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Study of the Characteristics of the Flow around a Sequence of Non-Typically Shaped Spur Dikes Installed in a Fluvial Channel

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Synopsis

In this study, the features of flow in a sequence of non-typically shaped spur dikes will be examined using a 3-D numerical code, SSIIM. The velocity field and shear stress contour will be presented and the effect of the spaces between the spur dikes on the flow will be discussed. The comparison between the non-typically T-type spur dikes and the straight shape spur dikes showed that by installing the T-type in stream, the distribution of high stress and high energetic zones around the spur dike as well as the main stream is more homogenous. This fact can highlight the capability of T-type spur dikes to provide a better route for navigation, as well as the better stagnation zones which are suitable environment for the life cycle of stream biota and fauna.

Keywords: spur dike, T-head, embayment, numerical simulation, SSIIM, CFD.

1. Introduction

The spur dike is one of the main transverse hydraulic structures installed in streams to prevent bank erosion and improve navigation routes in rivers. Recently, it has also been used to provide a better environment for those stream species that need a diverse bed with a range of hydrodynamic, topographic, and biological conditions in rivers.

Based on the construction method and materials or the hydraulic conditions of inflow, spur dikes can be categorized as impermeable or impermeable, and emerged or submerged, respectively. Moreover, based on the shape of the spur dike in the plan, different kinds of spur dikes can be recognized: “Straight shape" or "I-type,” “T-type,” “L-type,” etc. Indeed, the most typical type of spur dike constructed in rivers over the years is the straight one.

After installation of transverse structures in the rivers, due to the separation of approaching flow and the formation of shear layers, a fully three-dimensional turbulent flow will appear locally around the structures as well as inside the main stream. This can lead to the movement of sediment particles from the bed, erosion along the bed and banks of the river, and ultimately to changes in the morphology of the stream reach.

Numerous studies have proven that, by installing a series of straight spur dikes in the stream, a local scour hole will form and the eroded material can form a series of point bars downstream of the spur dike. Over time, these big bars would be able to interrupt the route of navigation in rivers. An increase in the resistance of the flow and, consequently, a greater risk of flooding might also result from the formation of such bars along the river. Alternatively, very limited studies of non-typical shapes of spur dikes show that these types of spur dike are capable of better performance in decreasing topological changes in the stream.

Linder et al. (1964) conducted a set of

experiments to find the optimum combination of a series of L-shape in a left bank of a reach of Missouri River in the U.S. According to these findings they suggested the optimum opening between two consequent spur dikes should be around 42 percent of the distance between the bodies of those groynes. Vaghefi and Ghodsian (2009) studied flow field scouring around a single T-shape spur dike in a 90 degree bend. Kadota et. al. (2010) conducted a series of experiments in which they studied hydrodynamic of flow around an individual T and L- shape spur dikes.

In this study, two different series of spur dikes will be examined: a simple series of straight spur dikes and a simple series of spur dikes with T-shaped heads. The effect of the length of the spur dikes' field on the pattern of flow field will be discussed. The discussions will focus mostly on comparing the mean characteristics of the structure of turbulent flow around these two types of spur dikes; the purpose is to evaluate and compare the performance of a series of T-shape spur dikes with that of straight ones, based on the primary objectives of the designs of the spur dikes.

2. Numerical model

In the present study, a numerical code will be utilized to solve the governing 3-D RANS equations. The code uses standard k-ε turbulence model to solve the turbulent stresses in the Reynolds-averaged equations. The convection terms are discretized using the SOU scheme. For velocity-pressure coupling, the SIMPLE algorithm is adopted. Water surface calculation was also applied in order to incorporate fully 3-D turbulent modeling and free-surface flow.

For boundary condition, the "velocity inlet" boundary condition is applied to the inlet plane. Therefore, in this study the channel length before the test area (first spur dike in the series of spur dikes) was checked to ensure about the enough length needed to fully-develop the velocity profile before reaching the spur dikes. The outlet of the channel is defined using "outflow" boundary condition. The bed and side wall are solid boundaries and the "wall" boundary condition is used for these boundaries. For k-ε turbulence model, the standard wall function is applied to bridge the near wall boundaries and turbulent regions.

2.1 Verification

Before employing the numerical model with the aim of the study the flow pattern around two series of spur dikes with different shapes of head, it was necessary to ensure the accuracy of the numerical code. Due to the lack of reliable experimental data for a series of T-head spur dikes, the verification of model was done by a set of available experimental data of single spur dike carried out with satisfactory precision by ADV. The test case had been conducted in a straight rectangular flume with 11m length and 1m width by Safarzadeh et al. (2010). The steady-state water discharge of 60 lit/s and the equivalent normal depth h=143mm was applied in the flume entrance. The spur dike had been installed in the channel 7 m downstream of the entrance of the channel with 15 cm length, 1 cm width and 15 cm height with a 90-degree angle toward the mainstream. To make the suitable mesh of modeling, the required criteria such as "y+" criterion near the walls and bed was checked to avoid from the instability in the results.

