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Effect of Obstacle Material Type on Local Scour

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Abstract: There have been decades of research on scour phenomenon. But, due to the complexity of the processes involved, it is not possible to take into account all parameters in a single study. One such parameter that has not been given its due consideration is the material of the obstacle. In the flow channel, any kind of obstacle can be encountered; it may be a well-defined hydraulic structure made of concrete; huge boulder or a wooden structure, etc. Laboratory experiments were conducted in a glass sided flume to study the effect of obstacle material type on local scour. Circular obstacles were modelled in three different materials; concrete, wood and steel. These obstacles were studied in bed material of silt factor 1.11. Scouring was observed for varying discharges along the periphery of these obstacles. The results were a clear indication that the material type of obstacle was an important variable affecting local scour. Along with the shape, the surface characteristics of the obstacle have also been found to have an effect on local scour. It was clearly evident that the wooden obstacle showed lesser scour while scour around the steel obstacle was maximum. This pattern of local scouring is clearly a response of the surface roughness of the material used; which offer the respective resistance to the removal of sediment around the obstacles. Based on these results an empirical model was developed for predicting local scour around an obstacle.

Keywords: *Scour, Local Scour, Obstacle, Flume, Absolute Surface Roughness, Hydraulic Structures, Discharge, Surface Characteristics, Concrete, Wood, Steel*

Introduction:

Scour is a physical phenomenon, which occurs as general scour and local scour. General scour is the degradation of overall bed material. Local scour is the removal of bed material when an obstacle like bridge pier or any other structure deflects the path of water, due to the formation of vortexes. When the flow hits an obstacle, the vortex is formed in front of it, i.e. the direction of flow is deflected causing turbulence, due to which the bed material is removed and scour hole is formed. The shape of the vortex resembles that of a horse-shoe and hence named so. Over the period of time, the scour hole may get filled by the bed material particles due to receding flows, but the damage to the structure cannot be reversed, since, the hole after getting filled is not a stabilised bed surface and is considered to be in motion.

Local scour is a phenomenon which constitutes an important factor while designing any flow channel or any structure within a flow channel. The maximum possible local scour depth is an integral step in the design of hydraulic structure. The accurate prediction of maximum local scour confines the risk of hydraulic structure failure within a permissible limit, most probably within the design period of any particular structure.

Local scour is the removal of soil/rock sediments around any obstacle by the flowing water. Scour depth increases with increase in velocity and turbulence of flow. Sediment removal is a cause of the horse shoe vortex formation in front of any obstacles/piers. Moncada et al. (2009) investigated these effects around a circular pier with collar. They conducted experiments using uniform sand for finding the condition of minimum scour. Scour is defined as the erosion of bed material around any structure in a flow field. Flowing water can excavate and carry with it huge material from river bed as well as around any obstacle encountered in the flow and hence resulting in the scour hole. The hole formation weakens the hydraulic structure and the disturbance of flow in its vicinity, which may lead to total collapse of the structure (Raudkivi and Ettema 1983 and Chang 1988).

There are number of reports on scouring. Scouring is a key parameter considered in the hydraulic design and planning as discussed by Breusers and Raudkivi (1991). Deva (1989) studied the scour depth estimation on an alluvial bed with graded materials. It predicted scour depths in the Little and Mayer's experimental flume and in the Missouri River, downstream from Gavins Point Dam, as expected. Chiew (1991) studied maximum scouring at submarine pipelines. Umeda et al. (2010) conducted laboratory experiments on time development of clear water scour in steady flow. Cylindrical pier was used and the results show that the process of sediment transport and scour depends on foundation depth. Mir et al. (*in press*) studied local scour depth in the

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laboratory using model studies based on laboratory data for varying obstacle shapes.

Studies indicate that bridge failures occur mostly as a result of scouring around piers during large floods (Melville and Coleman 2000 and Richardson and Davis 2001). Hong et al. (2012) studied the Houfeng Bridge in Taiwan and its collapse. Data was collected and an extensive survey illustrated the scour depth assessment. The study highlights the important effect of long term scour on hydraulic design. Landers and Muellers (1996) also reported scouring and its impact on hydraulic failures.

