THE EFFECT OF MINOR SPUR DIKE ON SCOURING AT THE FIRST SPUR DIKE IN THE GRAVEL BED

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ABSTRACT
Spur dikes are the most important river training structures. The main reasons for their usage are redirecting the flow of water and preserving the desired depth of a river or channel. Diversification of the flux is also a very important goal for spur dike planning. An experimental look on the effect of length and orientation of minor spur dike on scouring at the first spur dike in the gravel bed is presented in this paper. One of the important problems in spur dike design is a local scouring at the head of spur dike. This phenomenon is derived by area contraction and powerful vortex. This study is performed in the experimental flume. The spur dike used in this study was rigid, made of pressurized ply wood, straight and non-submerged. Four spur dikes with distance equal two times the first spur dike's length and perpendicular to the flume's wall are used in this study. Three different discharges are used in the gravel bed with constant slope. In all of the experimental studies performed, the method of reducing scouring at the head of spur dike and how the minor spur dike in the upstream end, can decrease the erosion at first spur dike is investigated. The ratio between lengths of minor spur dike to first spur dike length was recognized as a very important feature that results in preserving the head of the spur dikes from scouring.

Keywords: *Gravel bed, Spur dike, Scouring, Minor, Experimental model.*

INTRODUCTION

A spur dike may be defined as a structure extending outward from the bank of a stream for the purpose of deflecting the current away from the bank to protect it from erosion. In addition to bank protection, spur dikes have also been used to enhance aquatic habitat by creating stable pools in unstable streams. The volume of local scour in the vicinity of a spur dike is difficult to estimate accurately. Most investigations in this field have measured the maximum depth of scour. Many studies have been made which measured the scour depth associated with spur dikes. Different experimental results often do not match well; the dependence of phenomena on some parameters whose effect is probably not of secondary importance is still not well defined. As a consequence, scour predictions for spur dikes can be affected by significant errors. Preliminary evaluations have shown that this procedure might significantly overestimate the actual scour depth.

The flow hydraulic parameters have important effect on the erosion and protection of rivers. Increased velocity, discharge, shear stress and vortex cause bed and wall scouring (Azinfar H. and Kells[1)], Giuseppe O.et.al.[2)]; Pinter. N.[3)]).

One of the methods in coastal protection is building spur dikes and sub-merged Vanes structures that affect the streamlines and cause the flow toward thalweg of the river path (Ettema, R., and Muste, M.[4)]). Therefore, by reducing velocity impact from the shores it will increase the sediment aggregation on the river sides. In the natural rivers the most erosion occurs due to extreme events, especially at the time of heavy flooding (Hager, W. H., et al.[5)]). The stability of the first spur dike may be in danger and its structure may fail which will cause the river bank protection to be demolished (Kothyari, U. C., and Ranga Raju, K. G.[6)]).

In Iran, lack of protection of the first spur dikes and improper placement at river banks have caused the failure of these devices which were aimed at protecting the fertile and valuable lands and other pertinent facilities that may exit near the banks. Therefore, to investigate the reduction of scouring around the head of the first spur dike by a minor spur dike, a series of experiments were conducted in a smaller scale.

In our investigation it was realized the local scouring is of paramount importance. So, the research conducted emphasizes the protection needed for the first spur dike. Many researchers have investigated the cause of local erosion at the head of first spur dikes, (e.g.) Kuhanle, et.al.[7], have studied the effectiveness of orientation of spur dike with river banks, which they assumed to be 90 degrees with river flow. Also Soliman et. al.[8] studied the effect of length of spur dike with respect to river morphology on the Nile River. Oliveto, G., and Hager, W. H.[9] studied the effect of time on scouring depth .Mohan et. al.[10] and Elawady et. al.[11] evaluated the minimum height to the impervious spur dike and the distance of submerged spur dikes for shore protection .Peterson[12] in her findings suggested distance between two consecutive spur dikes should vary between 1.5 to 6 times the lengths of the upstream spur dike. Using her suggestions for this study, the distance between spur dikes are fixed at 2L (L= spur dike length) for the following experiments. Liu[13], Baosheng[14], Rajaratnam, N., and Nwachukwu, B. A[15], Jain S. C.[16], Chang[17], Rahman, M. M. et. al.[18] and Rahman, M. M. et. al.[19], Franzett and Wang[20] measured the maximum depth of scouring at the head of spur dike in a series of spur dikes.

To further enhance the capability of spur dike for damage protection from the previous studies, we proposed to find means for protection of the first spur dike. Therefore, minor spur dikes with different lengths at appropriate distances from the first one are investigated.

EXPERIMENTAL SET UP

The experimental flume has a length of 25m, width of 1.5m and depth of 0.8m.It has a constant slope of 0.001. The depth of water at downstream is regulated by flip gate having equal with the flume. Two models of spur dikes were used in the study, minor spur dikes and main spur dikes. Main spur dike's length was 0.45 m. The lengths of the minor spur dike were L' = 0.33, 0.50, 0.66 of L. Four spur dikes with distance equal two times the main spur dike’s length and perpendicular to the flume’s wall were used in this study, as main spur dikes. While one minor spur dikes with different lengths was placed at upstream end of the main spur dikes at intervals X equal to 1.5, 2 and 2.5 times the length of the main spur dikes and placed in an angle with first one as shown in (Fig. 1) the spur dikes were rigid, made of pressurized ply wood, straight and non-sub merged and had similar shape.

