Reduction of local scouring with protective spur dike

H.Karami [1], A.Ardeshir[2], M. Saneie[3], K. Behzadian[4], F.jalilsani[5]

[1] Ph.D. Student, Dept. of Civil Eng., Amirkabir Univ. of Tech., Tehran, Iran, Hkarami1359@yahoo.com
[2]Assistant Professor, Dept. of Civil Eng., Amir Kabir Univ. of Tech., Tehran, Iran,
[3] Assistant Professor, Soil Conservation and Watershed Management Research Center, Tehran, Iran.
[4] Ph.D. Candidate, Dept. of Civil Eng., Amirkabir Univ. of Tech., Tehran, Iran, [2]
[5] Lecturer, Dept. of Mechanical Eng., Amir Kabir Univ. of Tech., Tehran, Iran.

Abstract

One of the main parameters in design of spur dikes is the estimation of local scour depth around their tail. Spur dikes are usually built in series and their stability depends on the stability of the first spur dike. In this research, an experimental investigation is carried out in order to reduce local scouring around the first spur dike in a series of spur dikes (4 spur dikes). A smaller protective spur dike perpendicular to the flow direction is proposed to substantially reduce the local scouring. All experiments are performed in the experimental flume with moving bed. Also, all the spur dikes are rigid, and are made of pressurized plywood, straight and non-submerged. For various experimental lengths (L') and distances (X) of the protective spur dike, different value of relative velocity (u/u_c) is calculated. Finally, in favor of statistical analysis which has been done on the experimental data, an empirical equation for the relative scouring is derived.

Keywords: Spur Dike, local scouring, Experimental Study, statistical analysis.

Introduction

Spur dikes are man-made structures which are extended from the bank to the centre line with different angle to river direction. The main objective of constructing spur dike is to reduce flow velocities near the bank, which in turn encourages sediment deposition due to these reduced velocities. Increased protection of banks can be achieved over time, as some sediment is deposited behind the spur dikes. Sometimes, they are built to protect the fertile and valuable lands such as pertinent facilities that may exit near the banks. One of the important problems in spur dike design is a local scour around the spur dike. Many researchers have investigated the local scour around the spur dike, such as (Lacy 1930; Khosla 1936; Ahmad 1953; Liu et al. 1961; Garde et al. 1961; Gill 1972; Peterson 1986; Mellvile 1992; Kuhnle et al. 2002; Rahman 2003). As an example, Fig. 1 shows Stream flow pattern around spur dike.

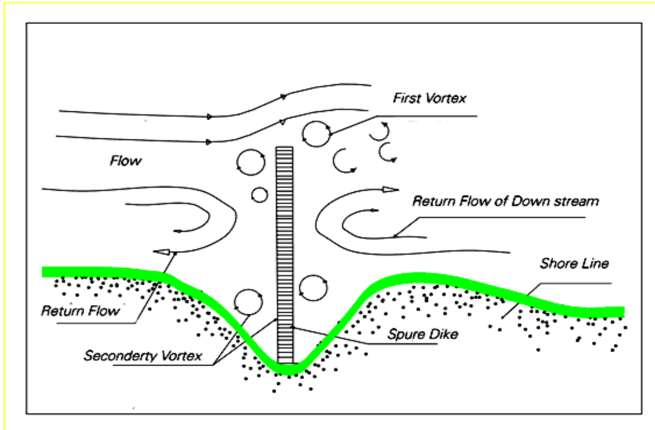

Fig. 1 Stream flow pattern around spur dike

One the problems involved in series spur dike is the insufficient protection of the first spur dikes, which will lead usually to the failure of such structures. Many methods exist to protect spur dike against local scour. In this paper, protection of series spur dikes are examined by making a *protective spur dike* located before the first spur dike in series in order to reduce local scour around the spur dikes. This is performed through a series of lab experiments in a smaller scale. Thus, different length of protective spur dike and its distance to the first series spur dikes are analyzed.

Dimensional Analysis

Dimensionless parameters can be generated by using Buckingum's- theorem. Based on the observation, the local scour depth around protective spur dike (d_3) and also the local scour depth around the first spur dike considering protective spur dike (d_2), with respect to the first spur dike without any protections (d_1) is estimated using Buckingham dimensional analysis as follows:

$$d_2/d_1 = f(L', L, u, u_{cr}, X, ...) \quad (1)$$

$$d_3/d_1 = f(L', L, u, u_{cr}, X, ...) \quad (2)$$

where L = length of the first spur dike; L' = length of protective spur dike; d_1 = local scour depth around the first spur dike without protective spur dike; d_2 = local scour depth around the first spur dike with protective spur dike; d_3 = local scour depth around protective spur dike; X is the distance between protective spur dike and first spur dike, u is flow velocity and u_{cr} is critical velocity (Fig. 2).

