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Effect of Changes in the Hydraulic Conditions on the Velocity Distribution around a L-Shaped Spur Dike at the River Bend Using Flow-3D model

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ABSTRACT: Evaluation of the characteristics and flow behavior of rivers and related structures is a complex phenomenon that makes it inevitable to use the software. Spur dike is a simple hydraulic structure which is used for rivers organization at the bends and straight paths, erosion control and protection of river banks. In this paper, flow pattern around a bunch of impermeable spur dikes with intervals specified at the bends is evaluated for various discharges and percentages of different narrowing of the flow widths; then they will be compared with each other. Also the velocity distribution around the L-shaped spur dikes is evaluated in two and three dimensions using the finite volume method. Based on the conducted experiments, maximum speed limit and thus the amount of scour has declined from the first spur dike at the angle of 30 ° to the last spur dike at the angle of 90° from the river bend and in the direction of water flow and all the turbulence of flow is lost when the flow reaches to the last spur dike.

Key words: Velocity distribution; river organization; L-shaped spur dike series; Flow-3D Numerical Model

INTRODUCTION

Nowadays the role of natural rivers as one of the main sources of water and energy needed for human is undeniable. River beds are rocky and this is why they are unstable and there is a possibility for the over time transformation of rivers. This transformation causes damages to the surrounding lands. The main reason for changing in the form of rivers is erosion and sedimentation. In this case, the depth of river decreases in the places with low gradient, but its width increases. In this case water will flow on the surrounding grounds due to the increase in the width of the river and makes these lands to be unusable for the agriculture and also causes water waste either through seepage or through evaporation. From the other hand, sedimentation also reduces the flow rate of the river and during flooding it causes damages due to the inability to remove flood (due to the reduced surface area of the sediment). So in this case, we should know and evaluate the flow pattern and flow rates in different areas of the river in order to prevent damage and consequently to reduce erosion. Erosion is taken place in the bed and bank of the river. From a quantitative perspective, erosion and sedimentation in the rivers is a function of many factors. Among them, type of spur dike, flow pattern around it, geometry, the amount of sediment carried by the water and engineering purposes can be mentioned. Also Among the important issues in the design of the spur dike, is the evaluation of localized scour of the spur dike head which is created due to the narrowing of the flow cross-section and the existence of strong vortex. Although the spur dike structures are constructed with the aim of sedimentation and preventing erosion of river margins and positioning of river, they are influenced by the erosion phenomenon caused by concentrated flow, especially at the head. Localized increase in the flow rate of spur dike head due to the narrowing of the cross-section and the occurrence of the falling rotational flow causes the horseshoe-shaped cavity and its progress endangers the stability of the structure. Since most of the rivers in nature have curved paths, therefore in order to study the behavior of a river it is necessary the model of the flow dominated on the bend to be entirely known.

After water flowing into the river bends due to the centrifugal force and its interactions with other dominating forces, the secondary flow is created and causes the flow's longitudinal momentum redistribution in the transverse section. The role of secondary flows in curved paths as a constituent of three-dimensional flow in these paths is very important. Despite many studies conducted to understand the hydraulics of flow in a river bend, secondary flows, longitudinal and transverse velocities, power of the secondary flow and other cases, no study was conducted so far using mathematical models on the flow pattern and localized scour of the L-shaped spur dike series in a 180 degree bend.

Therefore, in this study the effect of geometry and distance of a series of non-submerged L-shaped spur dikes on flow pattern in a river bend are evaluated using a Flow-3D numerical model. One of the important indicators in determining the amount of scour is the maximum speed limit and the flow pattern. Most of previous researches have been conducted on the blade spur dikes. Here some of the most important researches conducted on various spur dikes and flow patterns and erosion in river with a 180-degree bend are mentioned.

