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Experimental Study on the Time Development of Local Scour on Around Single T-Shape Spur Dike in a 180 Degree Flume Bend

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Abstract: In this study, investigation on the time development of local scour on around a T-shape spur dike in a 180 degree flume bend are presented. The T-shape spur dikes have been used extensively for erosion control in the external wall of river bends. 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 locations 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 amount of scour at the upstream of T-shape spur dike is much more as compare to that at the downstream of T-shape spur dike. 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 increase. All Froude numbers, at location of 60° results maximum increase in scour depth. Measuring depth of scouring based on experimental observation, an empirical relation is developed with high regression coefficient 92%.

Key words: Scour depth, T-shaped spur dike, river bend, froude number

INTRODUCTION

Breusers *et al.* (1977) defined scour as a natural phenomenon caused by the flow of water in rivers and streams. It is the consequence of the erosive action of flowing water, which removes and erodes material from the bed and banks of streams and also from the vicinity of bridge piers and abutments. The mechanism has the potential to threaten the structural integrity of spur dikes and hydraulic structures, ultimately causing failure when the foundation of the structures is undermined.

Spur dikes are constructed transverse to flow and extend from the bank into the river and are often utilized for increasing water depth, bank protection and rehabitation of flood plan. 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

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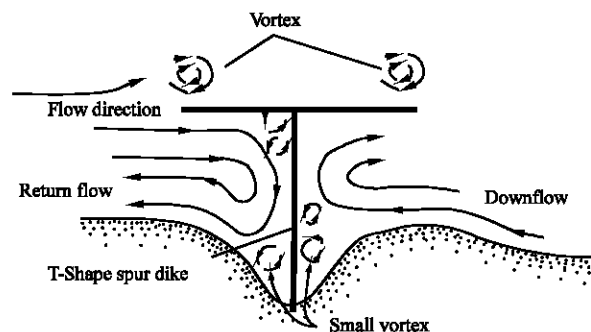
Fig. 1: Illustration of the flow and scour pattern at a T-shape spur dike (Plan)

associated by scour. As a result lateral migration of channel may take place. The spur dike may be used in a channel bend to control the bank scour and its lateral migration. The scour depth estimation has attracted considerable research interest and different prediction methods exist at present (Fig. 1).

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 study, 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 the equilibrium scour depth for clear-water scour conditions.

The scour in channel bend has been studied extensively by different researchers. One of the early studies on scour in bend is that due to Shukry (1950), who performed experiments in 90 and 180° bends in rectangular channels with different values for ratio of width to depth of flow and ratio of radius of the bend to width of flow.

Rozovskii (1957) studied the flow characteristics and boundary shear stress distribution in channel bends with a fixed bed. Yen (1967) performed experiments in a channel bend to study the equilibrium bed configuration and flow characteristics. Gill (1972) studied the effects of sand beds around spur dikes and suggested depth of scour was logarithmic with time.

Cardoso and Bettess (1999) studied the effects of time and channel geometry on scour at bridge abutments and suggested an exponential function. Oliveto and Hager (2002) 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.* (2003) studied clear-water scour development at bridge abutments and suggested an logarithmic formula. Recently, Ghodsian and Mousavi (2006) correlated the maximum scour depth in a channel bend to densimetric Froude number, relative bend radius and relative depth of flow.

Fazli *et al.* (2008) 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 (2009) 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 were: 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 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 was the principal objective of this study, to carry out experimental tests on the effect of Froude number on time development of scour at T-shape spur dike in locations of 45 and 60 degree in a 180 degree flume bend.

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, 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:

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

where, 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 is density of sediment, ϕ is friction angle of sediment, ρ is density of fluid and μ is viscosity of fluid.

