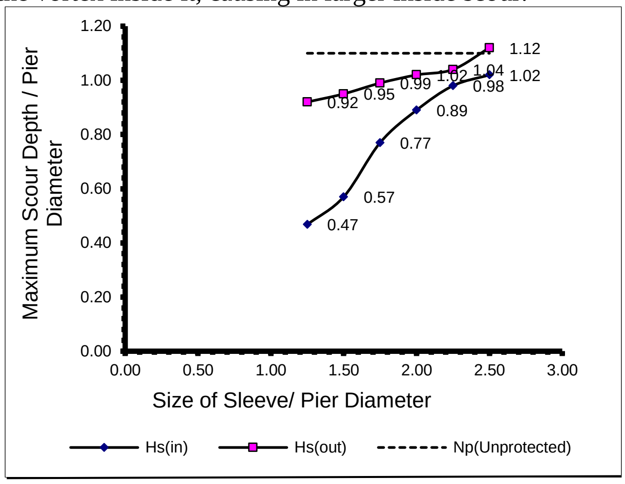

**Figure 4: Effect of Sizes of Circular Sleeves at Average Bed Level on Maximum Inside and Outside Scour Depth**

The relatively larger size of the sleeve of size, $D_s$ = 1.5D, when placed at ambient bed level, records an inside scour of 0.57D while the outside scour is 0.95D. This size of sleeve is able to reduce outside scour while the inside scours increase because the annular space amid the sleeve and bridge pier increases. Extending the trend further, it was observed that when sleeves of sizes 2.0D and 2.5D were placed at bed level, then scouring inside the sleeve increased. The larger size of the sleeve was not able to arrest the horseshoe vortex inside the sleeve. However, the same trend observes for maximal outside scour, $H_{s,\ out,}$ which increases from 0.92D to 1.12D for the same sleeve sizes of $D_s$ = 1.25D and 2.5D.

The performance potential for the sleeves of sizes $D_s$ = 1.25D, 1.5D, 1.75D, 2.0D, 2.25D and 2.5D are 57%, 48%, 30%, 19%, 11% and 7% respectively. A sleeve of size 1.25D provides maximum efficacy against inside scour, but the outside scour is higher. For sizes 2.0D and greater, the outside scour was less but inside scour more. Therefore, a sleeve of size 1.5D, which is able to protect equally from outside and inside scouring, was adopted as the optimum size.