Garde et al, (1961) conducted some tests on 4 sizes of spur dikes with different rates of contraction in a channel with a width of 0.61m. According to the results of the studies conducted by Garde, Froude number is an important parameter in the scour around narrowed places. The maximum depth of scour is also a function of patency rate, flow depth, angle of spur dike with channel, Froude number of flow and the runoff coefficient of seabed sediments [Garde et al, 1961]. Vortex flow in the spur dike field cause develop the secondary flow and sediment the mor coarse-grained at the bank of river that gradually cause to develop the shore and natural and biological fixation (Gray and Leiser, 1982). Mesbahi, (1992) determines his experiences on the arc that the width of flow in front of the spur dike does not change without spur dike and it concluded constraction the spur dike in the arc increase the depth of the scour hole (Mesbahi, 1992). Melville, (1992) introduced an empirical equation to predict the maximum depth of localized erosion in the spur dikes. This researcher has related the maximum depth of scour to the length of the spur dike (Melville, 1992). Kohnel et al, (1999) found that the ratio of narrowing and the depth of flow have a definite relation with the volume of scour hole around the spur dike (Kuhnle, 1999). Karami et al, (2006) conducted a series of experiments in a laboratory flume to examine the effect of the localized scour time of spur dike head for different rates of discharge (Karami et al, 2006). Mahmoudi et al, (2007) conducted a laboratory analysis (evaluation) on the scour and the flow pattern around a quintuple series of smooth spur dikes for the exchange rate and the percentage of various narrowing with specified intervals in a straight flume (Zanganeh, and M. Sane, 2007). Hashemi Najafi, (2008) conducted several experiments on the effect of the angle on L-shaped spur dike scour. The results showed that the maximum depth of scour in the L-shaped spur dike with a tab towards upstream side is less than the blade spur dike. If the L-shaped spur dike is going to be used in the upstream, then its placement in an angle of 60 degrees will lead to the minimum depth of scour. This angle is 110 degrees for the L-shaped spur dike with a tab towards downstream side. In their study, maximum depth of scour for the spur dike in different hydraulic conditions and size of different particles were studied by a series of laboratory studies on the spur dike in the direct path (Hashemi, 2008). Jahromi et al, (2010) made numerical simulation on flow pattern and sedimentation around the spur dike in a 180-degree bend. The results showed that with the increase in the length of the spur dike, increase in the river discharge and increase in the angle of the position in the river bend, depth and dimensions of the hole of bed scour increases (Jahromi et al, 2010). Abbasi Chenari et al, (2011) made numerical simulation on the effect of hydraulic conditions and the angle of the position of the L-shaped spur dike on the flow pattern in the 180-degree river bends using Flow-3D Software (Abasi et al, 2011).

And they prepared the flow pattern around a spur dike and evaluated the impact of these models on flow patterns around the spur dike by applying different models of turbulent flows, including different Froude numbers and placing the single L-shaped spur dike at 4 locations with angles of 30, 45, 60, 75 degrees relative to the flow direction and 180-degree river bend with constant depth of 12 cm.

Their findings showed that the maximum speed limit and the vortex flows have a highest value at the angle of 75 degrees and the minimum value will occur at the angle of 30 degrees. And at different angles, with the increase in Froude number, the velocity in spur dike head increases.

Theory of the research

River bend is always considered by hydraulic engineers due to the specific pattern called the helical flow.

When flow enters the river bend, centrifugal force acts on it. This force is variable along the radius of the river bend and in the direction of depth due to the speed changes. Centrifugal force on the bend causes latitudinal gradients in the water level which raises the level of water in the outer bend and causes reduction in the depth in the internal bend. This phenomenon will result in the adverse pressure gradient inside the section.

When the said pressure gradient overcomes the centrifugal force, a stream is formed inside the section in transverse direction which is known as the secondary flow. Particles in the water move towards the outer wall and the particles on the floor move toward the inner wall because of this flow. Erosion of river walls which is occurred in the old rivers causes a lot of damages in the land around the river and structures and creates false rivers right-of-way; and consequently the potential use of the land surrounding the rivers decreases.

The main flow of water in the main section and great bed of the river is the main cause of erosion and degradation of walls. The effect of these factors depends on the discharge, velocity, depth, slope, bottom and suspended sediment concentrations, density and viscosity of water and the characteristics of the bed material. When the flow shear stress exceeds the critical shear stress on the river bed and walls, the hydraulic destruction is occurred. Height and slope of the wall is increased due to the scour and occurrence of gravitational disconnection.

In addition, the walls with sticky clay fine materials are shed when floodwaters recede because of the rapid drainage of water and reduced shear strength of the soils of walls. Also, the walls composed of non-adherent material are at the risk of surface erosion. In the walls different from upper layers, the water flows from the river bank into the river with the rise in the level of the groundwater .

Water flow through the impermeable layers causes the materials of this layer to be washed and also causes the collapse of upper layers which in turn causes the erosion of walls. River bank erosion causes the reduction in the capacity of the rivers flood, reduction in the depth of the river, increase in the width of the river and eventually destruction of the agricultural lands bordering the rivers and destruction of the roads. Transfer of these sediments to the back of dams also reduces the reservoir capacity of dams and their life as well as inflicting damage to the facilities such as pumps and turbines. These problems cause a lot of irreparable damages.