Using dimensional analysis, Eq. 2 can be written as:

$$\frac{ds}{Y} = f\left(Fr, \theta, \alpha, S_0, \phi, Re, \frac{L}{B}, \frac{l}{L}, \frac{R}{B}, \frac{L}{d_{50}}, \frac{\rho_s}{\rho}, \frac{R}{L}\right) \tag{2}$$

where, Fr is approach Froude number and Re is Reynolds number. After simplification of above equation and eliminating the parameters with constant values, one can have:

$$\frac{ds}{Y} = f\left(Fr, \frac{\theta}{180}\right) \tag{3}$$

MATERIALS AND METHODS

Experimental Apparatus

This experiment was conducted in a laboratory flume at Hydraulic Laboratory of Islamic Azad University of Ahwaz during July 2008 to July 2009. The experiment reported herein, was conducted in a recirculation flume, with central angle of 180 degree, central radius (Rc) of 2.8 m and width (B) of 60 cm. Relative curvature of Bend (Rc/B) was 4.7 which defines it as a mild bend. Straight entrance flume with the length of 9.1 m was connected to the 180 degree bend flume. This bended flume is connected to another straight flume with the length of 5.5 m. The test area of the flume is made up of an aluminum bottom and Plexiglas sidewalls
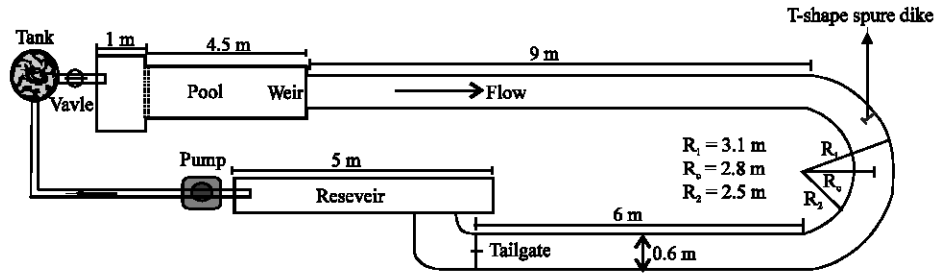
Fig. 2: Schematic illustration of the experimental setup (Plan)
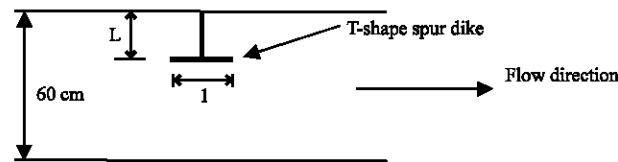

Fig. 3: Schematic illustration of a T-shape spur dike

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. 2).

The bed sediment consisted of uniform sand, with median diameter d50 = 2 mm and geometric standard deviation σg = 1.7 (Dey *et al.*, 1995). The spur dikes were made of Plexiglas T-shape in plan and located at section 45 and 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) and one wing length of spur dike (i.e., l = 100% of the spur dike length) were used (Donat, 1995). Figure 3 shows a schematic illustration of a spur dike in flume.

In this study, the experiments were performed under clear-water conditions at 4 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 two locations of 45 and 60 degree at 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 locations of 45 and 60 degree for a T-shape spur dike. The results are shown in Fig. 4. As it can be seen approximately 93% of scouring occurs during 10th first 5 h. Therefore, in all remaining of our experimental tests, duration of 5 h was selected for each test.
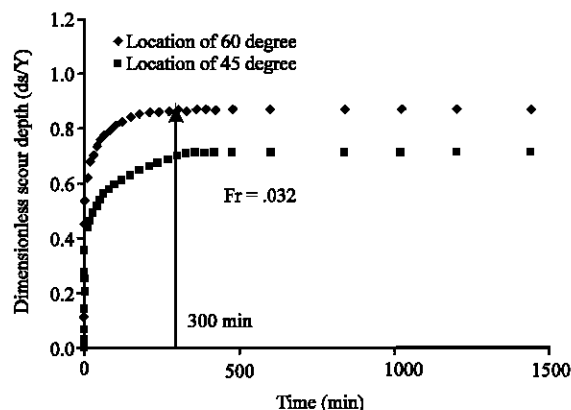
Fig. 4: Equilibrium time in the locations of 45 and 60 degree for a T-shape spur dike
(ds = Scour depth at time t)

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 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. 5).

