Numerical Investigation of Wing to Web Length Ratios Parameter of T-shaped Spur Dike in a 90 Degree Bend on Scour Pattern

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ABSTRACT

There are a lot of methods and techniques to protect of the outer wall of river bends against erosion that spur dike is an important element for protection of river banks. Spur dike causes variations in flow field, sediment transport and bed topography. The mechanism of flow and sediment transport in a channel bend is very complex, especially when a spur dike is constructed in a bend. This paper examines the effect of geometric parameter of wing to web length ratios of T-shaped spur dike in a 90 degree bend on scour around them using SSIIM software. The results show that the main scour hole to about two-thirds, or 67 percent of channel width has developed towards the outer wall. Analysis of scour pattern result, Cavity geometry changes, Bed topography and comparison of scour in transverse and longitudinal sections about spur dikes with different ratios of wing to web length have been studied.

KEYWORD

Wing Length, 90 Degree Bend, T Shape Spur Dike, SSIIM, Scouring

INTRODUCTION

The bends are important parts of rivers and locating spur dikes on the bend’s spot is used for such purposes as protecting the outer wall of bend against erosion, prevention of change in bend’s curve, controlling sedimentation in the vicinity of the inner wall, increasing water depth for ship traffic and environmental objectives. Some studies conducted by researchers in the field of flow pattern and bed topography around the spur dikes are as follow. Shuky in 1950, did an experimental study on the spiral motion around bends. The investigations showed the effect of varying the Reynolds number, the depth-breadth ratio, the radius breadth ratio and the deflection angle of the bend [1]. Rozovskii in 1957, studied the flow characteristics and boundary shear stress distribution in channel bends with a fixed bed [2]. Gill in 1972, did an experimental study showing that the distance between the spur dikes is very much dependent on the radius of curvature [3]. Rodiet al. in 1979, illustrated the flow in strongly curved with 180° in turbulence conditionally using the k-ε numerical model. Resultant surveys presented that flow model is affected by longitudinal pressure gradient [4]. Rajaratnam&Nwachukwu studied the structure of turbulent flow near groin-like structures in 1983. Based on experimental observations, the deflected flow has been analyzed using the model of the three-dimensional turbulent boundary layer. The flow bounded by the separating stream line, the groin, and the adjacent bank has been analyzed by being treated as a shear layer in which the velocity profiles have been found to be similar [5]. Demuren and Rodi in 1986, used athree-dimensional model where the turbulence was predicted by the k-ε model to calculate the flow and transport of a neutral tracer in a meandering channel [6]. In a two dimensional model, Kong and Platfoot in 1996, investigated the effect of channel geometry and operational parameters on the flow pattern in an transfer channel [7]. Graf and Blanckaertin 2001, did an experimental study on a 120° bend channel and measured secondary flow and maximum velocity at the 60° cross section [8]. Booij in 2003, by using Large Eddy Simulation (LES) simulated flow field in a 180 degree bend and measured Reynolds shear stress [8,9]. McCoy et al. in 2004, investigated flow pattern around and between two spur dikes in an open channel. They used LES method for simulation [10]. Dey and Barbhuiya in 2006, used an ADV to measure the turbulent flow field at various azimuthal planes around a 45° wing-wall and vertical-wall abutment. These measurements were conducted before and after equilibrium scour depths were reached, and provided insights of mean flow and turbulence around the dikes [11]. Vaghefi et al. in 2008 investigated the effect of T-shaped spur dike at the beginning of a 90 degree bend on...
bed topography [12], also in 2008 they did an experimental study on the effect of wing geometry of T-shaped spur dikes based on a 90 degree bend on the scour pattern around them [13]. In 2009, they investigated the effect of T-shaped spur dike length on scour in a 90 degree bend [14]. Ghodsian and Vaghefi in 2009, conducted experimental studies on scouring and flow field around T-shaped spur dike in a 90 degree bend[15].Vaghefi et al., in 2010, investigated the effect of wing length of T-shaped spur dike based on a 90 degree bend on scour pattern around them [16], and in 2010 did an experimental study of the effect of Froude number on two dimensional flow pattern around straight spur dike at the bottom of a 90 degree [17]. Naji et al. in 2010 did experimental and numerical studies of flow pattern in a 90 degree bend and concluded that stream lines in the level close to bed orient to inner wall and in the levels near water surface orient to outer wall. Also, the location of the maximum longitudinal velocity at the beginning of the bend is switched to the section’s inner half and then toward the channel’s outer wall [18]. Also in 2011, Vaghefi et al. did an experimental study on flow pattern around T-shaped spur dike in a 90 degree bend with live bed [19]. They studied the scouring around the T-shaped spur dike in the bend channel in 2012 [20].