Such problems make it necessary to conduct research in this field. On the other hand, if we can free up the flow of the river bend and to prevent erosion, we will automatically not have sedimentation in downstream and will be safe from its harmful effects. Figure 1 shows examples of the wall scour and increase in the width of the river in the 180-degree bends of Karoun River.

Figure 1. Example of 180-degree bends of the Karun River

Spur dikes are the structures constructed with the aim of diversion of flow from the erodible banks of river or provision of a proper way to direct the flow and to control the flood and in fact establishing a necessary depth for shipping purposes. These kinds of structures pave the way for the sedimentation between the spur dikes. Spur dikes are designed and constructed in a variety of shapes and types based on each case, river conditions and relevant objectives.

Although spur dike structures are constructed with the aim of sedimentation and preventing erosion of the sides and margins of rivers and also positioning of rivers, but they are under the influence of the erosion phenomenon caused by concentrated flow, especially at the spur dike head. In this part of the spur dike, localized increase in the flow velocity caused by the narrowing of the cross-flow and the occurrence of the falling rotational flow forms scour holes in the river bed improvement of which endangers the integrity of the structure.

Although, in most cases the blade spur dikes are used, but spur dikes with various forms of heads have also applications, among which trailing spur dikes, hockey shaped spur dikes, L-shaped spur dikes, T-shaped spur dikes and so on can be mentioned.

Spur dikes significantly affect the flow patterns through reducing the cross section of river. Flow lines will change their arrangement when approaching the spur dike structure. Different patterns of the spur dike are emerged at the spur dike head based on geometry, type of structure and other related specifications. Erosion in the spur dike head and sedimentation in downstream of spur dike follows the type and flow pattern. Vortex water flow in the effective level of spur dikes causes development of secondary flow and deposition of more coarse sediments in the lands along the river which is gradually led to the development of walls and its natural and biological stabilization. Figure 2 shows the effect of spur dikes and ineffectiveness of some of them on the scour of bends.

MATERIALS AND METHOD

Flow-3D Software used in this study is one of CFD software series. It is a suitable model for solving the complex problems of fluid dynamics and is able to model a wide range of fluid flow. The three-dimensional software is widely used to model free surface flows with complex geometry. In this software, equations of fluid are solved using finite difference (volume) approximations. Also, the environment is divided into a network with fixed rectangular cells where there is an average value of dependent quantities for each cell. Except for the velocity which is considered at the center of the cell dimensions, all variables are at the center of the cell. K-ε turbulence model was used to simulate turbulent flows.

Model geometry was defined in a manner in which the T-shaped spur dike was placed at the angles of 30, 45, 60, 75 and 90 degrees to the direction of flow, in a series at 180-degree bend. The initial conditions of this model were also applied to so that clear water fluid with a temperature of 20 ° C and a height of 0.22 mm was chosen. Meshing was also used in all areas of the bend according to the required high precision and high turbulence. In order to mesh the model, meshes with small size and high number, according to Figure 3, were used in the bends. Performed simulations include spur dike length (15 cm), angular position of the spur dike series in the bend (30, 45, 60, 75 and 90 degrees) and input discharge (18, 20, 22 and 25 liters/second).

RESULTS AND DISCUSSION

As can be seen in figures 4 and 5, the maximum speed limit and flow turbulence occur around the head of spur dikes. Also its maximum speed limits extend along the flow direction and these changes reduce from the angle of 30 degrees to the angle of 90 degrees while moving in the direction of flow and the highest turbulence is occurred around the head of the first spur dike which is located at the angle of 30 degrees from the bend and its minimum amount is at 90 degrees. Also, the maximum speed and strength of vortices in the head of spur dikes has the highest value (0.5) in the first spur dike and minimum value (0.2) in the last spur dike due to the existence of spur dike series at a 180 degree bend.

Therefore, we can conclude that the existence of a series of spur dikes at a 180 degree bend reduces the turbulence of the flow by 60 percent compared to the condition in which a single spur dike is used and consequently the rate of erosion of the walls is reduced. Hence it can be concluded that the flow turbulent and scour at the moderate180-degree bend is avoided only through placing two or three L-shaped spur dikes in a series at the first angles of 30, 45, and 60 degrees with a distance of 15 ° from each others and actually two other spur dikes (75 and 90 degrees) are ineffective because of the existence of the initial spur dike.

