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Reduction of Local Scour at Single T-Shape Spur Dike with Wing Shape in a 180 Degree Flume Bend

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Abstract: In this work, investigation of effect of wing shape on reduction of local scour at a T-shape spur dike in a 180 degree flume bend are presented. Spur dikes are structures constructed in rivers to maintain a suitable measures for bank protection and flood control. Experimental investigation on scoring and determination of depth of scoring are among the most important issues in T-shape spur dike designation. The study was conducted using in a 180 degree laboratory flume bend. Experiments were conducted for different wing shapes of T-shape spur dikes at the bend with various Froude number. In this study, the time development of the local scour around the T-shape spur dike plates was studied. The time development of the scour hole around the model T-shape spur dike installed was compared with similar studies on spur dikes. The results of the model study indicated that the maximum depth of scour is highly dependent on the experimental duration. It was observed that, as Froude number increases, the scour increases. All Froude numbers, oblong wing at location of 60 degree results maximum reduction in scour depth. Measuring depth of scouring based on experimental observation, an empirical relation is developed with high regression coefficient 95%.

Key words: Wing shape · T-shaped spur dike · River bend · Scour depth · Froude number

INTRODUCTION

Spur dikes are the structures used directly or indirectly for guarding river bends. The design, location, orientation, wing shape and length of spur dikes are very important subjects for the hydraulic engineers in the field. Basically, it is important to have a clear picture of scour phenomenon around these structures in order to be able to make a safe and economic design. Also, hydraulic conditions such as velocity, water depth, bed shape and bed material around dikes are so diverse to provide the ecosystem with suitable habitat.

In some locations dikes are constructed higher than the high water level, which are called emerged dikes. In rivers with unsteady flow conditions, spur dikes can serve as emerged in ordinary state or submerged during flood. The area behind the dike is either a dead zone during emerged conditions or a slow flow zone during submerged flow conditions.

The flow field at a spur dike is coupled with a complex 3D separation of approach flow upstream and a periodic vortex shedding downstream of the spur dike. The complexity of flow increases with the development of the scour hole. Outer banks of river bends are usually associated by scour. As a result lateral migration of channel may take place. The scour depth estimation has attracted considerable research interest and different prediction methods exist at present.

Local scour around the spur dike foundations failured spur dikes. In recent years, flood waters have closed many highways and local roads as well as interstate highways and caused scour that damaged many spur dikes and even resulted in loss of life.

Estimation of the depth of scour in the vicinity of spur dikes has been the main concern of engineers for years. Therefore, knowledge of the anticipated maximum depth of scour for a given discharge is a significant criterion for the proper design of a spur dike foundation. In current practice, the design scour depth is chosen to be the maximum equilibrium scour depth achieved for steady flow under the design flow conditions. A number of studies have been performed with a view to determining

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the equilibrium scour depth for clear-water scour conditions. In these studies, the maximum scour depth under steady flow conditions is related to the hydrodynamic and sediment parameters, Froude number, spur dike location and among others.

The scour in channel bend has been studied extensively by different researchers.

Cardoso and Bettess [1] studied the effects of time and channel geometry on scour at bridge abutments and suggested an exponential function. Oliveto and Hager [2] studied the temporal evolution of clear-water pier and abutment scour and found that the principal parameter influencing the scour process is the densimetric particle Froude number so suggested an logarithmic formula.

Coleman *et al*. [3] studied clear-water scour development at bridge abutments and suggested an logarithmic formula. Recently Ghodsian and Mousavi [4] correlated the maximum scour depth in a channel bend to densimetric Froude number, relative bend radius and relative depth of flow.

Fazli *et al*. [5] studied the scour and flow field at a spur dike in a 90 degree channel. It is obvious that there is lack of knowledge regarding the scour and flow pattern around the spur dike in a curved channel.

Ghodsian and Vaghefi [6] studied scour and flow field in a scour hole around a T-shape spur dike in a 90 degree bend. The effects of the length of the spur dike, the wing length of the spur dike and Froude number on the scour and flow field around a T-shape spur dike in a 90 degree bend were investigated in this study. The main results of this experimental study are: At the upstream of the spur dike, a main vortex with anti-clock wise direction is formed in the zone of the spur dike. At section 77.5 degree of the bend a vortex having a clock wise direction is formed between the spur dike wing and the channel wall. The maximum value of the longitudinal velocity component at section 65 degree of the bend is close to the outer wall of the channel and near the water surface. By increasing Froude number the maximum scour depth and the volume of scour hole increases. The dimensions of the scour hole increase as a result of increase in the length of the spur dike. The amount of scour at the upstream of spur dike is much more as compare to that at the downstream of spur dike.