In this study, the numerical and experimental effect of wing to web length ratio of T-shaped spur dikes on the scouring pattern and the bed topography formed around the spur dike based on a 90 degree bend are investigated.

INTRODUCING THE STUDIED MODEL

The studied model is a 90 degree arc-shaped channel with the central radius of 2.4 m which is consisted of the straight part of 7.1 m in the upstream and 5.2 in the downstream of the bend. The channel’s section is rectangular and has a height of 0.7 m and width of 0.6 m and its bottom is covered with sediments with thickness of 35 cm and average diameter of 1.28 mm.

The spur dikes used in these experiments have T-shaped plans and web length of 9 cm and thickness of 1 cm which are installed in the location of 45 degree and in the outer wall of 90 degree bend. In order to investigate the effect of spur dike’s wing to web length ratio, five wing to web length ratios (25, 50, 75, 100 and 125%) have been used. (Fig.1) shows a schematic representation of the studied channels.

EQUATIONS GOVERNING SEDIMENT TRANSPORT IN THE SSIIM SOFTWARE

SSIIM software solves Navier-Stokes equations with the (k-ε) model on a non-orthogonal three dimensional network. Finite Volume Method with power method algorithm or second-order algorithm can be used for discretization. SIMPLE method can also be used for pressure and velocity coupling. The implicit solution method is used to generate velocity field in geometry and these velocities are used when the diffusion-transport equations for various sediment sizes are solved.

SSIIM uses the diffusion-transport equation to calculate sediment concentration as follow(Eq.1):

\[
\frac{\partial c}{\partial t} + U_j \frac{\partial c}{\partial x_j} + W \frac{\partial c}{\partial z} = \frac{\partial}{\partial x_j} \left( \Gamma_T \frac{\partial c}{\partial x_j} \right)
\]

Where \( W \) is velocity of falling particles and \( \Gamma_T \) is diffusion coefficient, which are obtained from the following equation(Eq.2):

\[
\Gamma_T = \frac{\nu_T}{S_c}
\]

Where \( S_c \) is the Schmidt number and \( \nu_T \) is eddy viscosity and is obtained from standard k-ε model.

SSIIM software for calculating bed load (\( q_b \)) uses Van Rijn equation for bed load which is as follows(Eq.3):

\[
\frac{q_b}{\rho_w D_{50}^{0.5}} = 0.053 \left[ \frac{\tau - \tau_c}{\tau_c} \right]^{1.5} \left[ \frac{(\rho_s - \rho_w)g}{\rho_w \nu^2} \right]^{0.1}
\]

In this equation, \( \tau \) is bed shear stress, \( \tau_c \) is bed shear stress for sediment particles motion based on the Shields diagram, \( \rho_w \) and \( \rho_s \) are water and sediment density respectively, \( \nu \) viscosity of water, \( g \) acceleration of gravity and \( D_{50} \) is the average diameter of sediment [21].

PRODUCTION AND FORMULATION OF NETWORK MODEL

Given that SSIIM software is not able to generate complex networks, so Matlab software is used for building the model’s geometry. Given that sediment modeling in the SSIIM software is time-consuming, in order to reduce computation time network configuration is such that with approaching to the wall and spur dikes, due to the more sever changes, smaller network configuration than other parts of the channel is used. (Fig.2) is the schematic representation of model configuration in the plan and cross section.

![Fig.1. schematic representation of the studied channels](image-url)
RESULTS

(Fig.3) shows an example of dimensionless bed topography variations with flow depth in upstream for spur dike located in a 45 degree angle and in situations with different wings length. In this figure, \( ds \) indicates local scour depth, \( Y \) is flow depth in the upstream’s direct path. \( Q \) is discharge of flow, \( L \) is spur dike’s web length, \( l \) is spur dike’s wing length, \( Fr \) is the Froude number, and \( R_c \) is the central radius of a 90 degree bend.

With spur dike’s wing length increase, the area between spur dike’s wing wall and outer wall also increases. With the increase of this area’s scope, stable vortexes with vertical axis and clockwise are formed and these vortexes reduce the concentration stress in front of the nose of the spur dike in comparison with spur dikes with shorter wing length. Also, the role of spur dike’s wing is clearly evident in protecting the outer walls and as is observed, with the increase of spur dike’s wing to web length ratio, due to the increase in the area of flow’s stillness, the scour depth in the outer wall is also reduced. It is also observed that in these figures the scour hole has advanced to about two-thirds or 0.67 of channel width.