Studies through decades have established local scour as a function of a varied number of factors which include the fluvial properties, bed material properties as well as the properties of the structure/obstacle encountered.

Local scour is a complicated problem and physical modelling is the principal approach used to deal with it. Mohammed et al. (2007) collected data from the physical modelling and showed that flow, pier geometry and the contraction ratio have an appreciable effect on local scour at bridge site. Most of the scour studies have been accomplished by means of physical modelling, but, due to complexity of the factors involved, it has been a common practice to drop a few factors as compared to the most significant ones. One such parameter which has not been dealt in detail is the material type of obstacle, which accounts for the surface characteristic of the obstacle.

The present study was conducted with an aim to throw some light on the effect of the obstacle material type on local scour. Experiments were conducted in a glass flume on obstacles fabricated in three different materials, concrete, wood and steel. Based on the analysis of scour data obtained in the experimental runs, a model for predicting local scour for circular obstacle with varying obstacle material type is presented in this paper.

Experimental Setup:

The aim of present study was to assess the effect of obstacle material type on local scour by physical modelling. The experimental set-up used for the purpose consisted of a tilting flume 24 m long having a height of 0.6 m and a width of 1 m. The flume had glass side walls and a metallic base with necessary arrangements for water supply regulation and measurements. The view of experimental set-up is shown in Fig. 1.

Figure 1: Experimental Set-Up Used

Test Material:

The obstacles were modelled in circular shape and in three different materials; concrete, wood and steel as shown in Fig. 2-4. The study is about obstacle encountered in a flowing stream and not particularly a bridge pier. It was as such thought more appropriate to study the circular shape as a general reference. Nonetheless, in the future scope of the study, variation of shape is proposed. The values of the absolute roughness of wood, concrete and steel are 0.005, 0.0004 and 0.000015 m respectively (Green and Perry 2008). In the field conditions, concrete and steel structures may be encountered more commonly than the wooden structures but, wooden structures are sometimes employed when constructing sight-seeing/viewpoints etc. along the banks of streams and other water bodies. Moreover, in the present study a comparison has been drawn between the three varying obstacle materials, obviously the wood was one of the appropriate choices of materials for the comparison.

The present study is a preliminary effort to study the effect of obstacle material type on local scour depth estimation, because so far such investigation was not found in the literature. The experimentation of the scour studies is a time consuming process, while as; surface roughness analysis is in itself another study area. Due to the limited time period of the study, absolute roughness of surface could not be computed in the laboratory, but the values have been taken from well-established literature. An average value has been taken to arrive at an idea about how the surface roughness affects the local scouring around the obstacle.

The width of the obstacles was modelled as 1/10th of the channel width i.e. the dimension of each obstacle facing the direction of flow was modelled to be about 10 cm. Chiew and Melville (1987) recommended on the basis of their studies that the obstacle diameter should not exceed 10% of the flume width. In the present study, this aspect of the Chiew and Melville study has been taken in to account for more reliability of the results.

Figure 2: Obstacle made of Concrete

Figure 3: Obstacle made of Steel

Figure 4: Obstacle made of Wood

Table 1: Gradation Parameters of Bed Material Used

Parameters	**Designation**	**Material Used (Sand)**
10% of material finer	d_{10} (mm)	0.2
30% of material finer	d_{30} (mm)	0.39
50% of material finer	d_{50} (mm)	0.4
60% of material finer	d_{60} (m)	0.5
Uniformity Coefficient	C_u	2.5
Coefficient of Curvature	C_c	1.52
Silt Factor	f	1.11

Well graded sand was used as the bed material in the present study. The sand used has been taken from the local river Sindh site, at Ganderbal of J&K. The present study was aimed to find the effect of variation of obstacle material on scouring; as such only one bed material was used. The study can be further extended with variations in the bed material, as well. The gradation parameters of the bed material used are given in Table 1.

