Evaluating Scour at L-Shape Spur Dike in a 180 Degree Bend

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Abstract: A series of experiments were conducted on scour depth around a L-shape spur dike with model L-shape spur dike was measured in a laboratory flume with 180 degree bend under clear-water. L-shape spur dike models were angled for different locations and lengths of L-shape spur dikes at the bend with various Froude number. The main goals of the experiments were to evaluate the effect of the four length on the depth of scour and potential aquatic habitat and on minimizing erosion adjacent to the streambanks. The experiments showed that of the four length tested, the least local scour the near bank region was associated with the L-shape spur dikes with 30 degree angles, while the greatest depth of the scour hole was associated with the 75 degree spur dike. By increasing the length of the spur dike, the maximum depth of scour increases. With increasing Froude number the maximum scour depth increases. Measuring depth of scouring based on experimental observation, an empirical relation is developed with high regression coefficient 95%**.**

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1. Introduction

In general, rapid reivers transport much sediment often cauing degradation of river beds and scour of river banks. This leads to deterioration of low-flow channels and dike damage. To prevent these, spur dikes are used since they are very effective in containing river channels. Spur dikes are river structures with multiple function, including flow channel establishment, prevention of scour near dikes and revetments and causing sedimentation to change the flow direction away from river banks to the river center. Spur dikes may also be used to reduce flow velocities. However, much is yet to be learned about the influence and effects of spur dikes during floods.

The volume of local scour in the vicinity of a spur dike is difficult to estimate accurately. Most investigations in this field have just measured the maximum depth of scour and not the geometry of the scour hole. Few studies have been made which measured the velocity distribution associated with spur dikes and scour holes [10] and none to our knowledge which measure the velocity distribution as the scour hole evolves.

Result of spur dike construction against flow, there will be a difference in hydrostatic pressure at upstream and downstream of the construct which will cause a whirlpool disturbance around it. These whirlpool flows account for the main local scoring mechanism which in long term, produce large vortexs at spur dike head and this lead to construct failure. One of the important indictors in determining specifications of scoring and predicating the position and expanding range is maximum scoring depth. 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.

Coleman et al. [1] studied clear-water scour development at bridge abutments and suggested an logarithmic formula. The dimensionless time to equilibrium for scour development from plane-bed conditions can be expressed as a function of relative flow intensity and relative abutment length. Recently Ghodsian and Mousavi [5] correlated the maximum scour depth in a channel bend to densimetric Froude number, relative bend radius and relative depth of flow.

Fazli et al. [4] 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. Also the characteristics of flow pattern have been shown to be affected by the location of spur dike. It was found that: Bed topography in the bend is influenced by location of spur dike in the bend. When the spur dike is located in the second half of the bend, deposition is occurred near the outer bank at the exit of the bend. When spur dike is located in the first half of the bend erosion occurred in this region. Diversion of water by the spur dike cause a narrow zone of degradation in the channel from upstream stagnation zone up to downstream of standing eddy zone. Froude number is an important parameter and has a direct relation to maximum relative scour depth and height of point bar. By increasing the Froude number these parameters increases. By increasing the length of spur dike, the scour depth increases. New empirical equation for estimation of maximum scour depth is presented.

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.

Masjedi et al. [7] studied on the time development of local scour at a spur dike in a 180 degree flume bend. Tests were conducted using one spur dike with 110 mm length in position of 60 degree under four flow conditions. In this study, the time development of the local scour around the spur dike plates was studied. The effects of various flow intensities (u*/u*c) on the temporal development of scour depth at the spur dike were also studied. The time development of the scour hole around the model 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 flow intensities (u*/u*c) increases, the scour increases. Measuring time and depth of scouring based on experimental observation, an empirical relation is developed with high regression coefficient 97%.

Masjedi et al. [8] studied on reduction of local scour at single T-shape spur dike with wing shape. 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%.