**TABLE I**

**RESULTS OF CIRCULAR SLEEVES AT VARIOUS VERTICAL LOCATIONS**

| S.N. | Flow depth(cm) | Velocity(cm/s) | Fr | Cs/D | Z/D | Hs(in)/D | Hs, in | Hs(out)/D | Per. Pot. (in) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 15.95 | 20.06 | 0.16 | 1.25 | -0.50 | 0.68 | 4.22 | 0.62 | 38.18 |
| 2 | 16.16 | 19.80 | 0.16 | 1.25 | -0.25 | 0.56 | 3.47 | 0.75 | 49.09 |
| 3 | 16.21 | 19.74 | 0.16 | 1.25 | 0.00 | 0.47 | 2.90 | 0.92 | 57.48 |
| 4 | 16.09 | 19.89 | 0.16 | 1.25 | 0.25 | 0.34 | 2.11 | 1.10 | 69.06 |
| 5 | 15.85 | 20.19 | 0.16 | 1.25 | 0.50 | 0.21 | 1.30 | 1.14 | 80.94 |
| 6 | 16 | 20.00 | 0.16 | 1.5 | -0.50 | 0.89 | 5.52 | 0.70 | 19.06 |
| 7 | 16.8 | 19.05 | 0.15 | 1.5 | -0.25 | 0.81 | 5.02 | 0.83 | 26.36 |
| 8 | 16.11 | 19.86 | 0.16 | 1.5 | 0.00 | 0.57 | 3.53 | 0.95 | 48.18 |
| 9 | 16.6 | 19.28 | 0.15 | 1.5 | 0.25 | 0.45 | 2.79 | 1.12 | 59.09 |
| 10 | 16.15 | 19.81 | 0.16 | 1.5 | 0.50 | 0.34 | 2.10 | 1.15 | 69.21 |
| 11 | 16.15 | 19.81 | 0.16 | 1.75 | -0.50 | 0.97 | 6.01 | 0.72 | 11.82 |
| 12 | 16.05 | 19.94 | 0.16 | 1.75 | -0.25 | 0.88 | 5.46 | 0.87 | 20.00 |
| 13 | 16 | 20.00 | 0.16 | 1.75 | 0.00 | 0.77 | 4.77 | 0.99 | 30.00 |
| 14 | 16.2 | 19.75 | 0.16 | 1.75 | 0.25 | 0.61 | 3.78 | 1.13 | 44.55 |
| 15 | 16 | 20.00 | 0.16 | 1.75 | 0.50 | 0.39 | 2.42 | 1.18 | 64.55 |
| 16 | 16.08 | 19.90 | 0.16 | 2 | -0.50 | 1.02 | 6.32 | 0.81 | 7.27 |
| 17 | 16.1 | 19.88 | 0.15 | 2 | -0.25 | 0.93 | 5.77 | 0.92 | 15.45 |
| 18 | 16 | 20.00 | 0.16 | 2 | 0.00 | 0.89 | 5.52 | 1.02 | 19.09 |
| 19 | 16.1 | 19.88 | 0.15 | 2 | 0.25 | 0.73 | 4.55 | 1.15 | 33.28 |
| 20 | 16.04 | 19.95 | 0.16 | 2 | 0.50 | 0.45 | 2.79 | 1.20 | 59.09 |
| 21 | 16 | 20.00 | 0.16 | 2.25 | -0.50 | 1.08 | 6.70 | 0.85 | 1.82 |
| 22 | 16.2 | 19.75 | 0.16 | 2.25 | -0.25 | 1.03 | 6.39 | 0.99 | 6.36 |
| 23 | 16.05 | 19.94 | 0.16 | 2.25 | 0.00 | 0.98 | 6.08 | 1.04 | 10.91 |
| 24 | 16.1 | 19.88 | 0.15 | 2.25 | 0.25 | 0.82 | 5.10 | 1.18 | 25.22 |
| 25 | 16.2 | 19.75 | 0.16 | 2.25 | 0.50 | 0.56 | 3.47 | 1.24 | 49.09 |
| 26 | 16.015 | 19.98 | 0.16 | 2.5 | -0.50 | 1.11 | 6.89 | 0.92 | -1.03 |
| 27 | 15.93 | 20.09 | 0.16 | 2.5 | -0.25 | 1.06 | 6.57 | 1.05 | 3.64 |
| 28 | 16.1 | 19.88 | 0.16 | 2.5 | 0.00 | 1.02 | 6.32 | 1.12 | 7.27 |
| 29 | 16 | 20.00 | 0.15 | 2.5 | 0.25 | 0.93 | 5.77 | 1.20 | 15.45 |
| 30 | 16.05 | 19.94 | 0.16 | 2.5 | 0.50 | 0.62 | 3.84 | 1.30 | 43.64 |

### *B. Effect of sizes of sleeve at various vertical locations*

Experiments were conducted using sleeves of size $D_s$ = 1.25D, 1.5D, 1.75D, 2.0D, 2.25D, and 2.5D around the circular bridge pier. All these sizes of sleeves were tested at different vertical locations ($Z_s$) from –0.5D to 0.5D at an interval of 0.25D. The results, along with the scouring parameters of the circular pier, are given in Table 1. The sleeve of size 1.25D increases from -0.5D to 0.5D, then the maximum inside scour depth reduces from 0.68D to 0.21D. At the same time, the outside scour also increases from 0.62D to 1.14D. This location of the sleeve causes a larger obstruction to the flow, and it provides a larger outside scour. For sleeve of size 1.5D, maximum inside scour depth reduces from 0.89D to 0.34D at the location of sleeve from –0.5D to 0.5D. On the contrary, the outside scour grows considerably at a higher rate from 0.70D to 1.14D. Sleeves of sizes 2.0D and 2.5D also show the same trends as the location of sleeve increases from –0.5D to 0.5D, the inside scour gradually reduces from 1.02D to 0.45D and 1.11D to 0.62D, outside scour increases from 0.81D to 1.2D and 0.92D to 1.30D as shown in Figure 5 & 6.