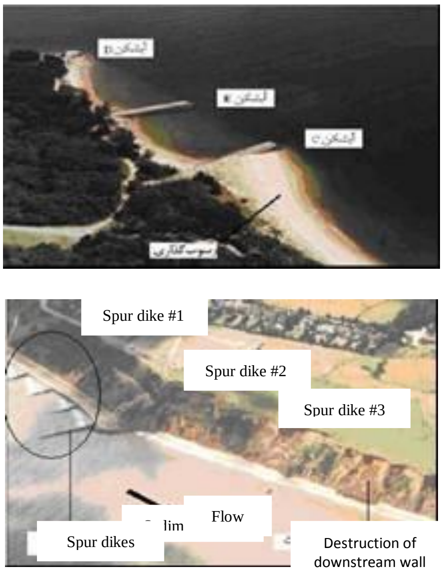

Figure 2. The effect of the spur dike series and ineffectiveness of some of them on the scour and deposition

The flow velocity at the upstream is zero after hitting the barriers such as the piers and spur dikes and it is divided into two parts similar to the jet stream and a vortex flow is created between the spur dikes which leads to the erosion and sedimentation in the area between the spur dikes. Being a barrier to the flow such as spur dike changes the flow pattern and results in erosion beneath the structures and near to the most of the heads of structures. This erosion occurs only around the mentioned structure. Hence, the resulted erosion is called localized erosion. Actually, this erosion is the result of three-dimensional turbulent flow which is constructed due to the acceleration of the flow and formation of complex vortex. Water hitting agent to the spur dike becomes a horseshoe vortex under a complex process and wake vortex is formed due to the separation of water from the spur dike.

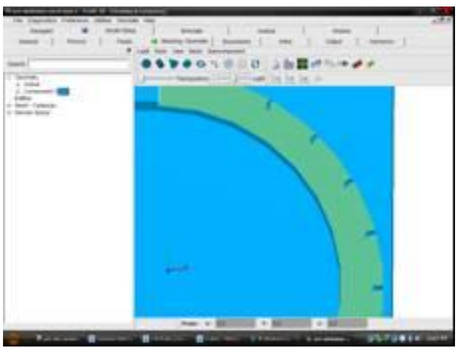

Figure 3. Meshing of the tested area and around a quintuple series of the spur dike in flow3D software

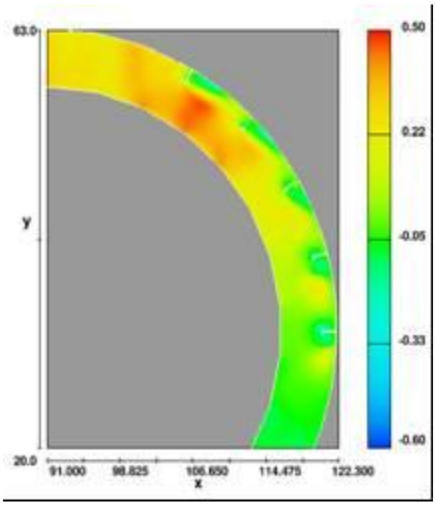

Figure 4. Distribution of speed around the spur dike series

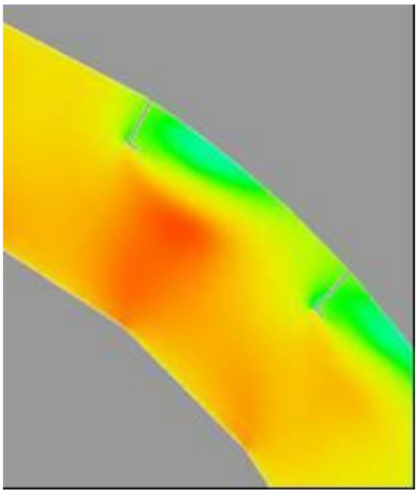

Figure 5. Speed distribution around two initial spur dikes

Because of the constant depth of flow, the velocity of the flow rises with the increase in the flow rate and the Froude number increases as well. With the increased velocity, the shear stress increases and strength of vortex near the substrate is enhanced and consequently scour at the head of spur dike and in the bed is increased. While assuming the constant size of spur dike in the direction of flow, the turbulence and flow around the head of spur dike increases with the increase in the Froude number and discharge.The process of scour is also increased in a similar trend.