As it can be seen from the forgoing paragraphs, fast majority of researches on scour at spur dike are conducted at a straight flume. In practice there are many examples where the spur dike the flume bend. In such a case the flow patterns which are mostly the cause of scour would not be the same as the case of straight flume and therefore it is the principal objective of this study is to carry out experimental tests on the effect of wing shape on time development of scour at T-shape spur dike in location of 60 degree in a 180 degree flume bend.

Dimentional Analyses: The scour geometry around a T-shape spur dike in a bend depends on channel geometry (channel width, channel radius and bed slope), spur dike characteristics (length and wing spur dike, wing form, angle with bank, location in bend), flow conditions (approach depth and discharge or velocity), sediment properties (specific gravity, grain size, friction angle) and fluid parameters (density and viscosity). Therefore for depth of scour *ds* one can write:

$$ds = f\left(L, l, \alpha, \theta, y, B, S_0, V, g, d_{50}, R, \rho_s, \phi, \rho, \mu, \lambda, t\right) \qquad (1)$$

in which L is length of spur dike, l is wing of spur dike, α is angle of spur dike with bank, θ is location of spur dike in bend, y is approach flow depth, B is channel width, S_0 is bed slope, V is approached flow velocity, g is gravitational acceleration, d_{50} is median grain size, R is radius of bend, ρ_s is density of sediment, ϕ is friction angle of sediment, ρ is density of fluid, μ is viscosity of fluid, λ is coefficient of wing form and t is time of scour. Using dimensional analysis, Eq. (2) can be written as:

$$\frac{ds}{y} = f\left(Fr, \theta, \alpha, S_0, \phi, \mathrm{Re}, \frac{L}{B}, \frac{l}{L}, \frac{R}{B}, \frac{L}{d_{50}}, \frac{\rho_s}{\rho}, \frac{R}{L}, \frac{t}{te}, \lambda\right) \qquad (2)$$

in which Fr is approach Froude number, Re is Reynolds number and te is maximum of time development of scour. After simplification of above equation and eliminating the parameters with constant values, one can have:

$$\frac{ds}{y} = f\left(Fr, \frac{t}{te}, \lambda\right) \qquad (3)$$

MATERIALS AND METHODS

Experimental Apparatus: This experiment was conducted in a laboratory flume at hydraulic laboratory of Islamic Azad University of Ahwaz. The experiment reported herein was conducted in a recirculation flume, with central angle of 180degree, central radius of Rc=2.8m and width of B=60cm. Relative curvature of bend was Rc/B=4.7 which defines it as a mild bend. Straight entrance flume with the length of 9.1 m was connected to the 180degree bend flume. This bended flume is connected to another straight flume with the length of 5.5m. The test area of

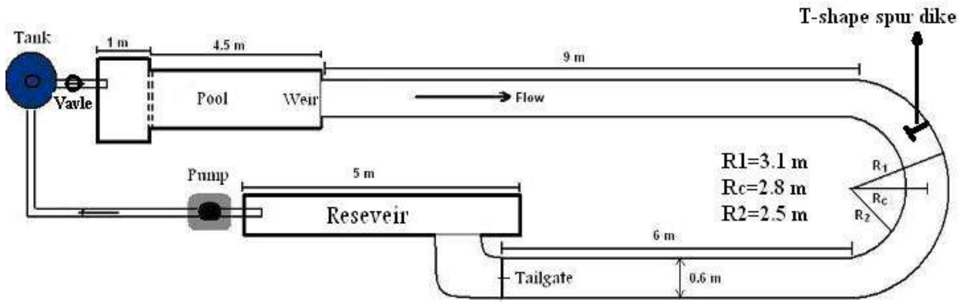

Fig. 1: Schematic illustration of the experimental setup (Plan)