Characteristic of flow in bend is different than in straight channel. Since in bend the general helical current induced by the balance of centrifugal force and the gravity force will force the water surface layers move toward the outer bank and the lower layers moved toward inner bank. Such flow pattern can redistribute the flow velocity and shear stress at the bed. The maximum flow velocity and shear stress occur at the outer bend. Therefore it is the principal objective of this study is to carry out experimental tests on the effect of local scour around a L-shape spur dike in a 180 degree bend.

The scour geometry around a L-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:

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

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 and t is time of scour. Using dimensional analysis, Eq. (2) can be written as:

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

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:

$$\frac{ds}{y} = f\left(Fr, \frac{L}{B}, \frac{\theta}{180}, \frac{t}{t_e}\right) \qquad (3)$$

2. Material and Methods

Tests of experiments were conducted in a flume located at hydraulic laboratory of Islamic Azad University of Ahwaz. The flume channel is recirculation, 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 bend 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 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).

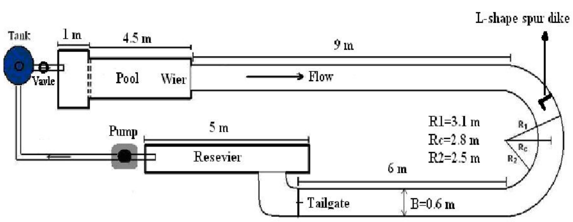

Figure 1. The experimental setup (Plan)

For the riverbed, nearly uniform sands with mean grain size of $d50$ = 2 mm and geometric standard deviation σg = 1.7 are placed with uniform 20 cm thickness [2]. The experiments was carried out using one length for spur dike (i.e. L =10%, 15%, 20% and 25% of the channel width) and one wing length of spur dike (i.e. l =50% of the spur dike length) were used [3]. Figure 2 shows a schematic illustration of a L-spur dike in flume.

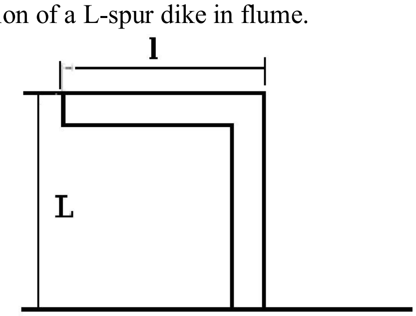

Figure 2. A L-shape spur dike (Plan)

The spur dikes were made of Plexiglas L-shape in plan and located at section 30, 45, 60 and 75 degree in the bend. The L-shape spur dikes were of 10 mm thick and 55 cm high.

In this study the experiments were performed under clear-water conditions at four different flow intensities (U / Uc) 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 [9]. Here U is approach flow velocity and Uc is critical velocity for sediment movement. Four Froude numbers of 0.23, 0.25, 0.28 and 0.35 were applied in order to investigate the effect of flow conditions on the scouring.

Equilibrium scour occurs when the scour depth does not change appreciably with time. For this purpose the experiments were conducted with spur dike having L/B=0.25,_Froude number 0.35 which corresponds to U/Uc= 0.85 respectively and locations of 30, 45, 60 and 75 degree a L-shape spur dike. Experiments were run under clear water scour regime for a period of more than 24 hrs when movement of sediment from scour hole was almost negligible and equilibrium state of scour reached (Fig. 3). As it can be seen approximately 93% of scouring occurs during the first 3 hours. Therefore in all remaining of our experimental tests, duration of 3 hours was selected for each test. Therefore in all our experiments, the scour depth 3 hours after the start of each test was recorded and considered here as maximum scour depth.