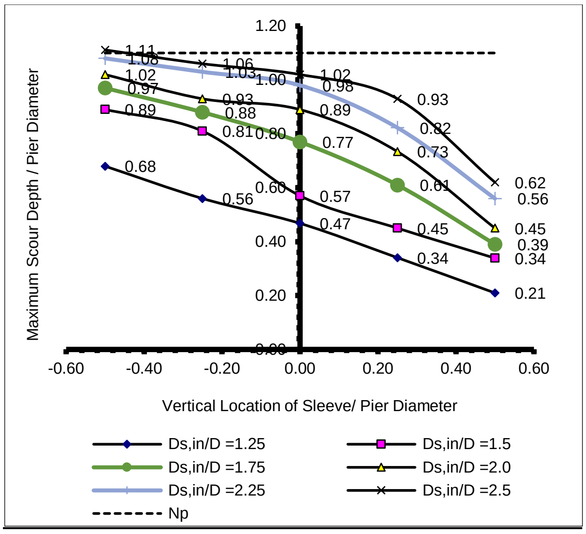

**Figure 5: Effect of Sizes with Locations of Circular Sleeves on Maximum inside Scour Depth**

Results show that the size of sleeves 2.0D and 2.5D are not able to provide any significant protection at any vertical location. The sleeve of size $D_s$ = 1.25D provides better efficacy against inside scours but at the same time, outside scour is higher. Sleeve of size $D_s$ = 1.5D balances the maximum inside ($H_{s,in}$= 0.57D) and outside scour depth ($H_{s,out}$ = 0.95D). Therefore, it was decided to choose a sleeve of size 1.5D. The sleeve has high effectiveness in preventing inside scour when located above or at bed level, but the outside scour grows around the sleeve. A sleeve of size 1.5D provides maximum efficacy against inside as well as outside scour and is the recommended size for effective scour protection.

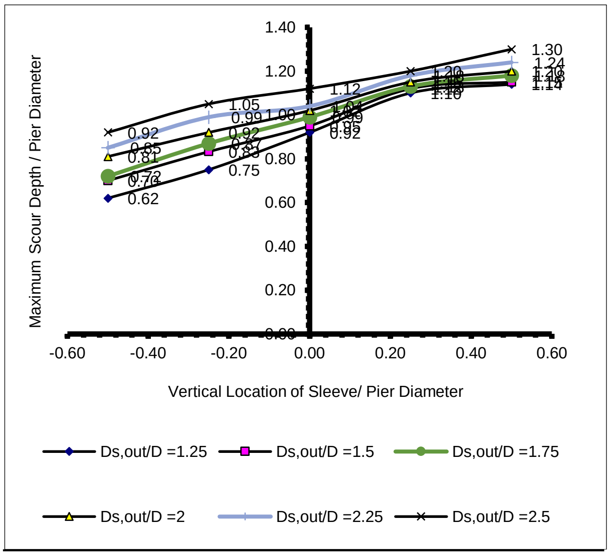

**Figure 6: Effect of Sizes with Locations of Circular Sleeves on Maximum outside Scour Depth**

## IV. CONCLUSIONS

All the experiments were performed on the six sizes of sleeves from 1.25D to 2.5D around the bridge pier. The sleeve was a concentric and axis-symmetric effective protection device to the bridge pier. The concept of Sleeve was developed from the caisson foundation, which provided for the bridge pier. A circular Sleeve, being axisymmetric, does not affect through an angle of attack of flow. The sleeve was able to confines the scouring horseshoe vortex in it, restricting the size of the vortex. All these sleeves worked well against inside scour around the bridge pier but outside scoured is a threat to the sleeve. Larger the size of sleeve larger will be inside and outside scour. But these sleeves are more efficient if they were kept around the bridge pier at sediment bed level.