Figures 6 and 7 show the effect of Froude number on the flow rate at the head of spur dike series.

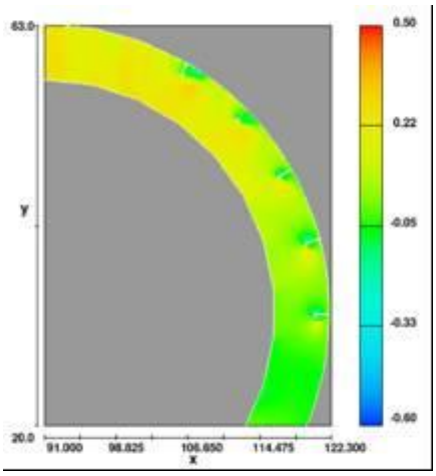

Figure 6. Distribution of the flow rate around the spur dikes with a discharge of 18 liters per second

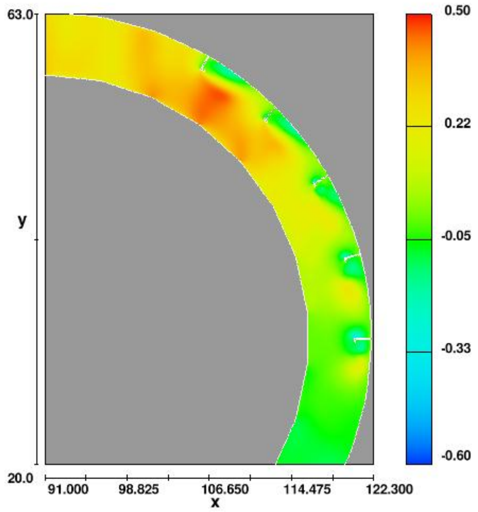

Figure 7. Distribution of the flow rate around the spur dike with a discharge of 25 liters per second

Figure 8 also shows the three-dimensional view of the flow velocity distribution around the spur dike series at a 180-degree bend in a numerical model.

Above results are consistent with the tests conducted in this field by other researchers and show that K-ε turbulence model has a good accuracy in the simulated return flow areas at the downstream of spur dike and the place of a vortex and turbulent flow around the spur dike. In Figure 9, scour around spur dike has a good accuracy. In Figure 9, scour around L-shaped spur dike is shown in the original model which has been drawn based on the maximum.

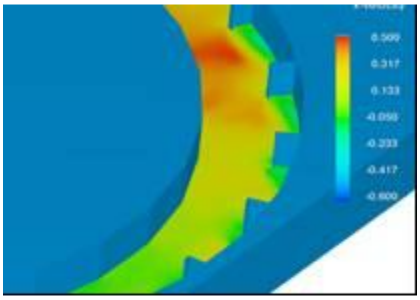

Figure 8. Flow pattern around the spur dikes in three dimensional form at numerical model

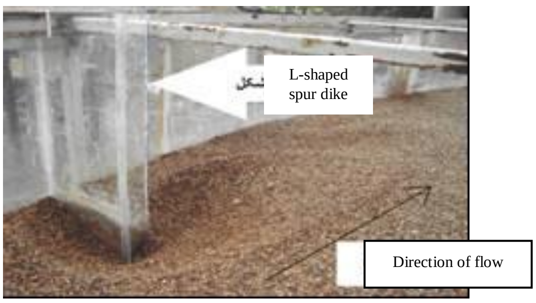

Figure 9. formation of scour and deposition around the spur dike in the original model.

CONCLUSION

Spur dike series in a 180-degree bend reduces flow turbulence by 60 percent compared to the condition when a single spur dike is used and consequently the rate of wall erosion is reduced.

Maximum speed limits , the flow rate and vortex flow at the head of spur dike series are reduced while moving along the direction of flow from the angle of 30 degrees to the angle of 90 degrees and the turbulence and scour at the moderate180-degree bend is avoided only through placing two or three L-shaped spur dike in a series at the first angles of 30, 45, and 60 degrees with a distance of 15 ° from each others and actually two other spur dikes (75 and 90 degrees) are ineffective because of the existence of the first spur dikes.

With increasing flow rate and Froude number, the maximum speed limit increases near the head of spur dike series and its shape is also elongated in the direction of flow. If there is a spur dike at the flow duct, the maximum flow velocity is occurred at the head of spur dike which has higher turbulence and velocity compared to the case without the spur dike.

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