In this research some parameters is assumed to be constant such as S, L/B, α_g,… . Finally, the following equations can be derived as dimensionless terms:

$$d_2/d_1 = f(L'/L, X/L, u/u_{cr}) \quad (3)$$

$$d_3/d_1 = f(L'/L, X/L, u/u_{cr}) \quad (4)$$

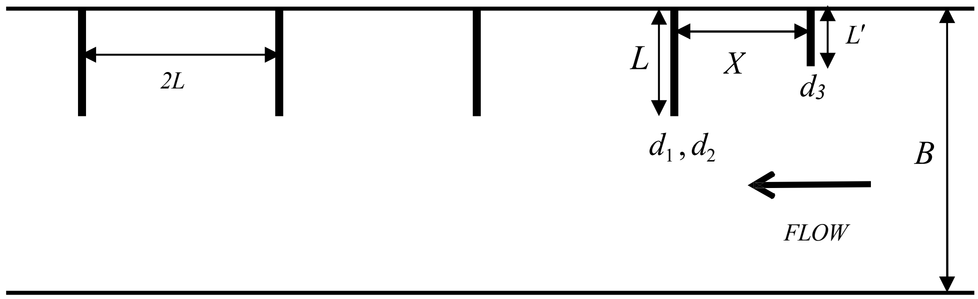

Fig. 2 Plan of spur dikes

Experiments

All of the experiments were accomplished in a flume located at the National Laboratory of Soil Conservation and Water Management Research Center in Tehran. The flume channel's specifications are as follows: 25 m length, 1.5 m width and 0.8 m depth. It has a constant slope of 0.001. The channel bed is covered with a relatively uniform–sized sand of 30 cm depth in all of experiments. The bed sediment has a median size (D_{50}) of 3 mm and geometric standard deviation ($\chi\rho_g = \sqrt{D_{84}/D_{16}}$) of 1.37.

There is a moving rail on top of the flume and a graded ruler with an accuracy of ± 0.5 *mm* for measurements of bed level variation and with 3 degrees of freedom (longitudinal, latitudinal and vertical directions). The discharge is measured using a sharp cross rectangular weir located at the end of the flume with a maximum error of ±0.4% and water level is measured using a point gauge with an accuracy of ±0.1 mm. (Fig. 3)

Fig. 3 Experimental flume components

The depth of water at downstream is regulated by flip gate. The spur dikes used in this research are rigid, straight and non-submerged. They are made of pressurized ply-wood with 20 mm thickness. Four spur dikes with equal distance, the first two spur dike's length and perpendicular to the flume's wall is used in this research (Fig. 2). After performing several experimental testes with different durations, it is observed that the local scour depth around the first spur dike after 40 minutes progresses slowly. Thus 40 minutes duration is considered for the rest of experiments. After finishing each experiment, the flume is drained in favor of a stilling basin. Then the local scour around of all spur dikes is measured. Here the assumed parameters introduced in Table 1 are used for all experiments. Furthermore, the length of main spur dikes is constant (450 mm), thus contraction ratio was 0.3 and the distance between them was 900 mm (2L) for all experiments.

Table 1.Experimental parameters

L (mm)	L' (mm)	X (mm)	u/u_{cr}
450	150,225,260,300	675,900,1125	0.7,0.8,0.9

Experimental observation

As mentioned earlier, the main purpose of this research is to determine the effect of length and distance of protective spur dike on local scour depth around the first spur dike. In the first test, the scour depths around first spur dike without protective spur dike under different velocity (u/u_{cr}) were measured. In the second phase, the test was performed considering protective spur dike and based on u/u_{cr} =0.7, 0.8, 0.9, L'/L = 0.33, 0.50, 0.58, 0.67 and X/L =1.5, 2, 2.5. Totally 36 experiments were accomplished. One sample of the observations is shown in Fig. 4. Fig. 5 shows the effect of protective spur dike on local scour around first spur dike. Using data obtained from observation and analyzing with surfer software, the two dimensional view of bed level and three dimensional scour profile are shown in Fig. 6.