Fig. 5: Scour pattern at the end of a test

RESULTS AND DISCUSSION

In this study, investigation on the time development of local scour on around a T-shape spur dike in a 180 degree flume bend are presented. The experiments were carried out using one length for spur dike (i.e., L = 20% of the channel width) and one wing length of spur dike (i.e., l = 100% of the spur dike length) were used. Experiments were at locations of 45 and 60 degree in flume bend with four Froude numbers of 0.23,0.26,0.28 and 0.32.

In all experiments, after adjusting the water depth and flow discharge, immediately vortex flows around the spur dike wing formed and scouring began with the high rate at upstream. Under these conditions, due to the secondary effects transported sediments from scouring cavity moves toward the inner wall and two or more small dune formed near the inner wall.

Effect of Froude Number at Time Development of Scour

The variation of Froude number on the temporal development of scour was also considered. Figure 6a and b show 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 two locations of 45 and 60 degree at 180 degree flume bend. From Fig. 6 it is obvious that, 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.* (2008), Ghodsian and Vaghefi (2009), Coleman *et al.* (2003), Oliveto and Hager (2002) and Cardoso and Bettess (1991).

Effects of Various Locations of T-shape Supr Dike at Time Development of Scour

Figure 7a-d show the time development of the local scour around the T-shape spur dike for two different locations were used at the 45 and 60 degree in flume bend. As it can be seen
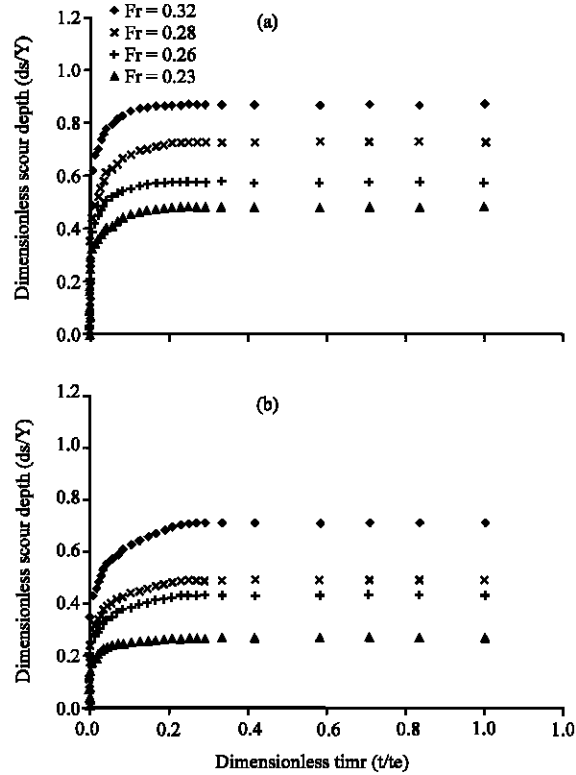
Fig. 6: (a, b) Time development of scour for different Froude numbers (t = Time development of scour and te = Maximum of time development of scour)

from Fig. 7, all Froude numbers, at location of 60 degree results maximum increase in scour depth. The main reason of such finding is that maximum value of vortex at section 60 degree (Ghodsian and Vaghefi, 2009).

Equation for Scour Depth

The Eq. 3 can be written as:

$$\frac{ds}{Y} = a(Fr)^{b}\left(\frac{\theta}{180}\right)^{c} \tag{4}$$

where, a, b and c are empirical constants and can be found using experimental data. By using least squares method for all the data it was found. Therefore, Eq. 4 can be written as:

$$\frac{ds}{Y} = 25.3(Fr)^{1.7}\left(\frac{\theta}{180}\right)^{0.13} \tag{5}$$

with regression coefficient of 0.92. Here, θ is in radian. Figure 8 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.
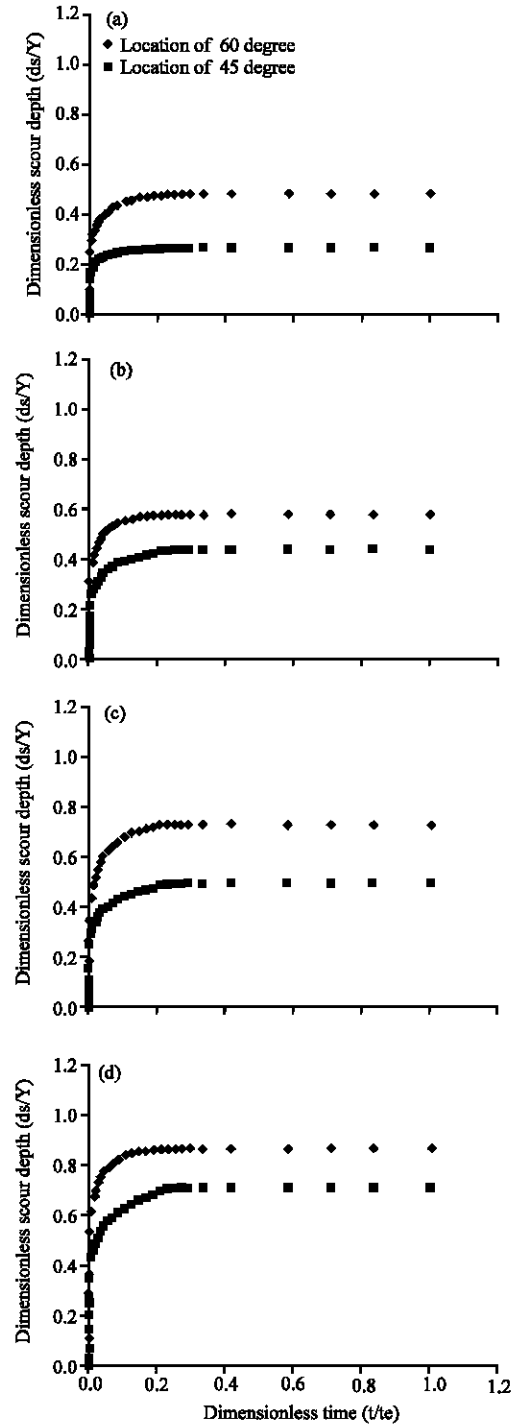
Fig. 7: Time development of scour for different location (ds = Scour depth). (a) Time development of scour at Fr = 0.23 and (b) time development of scour at Fr = 0.26, (c) time development of scour at Fr = 0.28 and (d) time development of scour at Fr = 0.32
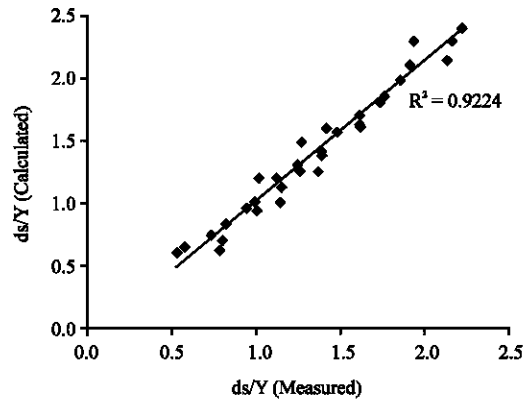
Fig. 8: Comparison of measured and calculated scour depth

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 location of spur dike in the bend and Froude number. The results of the model study indicated that the maximum depth of scour is highly dependent on the experimental duration. The depth of the scour hole increases as the duration of the increased flow that initiates the scour increases. It was found that:

- Increases depth of scour occurs at location of 60 degree compared to 45 degree
- By increasing the Froude number, the scour increases
- Minimum depth of scour occurs for the $Fr = 0.23$
- Measuring depth of scouring based on experimental observation, an empirical relation is developed with high regression coefficient 92%

ACKNOWLEDGMENT

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