Considering the time-consuming process of the solving of the domain, a non-uniform grid of 40*12 in the transverse and vertical directions was employed. In the stream-wise direction 300 planes were used.

Fig. 1 shows the comparison between the simulation results and the experimental data for the velocity magnitude (= $\sqrt{u^2+v^2+w^2}$ in which u, v and w are respectively longitudinal, transverse and vertical components of velocity) in different cross sections of upstream and downstream of the spur dike in the planes near the water surface and close to the bed. It can be seen that agreements between measured and computed velocity are quite satisfactory. However in some points the performance of the model was not pretty well which might be due to the lack of the k-ε turbulence modeling to model the turbulence-driven recirculation perfectly.

2.2 Case studies

In the next step and after the verification of the

Table 1 The hydraulic and geometrical characteristics of test cases

Case Study (A series of)	L (m)	Q (Lit/s)	h (m)	L/B	Lw/L	Fr	Re
Straight spur dikes	0.15	60	0.143	0.15	-	0.35	186000
T-shape spur dikes	0.15	60	0.143	0.15	1	0.35	186000

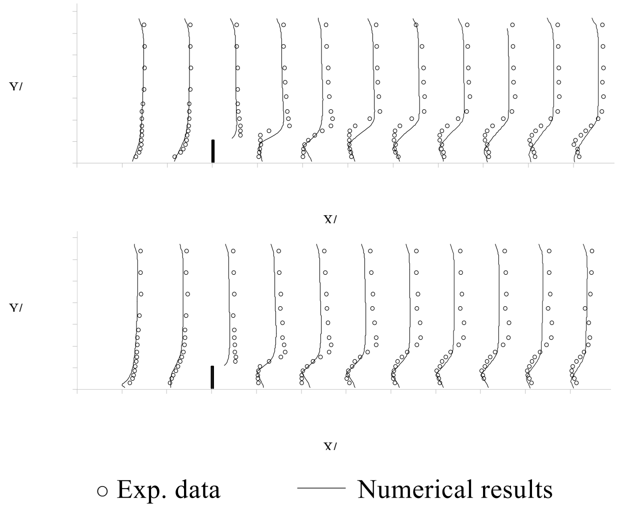

Fig. 1 Verification of numerical simulation with experimental data (velocity magnitude); Above: The plane near the water surface; Below: The plane close to the bed.

model, the 3D numerical code was applied on two different sequence of spur dikes: a simple sequence of straight spur dikes and a simple sequence of spur dikes with T-shape head (Fig. 2) and the effect of different shapes of head on the pattern of flow field will be discussed.

Table 1 shows the characteristics of each case in which L is the length of the spur dike, Q is the discharge in the upstream of the channel, h is the normal depth of water applied in the inlet of the

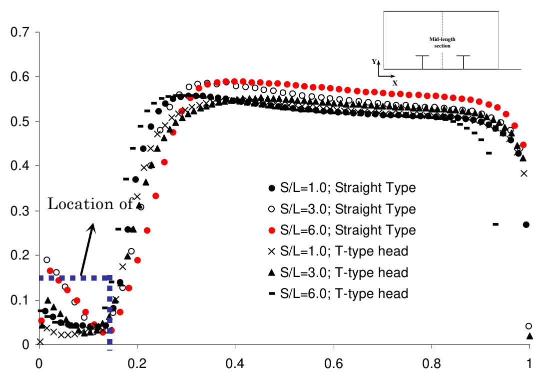

Fig. 3 Velocity distribution of (u) in the transverse direction, along the mid length of the embayments

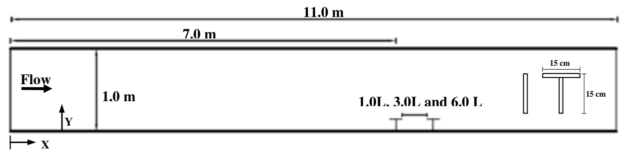

Fig. 2 Schematic view of case studies

channel, B is the width of the channel, Lw is the length of the wing of the spur dike (in the T-shape case), Fr is the Froude number and Re is the Reynolds number.