The physical parameters of the flume are as follows: B is the flume width, L is the first spur dike Length, L' is the length of minor spur dike, d_1 is the scour depth at the head of first spur dike without minor spur dike, d_2 is the scour depth at the head of first spur dike with minor spur dike at upstream, X is the distance between minor spur dike and the first spur dike. Test condition are shown indicated in table 1.

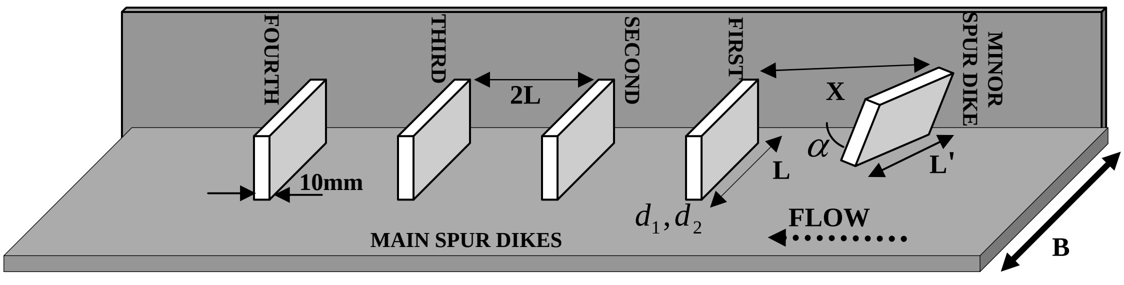

Fig.1 Definition sketch

Table 1 Test conditions

B(m)	Y(mm)	U(m/s)	U_C (m/s)	X/L	L(mm)	L'(mm)
1.50	76,98,117	0.612,0.625,0.646	0.680	1.5,2,2.5	450	150,260,300

Flow rate was measured using a sharp cross rectangular weir located at upstream end of the flume with a maximum error of $\pm 0.4\%$ and flow depth was controlled by measuring water level using a point gauge with an accuracy of $\pm 10mm$.

Relatively uniform-sized sand and gravel covered 6 m of the channel bed in all of the experiments. These particles had a density of $(\rho_s)2650kg/m^3$ and a mean size diameter (d_{50}) of 1 and 3mm, and standard deviation of sediment grading, σ_g as defined below equals1.25mm.

$$\sigma_g = \left(\frac{d_{84}}{d_{16}}\right)^{0.5} \qquad (1)$$

Where, for example, d_{84} is the size of sediment for which 84 percent of materials by weight are finer.

Therefore, the grain size could be considered as approximately uniform size.

After installing the spur dikes in their places, Bed-surface profiles were collected using measurement devices were mounted on an instrument carriage that traveled on steel rods over the channel. There was a graduated rod with an accuracy of $\pm 0.5mm$ collected bed topography, with 3 degrees of freedom (longitudinal, latitudinal and vertical directional). After several experimental tests ran with different durations it was observed after 4 hours local scour depth near the spur dike was occurring at much slower rate. Thus the 4 hours duration were taken for of the following experiments.

The following procedure was used for each experimental run. Before the run with the spur dike model in place, the sediment bed surface was leveled with a scraper blade mounted on a carriage that rode on the rails. After the bed was completely wetted and drained, a profile of the bed surface was collected. The flume was filled with water to obtain the desired depth. Before the pump was started, an initial set of transects of the scour region were collected. Next, the pump was started and the speed adjusted to obtain a bed shear velocity ratio of 0.9-0.95 times the critical value for the bed sediment for the approach flow as predicted from a modified form of the Shields curve (Miller et al.[21)]). These values were chosen to maintain conditions of clear water scour. The same rate of flow and approach depth was maintained for the entire experimental run. As the bed was completely wetted and drained, transects of the scour region were begun. For the next experiment, the bed material was refurbished to the original state and the next experiments were performed.

ANALYSIS OF EXPERIMENTAL DATA

The aims of the investigation were to determine the effect of length and orientation of minor spur dike on the first dike to minimize the scouring at the head of the first spur dike. The experimental results were based on $d_{50} = 3mm$ and the ratio of minor to first spur dike $\left(\frac{L'}{L}\right)$ of 0.33, 0.50, and 0.66 (fig.1). The result of maximum scouring depth for the first spur dike without minor one is shown in table2.

Table 2 Maximum scouring at the head of first spur dike without minor spur dike for various flow depths

$Y(mm)$	76	98	117
$d_1(mm)$	74	136	176

The first series of experiments were conducted for three different geometrical lengths of minor spur dike $\left(\frac{L'}{L}\right)$. Second series were based on three locations of minor spur dike $\left(\frac{X}{L}\right)$.