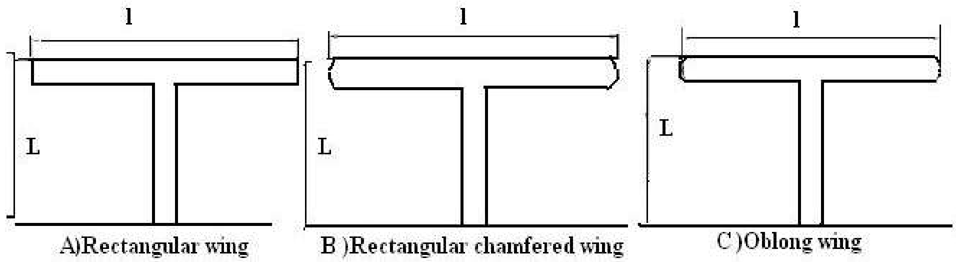

Fig. 2: Schematic illustration of a T-shape spur dike with different wing shapes

the flume is made up of an aluminum bottom and Plexiglas sidewalls along one side for most of its length to facilitate visual observations. At the end of this flume a controlling gate was designed to adjust the water surface height at the desired levels (Fig. 1).

In this study to maintain the clear water condition without formation of ripple, uniform sediment with median size of $d50$ = 2 mm and geometric standard deviation of óg ~ 1.7 were used [7] was used with a thickness of 0.2m and covered the total length of channel. The spur dikes were made of Plexiglas T-shape in plan and located at section 60 degree in the bend. The T-shape spur dikes were of 1 cm thick and 60 cm high.

The experiments was carried out using one length for spur dike (i.e. L = 20% of the channel width), one wing length of spur dike (i.e. l = 100% of the spur dike length) [8] and three different wing shapes of oblong, rectangulat chamfered and rectangular were used (Fig.2).

In this study the experiments were performed under clear-water conditions at four different flow intensities (u*/u*c) of 0.61,0.68,0.74 and 0.85 corresponding to a shear stress levels of 37%,48%,57% and 78% of the critical shear stress level based on Shields stress, respectively. The symbols u* and u*c are the shear velocity and the critical shear velocity, respectively.

Four Froude numbers of 0.23,0.26,0.28 and 0.32 were applied in order to investigate the effect of flow conditions on the scouring. All the experimental tests where conducted under the same flow depth and in one location of 60degree in 180 degree flume bend. A 60 degree triangular weir was used at the upstream section of the flume for flow measuring.

Duration of Scour Test: Equilibrium scour occurs when the scour depth does not change appreciably with time. In clear-water scour, scour depth is approached asymptotically with time and may take an infinite amount of time for the equilibrium scour hole to develop, while in live-bed scour the scour develops rapidly and then fluctuates in response to the passage of bed forms.

In this study, a long time experiment was conducted at a Froude number of 0.32 and location of 60 degree for a T-shape spur dike of rectangular wing. The results are shown in Fig.3. As it can be seen approximately 94% of scouring occurs during the first 5 hours. Therefore in all remaining of our experimental tests, duration of 5 hours was selected for each test.

Experimental Procedures: The T-shape spur dike was first installed in the flume at the desired location. Before each test, care was taken to level the sand bed throughout the entire length of the flume and particularly in the vicinity of the T-shape spur dike using a wooden screed that is of the same width as the flume. The screed can be dragged along the flume rails to produce a sand bed having a smooth, uniform surface. Thereafter, any uneven

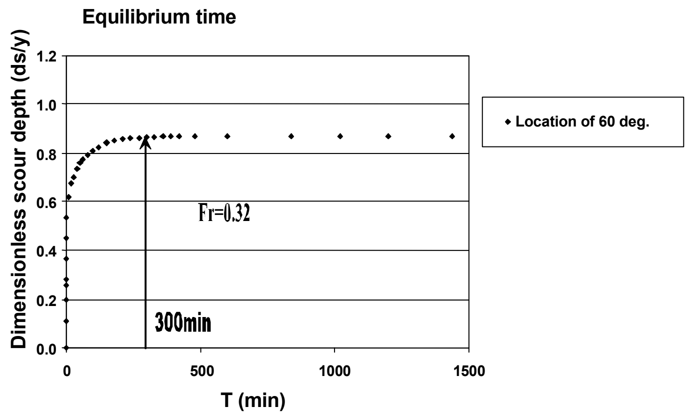

Fig. 3: Equilibrium time in the location of 60 degree for a T-shape spur dike of rectangular wing