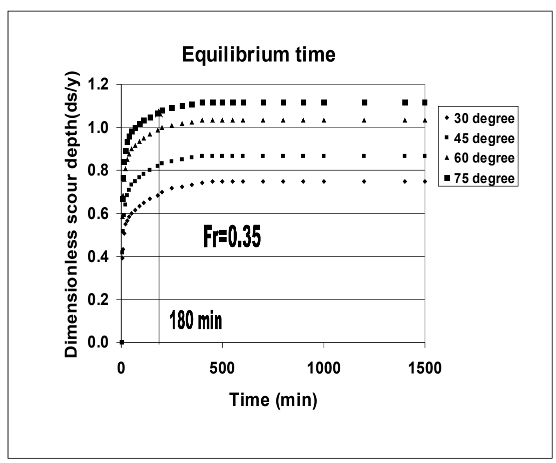

Figure 3. Equilibrium time in the different position for a L-shape spur dike

Water pumped from an underground water tank is passed through an electromagnetic flow meter, then introduced to the water channel. It flows down the water channel and is returned again to the underground water tank. A current-straightening part using filter materials is provided at the upstream end of the water channel and a water-level regulating plate, which can be adjusted to an arbitrary angle, is provided downstream.

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 having an accuracy of ±0.01mm (Fig.4).

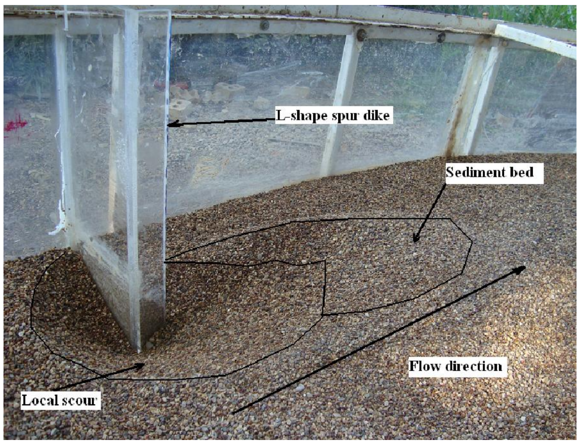

Figure 4. Scour pattern at the end of a test

3. Results

In this study, investigation on local scour at around a L-shape spur dike with four different wing length in a 180 degree flume bend are presented. The experiments was carried out using one length for spur dike (i.e. L =10%, 15%, 20% and 25% of the channel width) and one wing length of spur dike (i.e. *l* =50% of the spur dike length) were used. Experiments were at location 30,45,60 and 75 degree in flume bend with four Froude numbers of 0.23, 0.25, 0.28 and 0.35.

3.1. Effect of Length of L-shape Spur Dike on the Scour

Figure 5 shows effect of length of L-shape spur dike on the time development for Fr=0.35 and location of 75 degree at 180 degree flume bend. Four different length of L-shape spur dike L/B=0.10, 0.15, 0.20 and 0.25 were applied in order to investigate the effect of length of L-shape spur dike on the scouring. As it can seen from Figure 5, all lengths, at location of 75 degree results maximum increases in scour depth.

Figure 6 shows, typical dimensionless graphs for the relative maximum depth of scour dsmax/y against L/B. This figure corresponds to Fr = 0.35 for four location. It is evident from this figure that by increasing length of the L-shape spur dike the maximum relative scours depth increases. The main reason of such finding is that increase in length, value of vortex maximum.