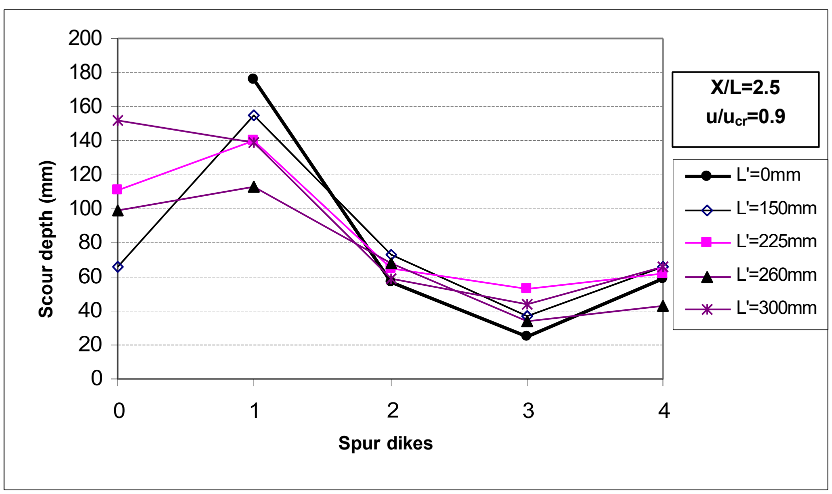

Fig. 4 Local scour depth around sequent spur dikes (X/L=2.5 , u/u_{cr}=0.9)
Note that spur dike with number of 0 is protective spur dike; Bold line (L'=0) is local scour depth around main spur dike without protective spur dike

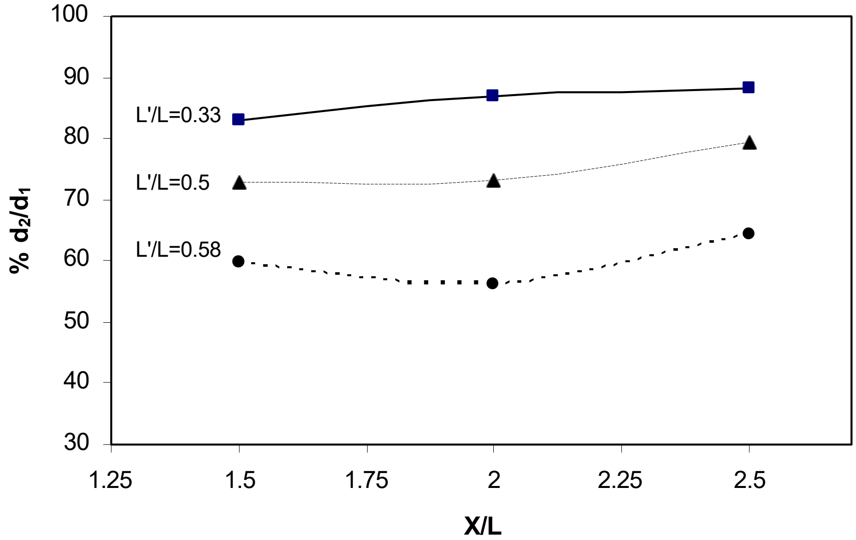

Fig. 5 Effect of X/L and L'/L on local scour around the first spur dike (u/u_{cr} =0.9)