Moreover, since the morphological pattern inside a spur dike field corresponds to the number and shape of circulation cells between the spur-dikes (Sukhodolov et al. 2002, 2004) and the ratio S/L (S=length of the embayment between the spur-dikes) determines the number and shape of the horizontal eddies that form along the downstream of the spur-dikes (Yossef, 2010), in this study, three ratio of S/L (S/L=1.0; 3.0, 6.0) was investigated.

For the T-shape case this length (L) was assumed between the downstream tip of the wing of first spur dike and the upstream tip of the wing of the latter one in the series.

3. Results and discussion

3.1 Velocity distribution

Fig. 3 shows the distribution of longitudinal component of the velocity in the transverse direction, along the mid length of the embayments of the spur dikes. As it can be seen, in all cases due to present of the spur dikes the uniformity of transverse distribution of velocity has been quite changed and a considerable drop has been occurred by reaching to the point of the spur dikes. Moreover, in this figure, this is clear that inside the embayment the velocity field is significantly less than the main channel and then a stagnant zone has been formed behind the first spur dike in the series. By comparing the T-shaped cases with their

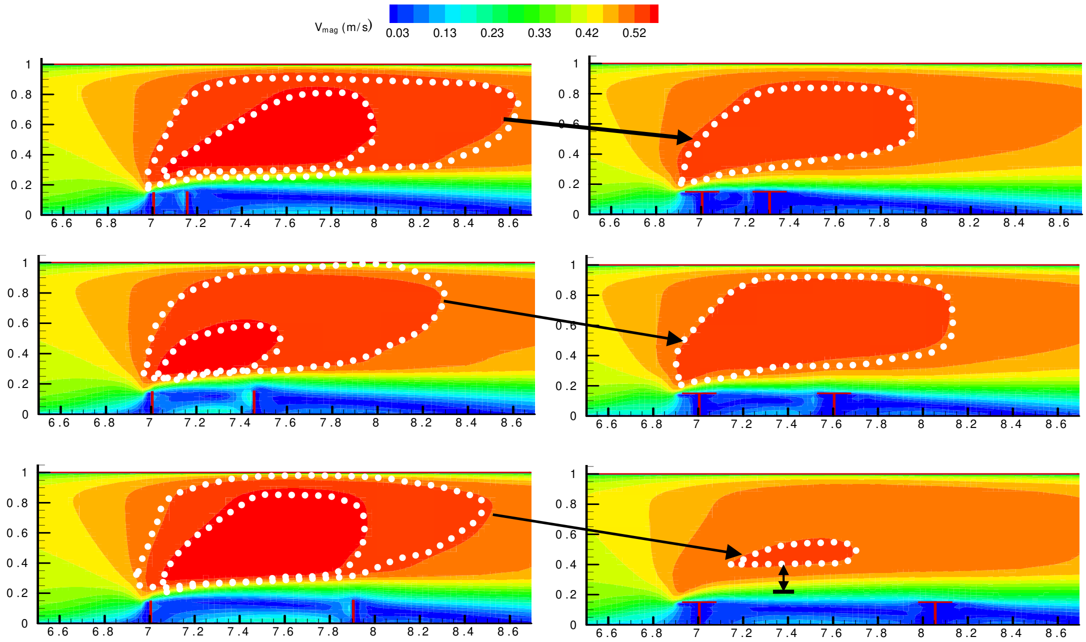

Fig. 4 Contour of velocity magnitude in the plane close to the bed of straight spur dikes (left) and T-shaped spur dikes (right)

counterparts of straight shaped, it can be recognized that the maximum velocity inside the embayments of t-shaped spur dikes is reasonably less than straight ones. This means that the t-types spur dikes can provide even more stable embayment compared to the straight ones.

Fig. 4 shows the contour of velocity magnitude in the level of near bed for both types of the spur dikes with three different ratio of S/L. In all cases the zone of maximum velocity occurs alongside of the outer zone of the shear layer. Comparison between the contours of plane near the bed for both shapes shows that regardless of the S/L, in the T-shaped cases the zone of high velocity has moved toward the opposite bank of the channel. The main cause of this fact can be the presence of the wing of the spur dike for T-shaped cases. In other word, the wing of the T-shaped spur dike moves the high velocity zone away from the body of the spur dike toward the main channel and/or opposite bank. In addition, the amount of maximum velocity magnitude has reduced for T-shape spur dikes. The direct effect of this decrease can be arising on the changes in the bed shear-stress. Then it can be expected that in this case the pattern of bed-shear stress as well as the potential of the erosion would be reduced. This fact will be further discussed later. Generally, it can be seen that the extension of high velocity zone in the series of straight spur dikes is more than the T-shaped cases.