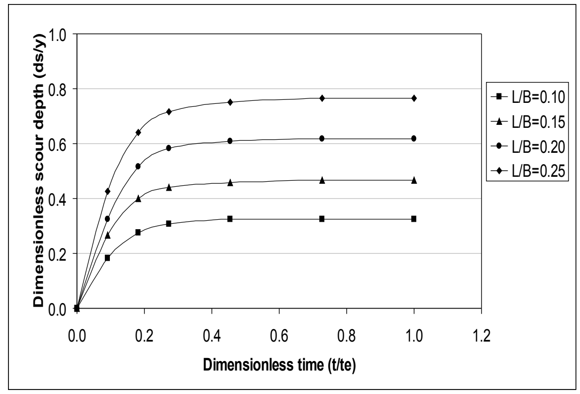

Figure 5. Time development of scour for different lengths

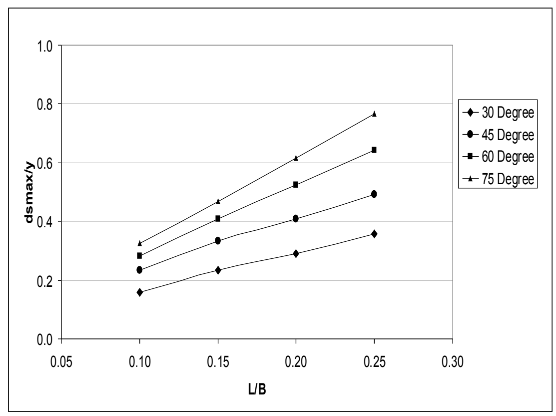

Figure 6. Effect of length on relative maximum depth of scour

3.2.Effect of Froude Number on the Scour Depth

Figure 7 shows effect of Froude number on the time development for L/B=0.15 and location of 75 degree at 180 degree flume bend. Four different Froude numbers 0.23,0.25,0.28 and 0.35 were applied in order to investigate the effect of flow conditions on the scouring. Increasing Froude number is associated by increase in the flow velocity, as a result the amount of scour increases. The main reason of such finding is that with increases in Froude number, occurs increases in vortex. This finding also is in agreement with the results of Ghodsian and Vaghefi [6] and Masjedi et al. [8] which they found that, as Froude number increases, the vortex and scour increases.

Froude number the maximum scour depth and the volume of scour hole increases.The influence of Froude number on the relative maximum scour depth dsmax/y is shown in Figure 8 for L/B=0.15. It is evident from this figure that by increasing Froude number the maximum relative scours depth increases.

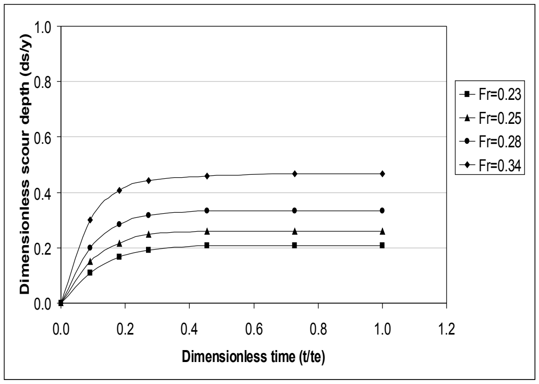

Figure 7. Time development of scour for different Froude number

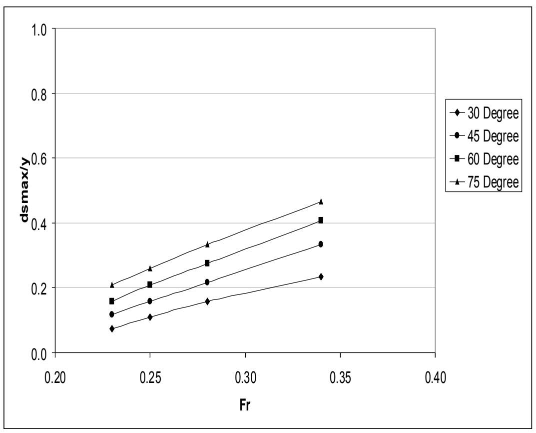

Figure 8. Effect of Froude number on relative maximum depth of scour

3.3.Effect of Location of L-shape Spur Dike on the Scour Depth

Figure 9 shows typical influences of the location of the L-shape spur dike on the time development for Fr=0.35 and L/B=0.15. Four different location of L-shape spur dike ϴ=30, ϴ=45, ϴ=60 and ϴ=75 degree were applied in order to investigate the effect of location of L-shape spur dike on the scouring. As it can be seen from Figure 9, at location of 75 degree results maximum increases in scour depth. The main reason of such finding is that at location of 75 degree of the bend a maximum increases in vortex. This finding also is in agreement with the results of Ghodsian and Vaghefi [6] which they found that 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.