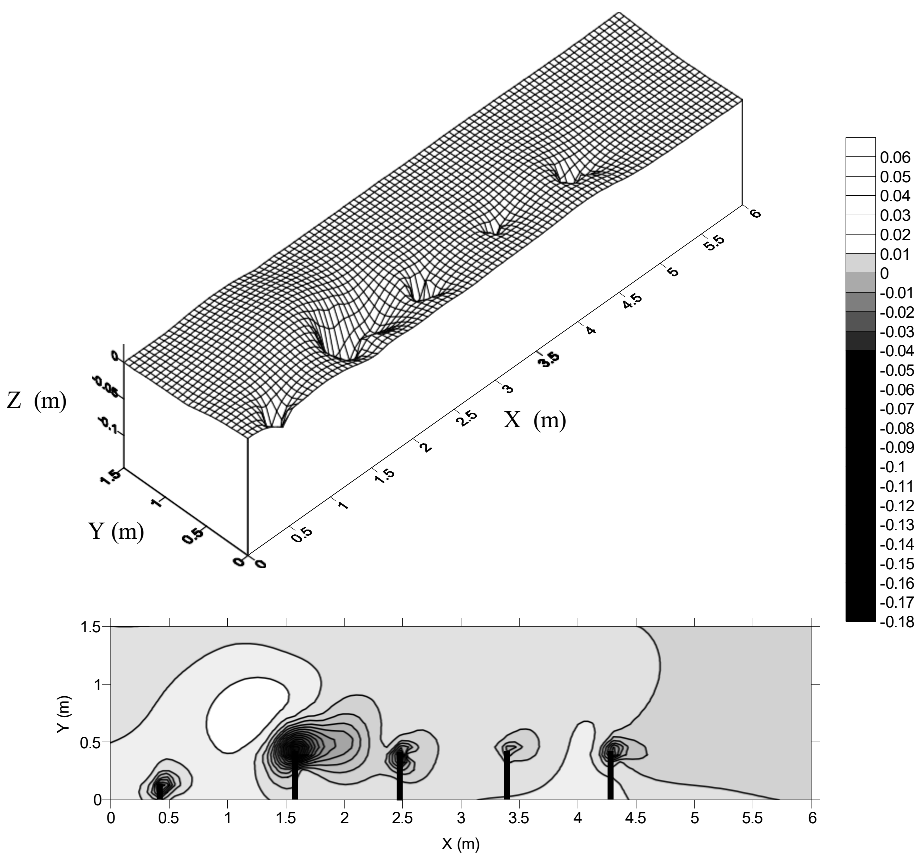

Fig. 6 Scouring profile around spur dikes (u/u_{cr} =0.9, L'/L=0.33, X/L=2.5)

Results

Regression analysis based on experimental observation shows the relationship between d_2/d_1 for different value of $X/L = (1.5 \quad 2)$ as shown in equation (5) with $R^2 = 0.66$ and also for d_3/d_1 in $X/L = (1.5 \quad 2.5)$ as shown in equation (6) with $R^2 = 0.75$.

$$\frac{d_2}{d_1} = 1.3\left(\frac{L'}{L}\right)^{-0.85}\left(\frac{X}{L}\right)^{0.001}\left(\frac{u}{u_{cr}}\right)^{2.59} \tag{5}$$

$$\frac{d_3}{d_1} = 7.5\left(\frac{L'}{L}\right)^{1.69}\left(\frac{X}{L}\right)^{0.05}\left(\frac{u}{u_{cr}}\right)^{3.17} \tag{6}$$

Comparisons between observation data for first and protective spur dike are shown in Fig.7 and 8.

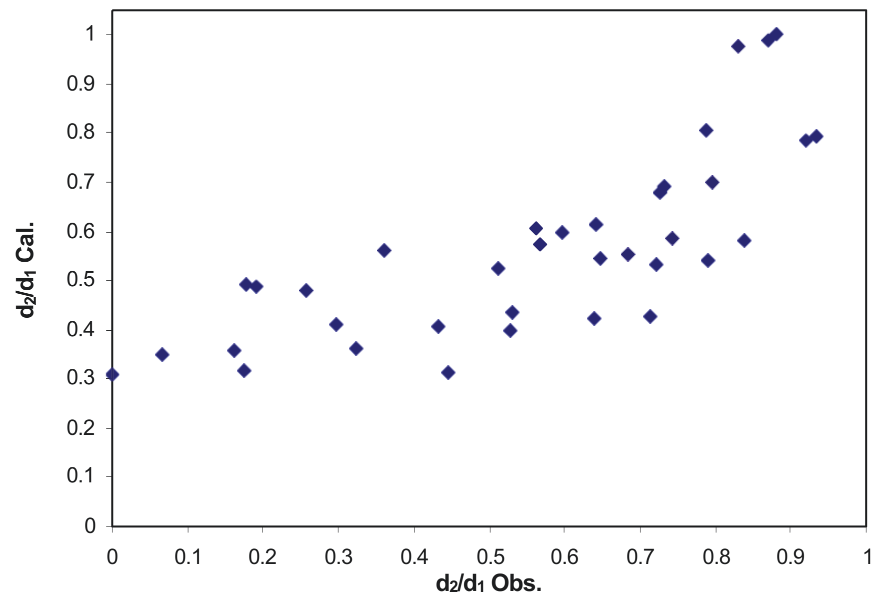

Fig. 7 Comparison between observed data and regression analysis (equation 5)