Experimental Procedure:

The experiments were carried out in the tilting flume described under the experimental Set-up. The middle section was chosen for placement of the obstructions so as to minimize the effect of inlet disturbances and tail gates. The flume was then filled with the above described bed material, up to a depth of 12 cm. The material was properly levelled in order to achieve results nearer to natural conditions. At the entrance section of the flume boulders were placed on the sand bed to still the flow so as to add stability to the bed material and prevent it from getting washed away due to inlet turbulence. Water supply to the flume was regulated with the help of valves located in the supply line fed by a constant head tank. The slope of the flume was fixed at 1 in 114 m.

Data Collection:

The variables of the study include obstacle surface condition and the discharge through the flume, the discharge was varied and scouring was measured for all discharges along the boundaries of the obstacles till the clear water conditions existed. First an obstacle was placed at the middle of flume. It was filled with the bed material and properly levelled. Initial readings around the obstacle were measured from the top of obstacle to the bed material surface by laser meter for no flow- no scour condition. For each discharge, the degradation of the bed material surface around the obstacle was measured at regular intervals of 10 minutes. The reading for which the scour hole was maximum was taken as max scour. The procedure was repeated for each discharge and each obstacle material. As soon as the scour hole starting filling up, the reading was stopped. The clear water conditions approximately existed for about 15-20 minutes for each run in this case. Table 2 gives the flow parameters for the given experimental runs. Flow measurements were done using a weir at the end of the flume as shown in Fig. 5.

Figure 5: Discharge measurements with the help of a weir at the end of flume

Table 2: Flow parameters of the experimental runs

S. No.	Head over weir *h* (cm)	Discharge Intensity *q* (m^2/s)	Flow Depth *y* (cm)
1	1.0	0.000863	1.8
2	2.0	0.005237	2.75
3	3.0	0.01231	3.8
4	4.0	0.02032	4.8
5	5.0	0.029637	5.9

After allowing the discharge through the flume, the scour process starts around the obstacles. Over the period of time, the scour hole gets filled with water along with the sediments and it appears opaque and hinders the scour hole measurement. This shortcoming was overcome by use of a laser meter which gives relatively more accurate values of scour depth with the varying discharges over the period of experimenting time. The scour depth around the periphery of each obstacle was measured at varying discharges for clear water conditions.

Results and Discussion:

The Experimental runs were conducted on the circular obstacles made of concrete, wood and steel as already discussed in the experimental procedure. The study focussed on the effect of the obstacle material type on local scour, keeping all other variables like bed material, slope, obstacle size, etc. constant. Local scour depth values around the periphery of the obstacles were measured for the gradually varying discharges and maximum equilibrium scour at each discharge for every obstacle material type was computed as given in Table 3. The paper presents local scour depth as a function of the obstacle material type.

It is clearly evident from the values presented in Table 3 that the material type of the obstacle affects the local scour depths. Fig. 6 depicts the difference in scour depths for wood, concrete and steel obstacles. For each material type, local scour depth increases with increasing discharge, also, the relative scour depth values among the concrete, wood and steel are clearly an indication that the smoothness or the absolute roughness of the surface of the obstacle play a role in the local scour phenomenon; with wooden obstacle depicting lesser scour than the concrete obstacle, which in turn shows lesser scouring as compared to steel obstacle.

Table 3: Experimental values of scour depths (in cm) for different obstacle material type

Discharge Q (m^3/s)	Scour Depths (cm)		
	Wooden obstacle	**Concrete Obstacle**	**Steel Obstacle**
0.000863	1.25	1.4	3.5
0.005237	2.375	3	4.25
0.01231	4.4375	7.3	7.75
0.020329	5.0625	8.4	9.735
0.029637	7.35	9.7	10.11

Figure 6: Difference in scour depths for wooden, concrete and steel obstacles

The roughness coefficient and the local scour show an inverse trend. Scour depth is inversely proportional to the roughness coefficient of obstacle material type. Lesser the roughness coefficient of obstacle material, lesser is the resistance to flow around its immediate vicinity and hence, higher the scour depth and vice versa. Greater the surface roughness of the obstacle, greater is the interlocking between the obstacle surface and bed material particles and the dislodgement of the particles is reduced.

There is another important observation regarding this phenomenon, the obstacle material type will have a greater precision in predicting the progression of scouring at the start of the phenomenon, since the bed material will have a higher adhesive forces in contact with the obstacle as compared to a later stage when the material is already detached and is highly susceptible to dislodgement.