(Fig.4) is an example of lateral variations of dimensionless bed topography with flow depth in upstream against channel width in sections before and after the scouring and for different wing to web length ratios. In these graphs, \( B \) represents the distance from the inner bend. As we see in these figures, the scour depth for wing to web length ratio of 1.25 is the lowest. Also, the role of spur dike’s wing is clearly evident in protecting the outer walls and as is observed, with the increase of spur dike’s wing to web length ratio, due to the increase in the area of flow’s stillness, the scour depth in the outer wall is also reduced. It is also observed that in these figures the scour hole has advanced to about two-thirds or 0.67 of channel width.
Fig. 3. Dimensionless bed topography variations with flow depth in upstream for spur dike with wing to web length ratio equal to (a) 1.25 (b) 1 numerical (c) 1 experimental [16] (d) 0.75 (e) 0.5 and (f) 0.25.

Fig. 4. Dimensionless lateral profile variations with upstream flow depth in section (a) 44, (b) 46 degree.

(Fig. 5) shows an example of longitudinal variations of dimensionless bed topography with flow depth in upstream against the channel length at different sections. In these
figures, $\theta$ is the angle from the beginning of the bend. In fig. 5, reduction in the scour depth in the spur dike with the wing length equal to 1.25 of spur dike’s web length and downstream and in the area between wing and outer wall is lower compared with other states. (Fig.5-c) shows the longitudinal section passing through the middle of channel and as it is observed, for a spur dike with wing to web ratio equal to 1.25 of web length, the second scour hole with less depth compared to main scour hole has developed from a situation about 65 to 90 degree. Also, in the distance between the first scour hole and the second hole in the channel’s middle section sedimentation is observed. In the (Fig.5-d) and in the section within 95% distance of channel’s width from the outer wall to the position of around 40 degrees, no significant change is observed and from this section to the end of bend, sedimentation in the inner wall is observed.

(Fig.6) represents dimensionless maximum scour depth ($d_{sm}$) with flow depth in upstream against the dimensionless wing length to scour’s web length for experimental and numerical data. As it is evident, the variation area of maximum scour depth is between 1.29 to 1.42 of flow depth in the upstream and it is also observed that with the increase of wing to web length ratio, maximum scour depth for the two experimental and numerical models is reduced due to the reduction of stress concentration in front of the nose of the scour dike. Also, the location of maximum scour depth is near the spur dike’s upstream wing and from a distance of about 12 to 40% of spur dike’s length from the tip of scour dike’s upstream wing.

Fig.5. dimensionless longitudinal profile variations with upstream flow depth from (a) 5 (b) 25(c) 50 and (d) 95% of channel’s width distance from outer wall.

Fig.6. the variation of maximum scour depth with upstream flow depth against dimensionless wing length with spur dike’s web length for experimental and numerical models.

(Fig.7) and (Fig.8) represent the variation’s range of maximum amount of sediments and position of maximum sediment to spur dike, respectively and dimensionless with flow’s depth against the section's narrowing percentage.
As it is observed in these figures, with the increase of section’s narrowing amount, the amount of maximum sediments and their positions to spur dikes also increases.

**CONCLUSIONS**

- With the increase of spur dike’s wing to web length ratio, maximum scour depth decreases.
- With the increase of spur dike’s wing to web length ratio, due to the increase of the flow stillness area, the scour depth in the outer wall and in the spur dike’s downstream decreases, which represents the role of spur dike’s wing in protecting the outer wall.
- The main scour hole has advanced up to two-thirds or 0.67 of channel’s width.
- In the longitudinal section, by passing through the middle of the channel of the second scour hole with less depth compared to the main scour hole and has developed from position of about 60 degrees to position of 90 degrees. Also, sedimentation is observed in the distance between the first scour hole and the second scour hole in the middle section of channel.
- In the section from 95% of the channel’s width from outer wall, to the position about 40 degree no significant change is observed and from this section to the end of the bend, sedimentation is observed in the inner wall.
- The range of maximum scour depth variations are between 1.29 to 1.42 times of flow depth in the upstream.
- The location of maximum scour depth is near the spur dike’s upstream wing and happens in the distance about 12 to 40% of spur dike’s wing length from the nose of the spur dike’s wing.
- With the increase of the section’s narrowing, the maximum amount of sediments and also their positions to spur dikes increase and their variation changes are between 0.5-0.75 and 9-13.5 times of upstream’s flow depth.

**REFERENCES**