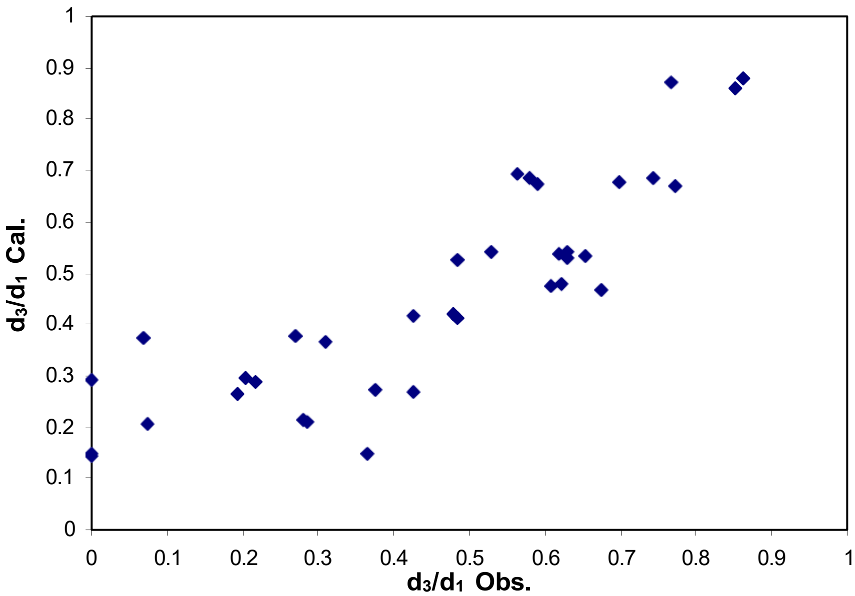

Fig. 8 Comparison between observed data and regression analysis (equation 6)

Based on the results of observation and data analysis using regression the following can be noted:

1- If L'/L increases (52 -100) percentage, d_2/d_1 decreases (30-45) percentage.

2- If X/L increases (33-67) percentage, d_2/d_1 increases (1) percentage.

3- If u/u_{cr} increases (15-29) percentage then d_2/d_1 increase (41-92) percentage.

4- If L'/L increases (52 -100) percentage, d_3/d_1 increases (100-230) percentage.

5- If X/L increases (33-67) percentage, d_3/d_1 increase (1-3) percentage.

6- If u/u_{cr} increases (15-29) percentage then d_3/d_1 decreases (53-122) percentage.

In addition, the following can be noted from bed profile analysis (Fig. 6):
- Shape of scouring hole is like a reverse cone that whenever depth is deeper then cone's radius becomes smaller.
- First spur dike has maximum scouring and fourth (i.e. last) spur dike has second maximum scouring.
- First spur dike causes flow to be diverted away from the wall therefore second spur dike has minimum scouring.
- In all of the tests performed the maximum scouring occurred near the upstream corner of every spur dike.
- Observation showed that the upstream slope of the hole (60-80 degrees) is steeper than downstream slope (30-45 degrees).

- Maximum amount of sediment aggregation occurred between the first and second spur dikes.

Summary and Conclusion

This paper presented the effect of protective spur dike on local scour around the first spur dike in a series of spur dikes. The results recommended the length of protective spur dike (L') between 0.5 and 0.58 of L; and the distance between protective spur dike and first spur (X) in the range of $X = (1.5 \quad 2)L$. The experimental findings indicate the use of protective spur dike can effectively decrease the amount of erosion and scouring at the first spur dike. It is noticed that the economical investigation of the cost of replacing the spur dike and damage to the shoreline needs to be taken into account in some real scenarios in the future researches.

Notation

The following symbols are used in this paper:

B = wide of the flume;

D_{50} = diameter of grain which is finer than 50%;

D_{84} = diameter of grain which is finer than 84%;

D_{16} = diameter of grain which is finer than 16%;

d_1 = local scour depth around the first spur dike with out protection;

d_2 = local scour depth around the first spur dike with protective spur dike;

d_3 = local scour depth around the protective spur dike ;

L = length of first spur dike;

L' = length of protective spur dike;

Q = discharge;

S = bed slope;

X = distance between protective spur dike and first spur dike;

u = flow velocity;

ucr =critical velocity;

α_g = standard deviation of bed material sediment.

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