Each of the first and second series was carried out with three different discharges, totaling 27 experiments in all. Scour reduction was occurred at the head of main spur dikes presented in (Table 3.) comparing with unprotected spur dikes. In all of the tests performed the maximum scouring occurred near the upstream corner of every spur dike.

Considering (Table 3.) the first spur dike is the first priority for protection and other spur dikes are secondary. Also Maximum amount of sediment aggregation occurred between first and second spur dikes**.**

Table 3 Scour Depth Reduction for main spur dikes using minor spur dike

Test number	Y(mm)	X/L	L'/L	Main spur dike scour reduction (%)			
				1st spur dike	2nd spur dike	3rd spur dike	4th spur dike
1	76	1.50	0.33	19.51	22.50	18.67	15.50
2	76	1.50	0.50	22.68	25.50	20.00	21.00
3	76	1.50	0.66	12.76	18.25	14.33	12.85
4	98	1.50	0.33	19.35	16.67	19.03	16.30
5	98	1.50	0.50	21.62	24.58	21.38	20.86
6	98	1.50	0.66	13.47	14.67	17.14	14.65
7	117	1.50	0.33	17.50	19.08	19.00	16.56
8	117	1.50	0.50	21.50	22.07	21.00	18.64
9	117	1.50	0.66	15.05	15.61	15.13	14.86
10	76	2.00	0.33	24.32	27.50	26.67	18.75
11	76	2.00	0.50	27.43	30.00	33.33	26.25
12	76	2.00	0.66	17.57	20.50	18.00	15.00
13	98	2.00	0.33	22.29	22.58	28.62	19.91
14	98	2.00	0.50	25.44	30.42	32.07	25.26
15	98	2.00	0.66	18.56	17.50	25.17	17.12
16	117	2.00	0.33	22.82	22.67	24.46	21.39
17	117	2.00	0.50	26.22	28.60	27.00	25.18
18	117	2.00	0.66	19.93	19.00	19.21	17.25
19	76	2.50	0.33	15.51	16.88	16.67	13.60
20	76	2.50	0.50	17.57	22.50	19.33	17.50
21	76	2.50	0.66	10.35	12.25	11.67	11.63
22	98	2.50	0.33	14.47	14.58	16.24	13.30
23	98	2.50	0.50	16.15	20.00	18.48	16.70
24	98	2.50	0.66	10.06	12.25	14.83	12.33
25	117	2.50	0.33	13.13	15.33	13.13	12.86
26	117	2.50	0.50	15.89	21.67	16.69	16.56
27	117	2.50	0.66	11.00	12.00	11.13	10.08

RESULTS

The experimental results showed a range of intriguing morphological features in the sediment beds around spur dykes.

The findings include the following:

- Shape of scouring hole is like a reverse cone geometrically that the deeper the depth is, the smaller the cone's radius is. Observation showed, the upstream slope of the hole (55-60 degrees) is steeper than downstream slope (27-35 degrees).
- First spur dike has maximum scouring and fourth spur dike has second maximum scouring (Table 3.).
- Minor spur dike has insignificant scouring.

CONCLUSIONS

Minor spur dike are used on upstream of main spur dikes in group to reduce local scouring. Minor spur dike diverts the flow and protects the head of spur dike from its direct impact. In this paper application of minor spur dike are studied on group of four spur dikes. Three different lengths of minor spur dike were considered with three different flow depths in the gravel bed. Minor spur dike was installed at the upstream of main spur dikes in three different spacing.

Experiments were continued until change in scour depth in the deepest scour hole was 90% of maximum scouring was expected based on the results of the long-term experiment. All tests were carried out at the threshold of bed material motion at which the maximum depth of the scour hole is expected. However according to Raudkivi and Ettema[22], a second peak may also exit at higher flow velocities. Moreover Chiew[23] explains that when general sediment transport occurs, through of migrating bed forms may lowers effectiveness of protection. Therefore, performance of minor spur dike in live bed condition needs further attention and research. Additional experiments are necessary to verify the present observations on a wider variety of flow conditions, especially for different b/B and y/d50 values.

Minor spur dike was effective on group of spur dikes compared to unprotected spur dikes. It reduced the scour rate at the head of spur dikes between 10 and 33.33%. Minor spur dike had a better efficiency when located at X/L=2.00 upstream of group of spur dikes with L'/L=0.50.

NOTATION

B = Flume width;

$b =$ flow concentration parameter;

d_1 = Scour depth at the head of first spur dike without minor spur dike;

d_2 = Scour depth at the head of first spur dike with minor spur dike;

d_{50} = Median grain size of sediment;

d_{84} = the size of sediment for which 84 percent of materials by weight are finer;

d_{16} = the size of sediment for which 16 percent of materials by weight are finer;

Fr = Froude numbre;

σ_g = Standard deviation of bed material sediment;

L = First spur dike Length;

L' = Length of minor spur dike;

ρ_s = Particle's density;

$R^2 =$ Regression coefficient;

S = Bed slope;

X = Distance between minor spur dike and the first spur dike;

Y = Flow depth;

α = Angle of minor spur dike to first spur dike.

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