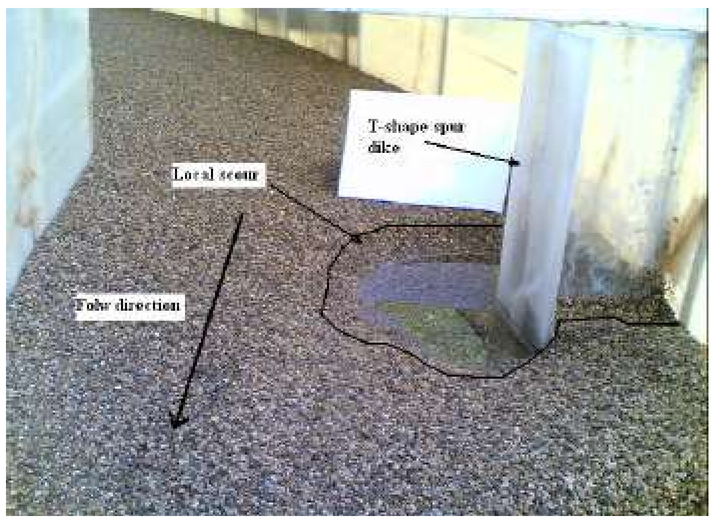

Fig. 4: Scour pattern at the end of a test

bed surface was leveled using a hand-trowel. By employing the point gauge mounted on a carriage, initial bed elevations were taken randomly to check the leveling of the flume. To start the test, the flume was slowly filled with water to the desired flow depth. It should be noted that extra care is required when filling the flume, especially for tests of this nature where no sediment movement is allowed. Any deformity in the bed surface may trigger the development of ripples or dunes and general movement of the sand if the shear stress on the smooth bed is close to the critical shear stress. The pump was then started and the upstream gate slowly opened until the desired flow rate had been achieved. At the same time the tailgate gradually opened and was adjusted so as to maintain the desired flow depth in the flume.

Throughout the test period, the location and magnitude of the point of maximum scour depth was recorded, with the depth being acquired either using the point gauge or the 5 mm scale marked onto the side of the spur dike. The frequency of the measurements varied throughout the test period, with the maximum scour depth readings being taken every few minutes during the first hour or so of the test and less frequently thereafter. It should be noted, however, that the first five hours of each test is very important as frequent readings are required to be taken in order to properly define the early stage of the graph of maximum scour depth versus time. The required frequency of scour depth measurements decreases as the rate of scouring decreases.

At the completion of each test, the pump was shut down to allow the flume to slowly drain without disturbing the scour topography. The flume bed was then allowed to dry, during which time photos of the scour topography around the pier were taken and the final maximum scour depth was recorded using the point gauge (Fig. 4).

RESULTS AND DISCUSSION

In this study, investigation on the time development of local scour on around a T-shape spur dike with three different wing shapes in a 180 degree flume bend are presented. The experiments was carried out using one length for spur dike (i.e. L = 20% of the channel width), one wing length of spur dike (i.e. l = 100% of the spur dike length) were used. Experiments were at location 60 degree in flume bend with four Froude numbers of 0.23,0.26,0.28 and 0.32.

Effect of Froude Number at Time Development of Scour: The variation of Froude number on the temporal development of scour was also considered. Figure 5 shows the time development of the local scour around the T-shape spur dike have been tested in this study. Four different Froude numbers 0.23,0.26,0.28 and 0.32 were applied in order to investigate the effect of flow conditions on the scouring. The T-shape spur dike were placed at one location of 60 degree at 180 degree flume bend. From this figure it is obvious that, all wing shapes, it can be seen that the higher the Froude number the deeper the scour depth at a given time. The reason for this is related to the fact that at higher Froude number there is a greater acceleration of the flow within the vicinity of the spur dike and thus the intensity of the downflow and the vortex is greater. The same trend was observed by Fazli *et al*. [5], Ghodsian and Vaghefi [6], Coleman *et al.* [3], Oliveto and Hager [2] and Cardoso and Bettes [1].