The smaller size of sleeve 1.5D restricts the confinement of vortices, while the size of the sleeve of 2.5D was not able to restrict the size of vortices at all. Scour depth was occurred 0.92D outside the sleeve for the size 1.25D but for the sleeve of the size of 2.5D, scour depth was observed 1.12D, which was having higher outside scour. The vertical location of the sleeve was kept from -0.5D to 0.5D with an interval of 0.25D, which affects the maximum scour depth around the bridge pier. As the elevation of the sleeve increases from -0.5D to 0.5D, then the inside scours decrease, but on the other hand, the outside scours around the sleeve increases. A sleeve is a necessary evil as it is associated with scouring at its upstream front. Out of all the six sleeves, which were tested at various locations, a sleeve of size 1.5D balances inside and outside scour of the sleeve when it was kept at average bed level. The circular sleeve of size 1.5D, when placed at bed level, is capable of reducing scour of the order of 48% around the bridge pier in comparison to an unprotected pier.

## REFERENCES

[1] R. Fernandez Luque, Mechanics of sediment transportation and alluvial stream problems, Sedimentary Geology, 25(1-2) (1980) 165-166.

[2] P. Julien, and J. Tuzson, River Mechanics, Applied Mechanics Reviews, 56(2)(2003) B30-B31.

[3] Y. Chiewand B. Melville, Local scour at bridge piers with non-uniform sediments., Proceedings of the Institution of Civil Engineers, 87(2) (1989) 215-224.

[4] V. Kumar, K. Raju, and N. Vittal, Reduction of Local Scour around Bridge Piers Using Slots and Collars, Journal of Hydraulic Engineering, 125(12) (1999) 1302-1305.

[5] B. Melville, Scour at various hydraulic structures: Sluice gates, submerged bridges, and low weirs, Australian Journal of Water Resources, 18(2) (2014).

[6] V. Garg, B. Setia, V. Singh, and A. Kumar, Scour protection around bridge pier and two-piers-in-tandem arrangement, ISH Journal of Hydraulic Engineering, 1-13 (2021).

[7] A. Zarrati, M. Nazariha, and M. Mashahir, Reduction of Local Scour in the Vicinity of Bridge Pier Groups Using Collars and Riprap, Journal of Hydraulic Engineering, 132(2) (2006) 154-162.

[8] V. Garg, B. Setia, and D. Verma, Reduction of scour around a bridge pier by Multiple Collar Plates, ISH Journal of Hydraulic Engineering, 11(3) (2005) 66-80.

[9] A. Zarrati, H. Gholami, and M. Mashahir, Application of collar to control scouring around rectangular bridge piers, Journal of Hydraulic Research, 42(1) (2004) 97-103.

[10] V. Garg, B. Setia, V. Singh, and A. Kumar, Scour protection around bridge pier and two-piers-in-tandem arrangement, ISH Journal of Hydraulic Engineering, (2021) 1-13.

[11] A. Parola, S. Mahavadi, B. Brown and A. El Khoury, Effects of Rectangular Foundation Geometry on Local Pier Scour, Journal of Hydraulic Engineering, 122(1) (1996) 35-40.

[12] G. Veerappadevaru, T. Gangadharaiah, and T. Jagadeesh, Vortex scouring process around bridge pier with a caisson, Journal of Hydraulic Research, 49(3) (2011) 378-383.

[13] Q. Xiang, K. Wei, F. Qiu, C. Yao, and Y. Li, Experimental Study of Local Scour around Caissons under Unidirectional and Tidal Currents, Water, 12(3) (2020) 640.

[14] H. Shen, V. Schneider, and S. Karaki, Local Scour Around Bridge Piers, Journal of the Hydraulics Division, 95(6) (1969) 1919-1940.

[15] A. Raudkivi and R. Ettema, Scour at Cylindrical Bridge Piers in Armored Beds, Journal of Hydraulic Engineering, 111(4) (1985) 713-731.

[16] H. Breusers, Discussion of Local Scour Around Bridge Piers, Journal of the Hydraulics Division, 96(7) (1970) 1638-1639.

[17] S. Liao, X. Lin, and D. Christiani, S132 Chronic Bronchitis, Pulmonary Function, and Occupational Exposure in Framingham Heart Study, Thorax, 67(2) (2012) A62.3-A63.