The results were analysed using the statistical tool, "R" software. Multiple regressions were carried out for the variables earmarked. Depending on the R^2 value and p value, the following models were selected to be more predictive.

Following empirical model for predicting maximum local scour depth was put forth:

$$d_s = 3.23 + 249.41Q - 516.29k_s \quad (1)$$

Where, d_s is local scour depth in cm, Q is discharge in cumecs and k_s is absolute roughness of obstacle material type in m. Fig. 7 shows the Normal Q-Q graph for the said model. The model has a good R^2 value of 89.93%.

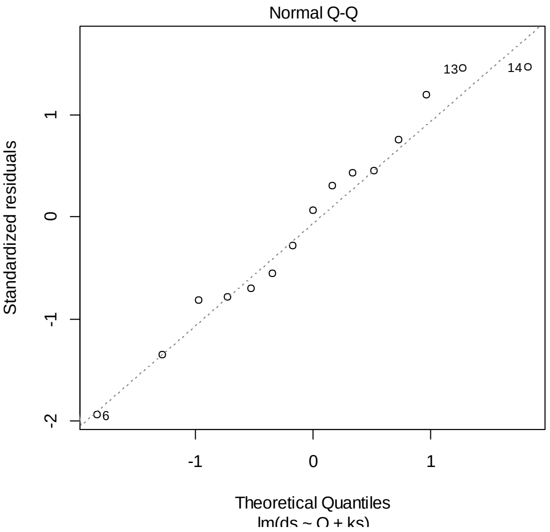

Figure 7: Normal Q-Q Graph for model viz. Eq. (1)

The regression was repeated after incorporating the Froude number (Fr), and the following model was suggested:

$$d_s = 0.215 + 175.36Q - 516.29k_s + 8.70Fr \quad (2)$$

Fig. 8 shows the Normal Q-Q plot for the said model. This model has a better R^2 value of 91.91% than the preceding model (Eq. 1).

Hence, the maximum local scour depth can be computed using Eq. (1) and Eq. (2) based on the obstacle material type.

For the given bed material type, these models satisfactorily account for about 90% of the local scour behaviour based on discharge, Froude number and absolute roughness coefficient of the obstacle material.

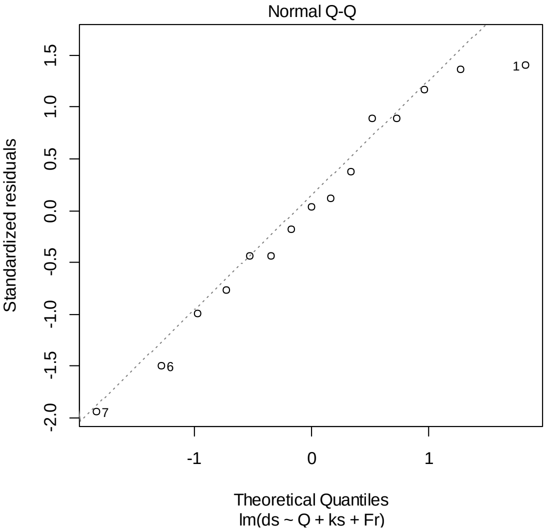

Figure 8: Normal Q-Q Graph for model viz. Eq. (2)

Conclusion:

Scouring being a combination of complex processes, the present study was aimed at study of this phenomenon with respect to the type of obstacle material. The three materials used for study were wood, concrete and steel; which were defined in terms of their absolute surface roughness. The results clearly indicate the pattern of increasing scour depth with decrease in the absolute roughness of the obstacle material and vice versa. Two models for predicting the maximum local scour depth around an obstacle on the basis of above study have been presented in this paper.

The present study was limited to only one bed material, as the purpose of the study was to ascertain the effect of obstacle material type on the local scour. However, further study can be taken up for incorporation of the effect of variation of bed material along with the variation of obstacle material type (i.e. absolute surface roughness). In the future scope of the present study, it is highly recommended to study/compute the roughness of the surfaces using the physical methods in the laboratory and also extending the study to a wide range of obstacle materials

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