Effects of Various Wing Shapes of T-shape Supr Dike at Time Development of Scour: Figure 6 shows the time development of the local scour around the T-shape spur dike for three different wing shapes were used at location 60 degree in flume bend. As it can be seen from Figure 7, all Froude numbers, at wing shape of oblong results maximum reduction in scour depth and gives a maximum reduction in scour depth equal to 20% of the wing shape of rectangular. The main reason of such finding is that minimum value of vortex at wing shape of oblong [6].

Equation for Scour Depth:
The equation (3) can be written as:

$$\frac{ds}{y} = \lambda a\left(Fr\right)^{b} c\left(\frac{t}{te}\right)^{d} \quad (4)$$

in which a, b, c and d are empirical constants and can be found using experimental data and Re is shape factor. By using least squares method for all the data it was found. Therefore, equation (4) can be written as:

$$\frac{ds}{y} = 3.5\lambda(Fr)^{0.15} Ln(\frac{t+te}{te})^{0.1} \quad (5)$$

with regression coefficient of 0.95. Table 1 shows value of shape factor for T-shape spur dike with different wing shapes. Figure 7 shows the comparison of calculated values with use to Eq. (5) and tested values of relative maximum scour depth. It is evident that Eq. (5) predicts the maximum scour depth with acceptable accuracy.