3.2 Shear Stress Distribution

Fig. 5 represents the contour of the bed shear stress distribution in all cases. The first point which can be seen from this figure is the ability of the T-shaped spur dike to deviate the high stress points from the body of the spur dike. This can lead to more stability for the body of spur dikes against the erosion due to formation of scour hole around the tip of first spur dike in the series.

In fact, the presence of the wing of T-shape head has not only the major effect on the deviation of high stress points from the body of first spur dike of the series, but also has caused the extensive changes on the distribution of the shear stress in front of the sour dikes inside the main channel. As it is shown in the fig. 5, in all cases of T-shaped spur dikes, the extension of the maximum zone of shear stress has been confined to a very limited area in the middle of the channel. The first expectation of this is that the less probability of the formation of large point bars along the channel in T-shaped cases. In other words, the expected bed topography due to installation of a sequence of T-shaped spur dikes is more homogenous and uniform than that of straight spur dikes'.

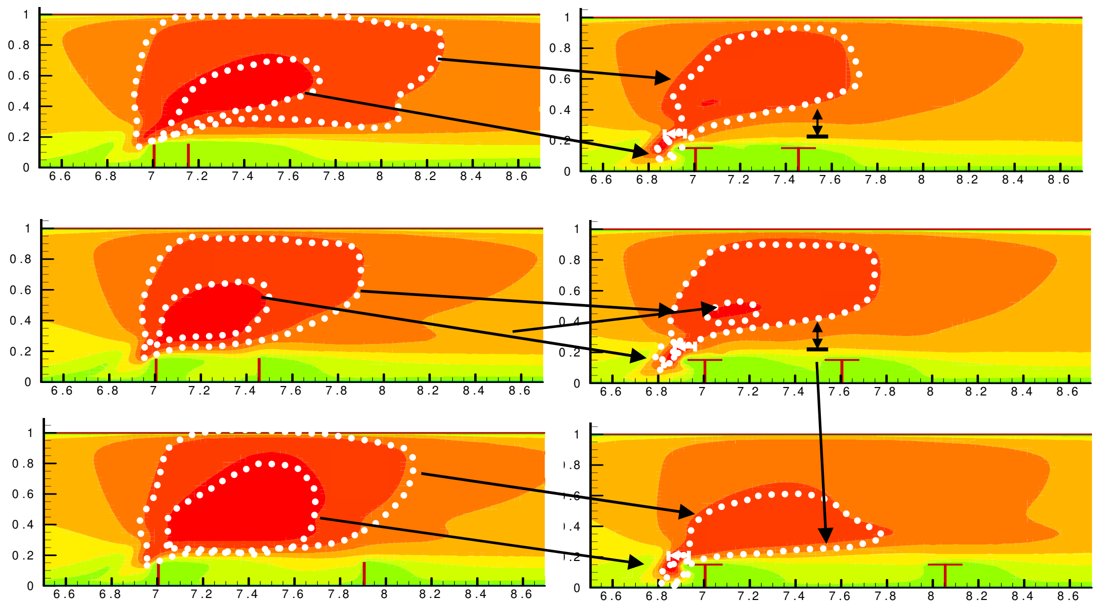

Fig. 5 Contour of shear stress distribution of straight spur dikes (left) and T-shaped spur dikes (right)

4. Conclusion

In this paper, velocity and shear stress distribution around two sequences of spur dikes with different head shapes were studied using a 3D-numerical model. This study showed that inside the embayment of T-shaped spur dikes there is a more stagnant zone compared to the embayment of the straight spur dikes. Overall, the existence` of the wing can increase the stability of the body of the spur dike against the erosion because of the moving the high-stress (energetic) regions away from the body. Besides, it has another type of effect on the distribution of high velocity zone toward the main flow (as well as the opposite bank) which can have effect on the formation of point bars and bed topography in the main part of the channel and consequently can roughly be considered as a better option for improving the navigation.

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河川に設置された非典型的な形状の連続型水制周辺の流れの特徴に関する研究

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要　旨

本研究では，非典型的な形状の連続型水制周辺の流れの特徴について，3次元流れ解析モデルSSIIMを用いて調査した。流れとせん断応力の分布を示し，水制間の流れにおける水制形状の効果を考察した。T型とI型水制の比較によって，T型水制の設置は水制周辺にせん断力の大きな領域を創り出すだけでなく，主流路側を均一な流れ場にすることが示された。このことは航路維持にとって着目すべき事ことであり，そして淀み領域においても河川生物および動物相のライフサイクルによって適した環境を提供している。

キーワード: 水制，T型，わんど，数値解析，SSIIM，計算流体力学