Figure 10 show typical dimensionless graphs for the relative maximum depth of scour dsmax/y against ϴ/180 respectively. This figure corresponds to Fr = 0.35 for L/B=0.10, 0.15, 0.20 and 0.25. It is clear that the location of the spur dike increase at bend, the maximum depth of scour increase.

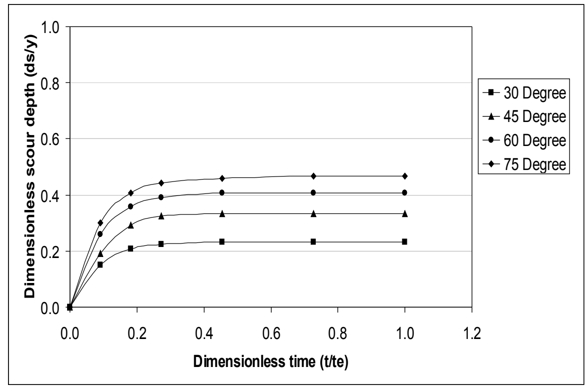

Figure 9. Time development of scour for different locations

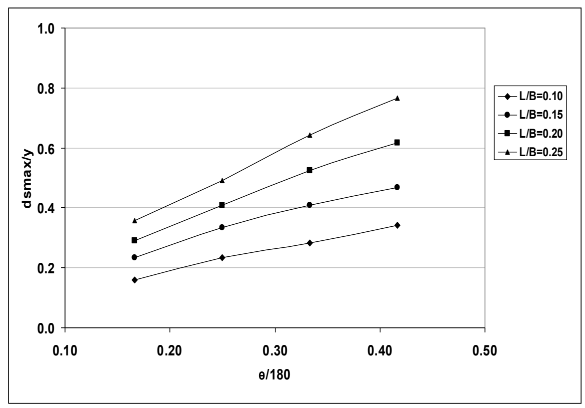

Figure 10. Effect of location on relative maximum depth of scour

3.4.Equation for Scour Depth

The equation (3) can be written as:

$$\frac{ds}{y} = a(Fr)^b \left(\frac{L}{B}\right)^c \left(\frac{\theta}{180}\right)^d \left(\frac{t}{t_e}\right)^e \qquad (4)$$

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

$$\frac{ds}{y} = 6.15(Fr)^{1.12}\left(\frac{L}{B}\right)^{0.28}\left(\frac{\theta}{180}\right)^{0.5} Ln\left(\frac{t+t_e}{t_e}\right)^{0.22} \qquad (5)$$

with regression coefficient of 0.95. Here θ is in radian. Figure 11 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.

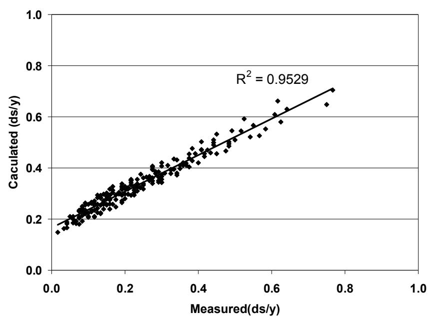

Figure 11. Comparison of measured and predicted scour depth

4. Discussions

The effects of length, Froude number and location of spur dike on the scour and flow field around a L-shape spur dike in a 180 degree bend were investigated in this study. It was found that:

- The depth of the scour increases as the time increases.
- By increasing Froude number the maximum scour depth increases.
- By increasing the length of the spur dike, the maximum depth of scour increases and increases depth of scour occurs at L/B=0.25.
- Increases depth of scour occurs at location of ϴ/180 =0.41.
- The comparison of the present study data with predicts formula shows good accuracy.
- Measuring depth of scouring based on experimental observation, an empirical relation is developed with high regression coefficient 95%.

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