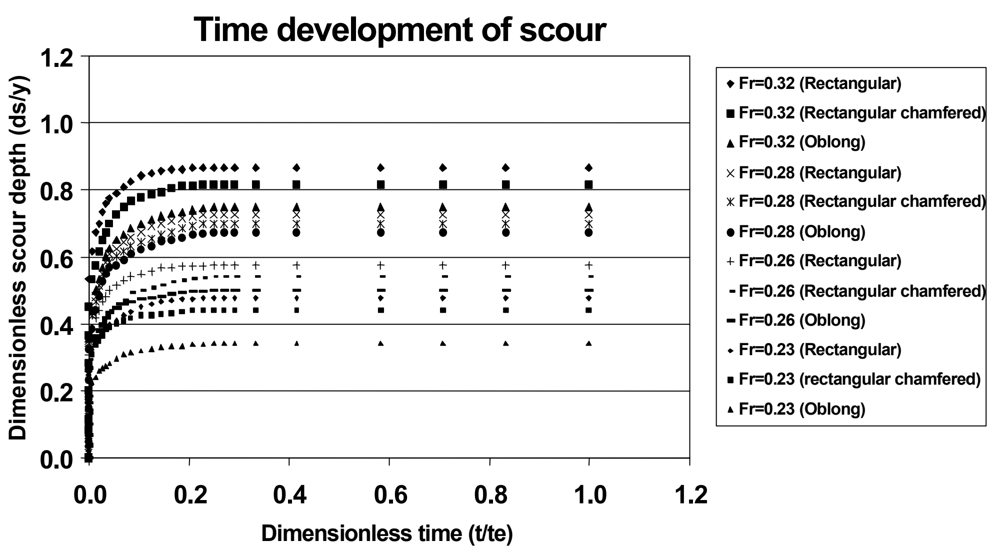

Fig. 5: Time development of scour for different Froude numbers

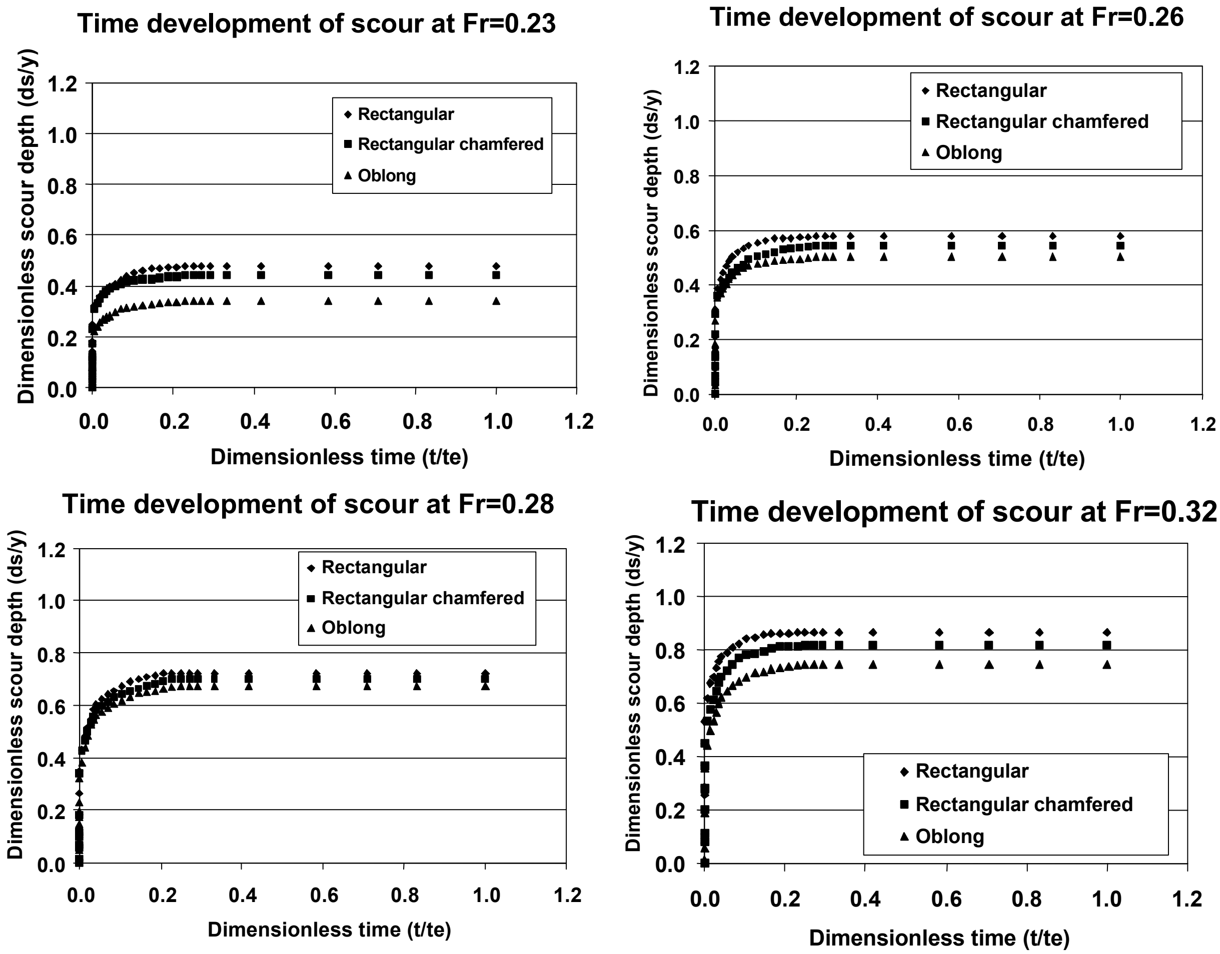

Fig. 6: Time development of scour for different wing shapes

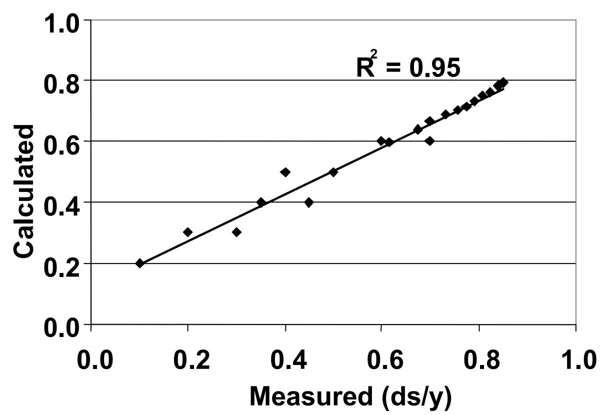

Fig. 7: Comparison of measured and calculated scour depth

Table1: Value of shape factor for T-shape spur dike with different wing shapes

Type of spur dike	Rectangular wing	Rectangular chamfered wing	Oblong wing
Value of shape factor	1	0.92	0.84

CONCLUSIONS

Experiments were conducted to study scour and flow pattern around a T-shape spur dike located in a 180 degree channel bend. The characteristics of the scour hole have been shown to be affected by the shape of spur dike in the bend and Froude number. It was found that:

- By increasing the Froude number, the scour increases.
- Maximum depth of scour occurs for the Fr=0.32.
- Measuring depth of scouring based on experimental observation, an empirical relation is developed with high regression coefficient 95%.
- Wing shape of oblong results maximum reduction in scour depth and gives a maximum reduction in scour depth equal to 20% of the wing shape of rectangular.

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