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MOVABLE BED SCOUR AROUND SUBMERGED SPUR-DIKES

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This paper presents the results of an exploratory study on scour occurring around submerged spur-dike. The effect of flow depth and spur-dike dimensions was studied with the help of the experimental data. It was found that the overtopping ratio and the opening ratio are significantly affected on the maximum scour depth. The larger opening ratios (α) caused relatively small scour area and the bank erosion downstream the spur-dike hardly can occur. The longer spur-dike length & the lower flow depth produced scour area wider than the shorter spur-dike length & the higher flow depth. The data collected in this investigation would be useful for the development of numerical models of scour around submerged dikes.

Key words: *Open channel flow, submerged spur-dikes, local scour and maximum scour depth.*

1. INTRODUCTION

Local scour around any obstruction placed in an alluvial channel is of great importance to hydraulic engineers. To be able to design a safe and economic structure, it is important to have a clear picture of scour phenomenon around these obstructions1). In order to study some of the variables governing the depth of scour around river structures such as spur-dikes, investigations were conducted at the Hydraulics Laboratory of Tottori University, Japan.

Spur-dikes are a kind of river training works constructed at an angle to the flow direction beginning at the regulation line with a head2). Spur-dikes are frequently used in rivers to guide the flow, protect banks from erosion and improve navigation channels3).

As the water flows around the spur-dike, the flow pattern is changed due to the reduction of the width of channel, and the shear distribution around the spur-dike is modified. This leads to scouring action until equilibrium is established between the various forces influencing the scouring action1).

Local scour at piers, abutments and spur-dikes has been studied in detail by many researchers in the last few decades4). Contributions by Ahmad (1953)5), Laursen (1960)6), Grade (1961)1), Awazu (1967)7) and Gill (1972)8) are among the notable earlier studies. Recent studies include Zaghloul (1983)9), Rajaratnam (1983)3), Michiue (1984)10), Melville (1988, 1992)11),12), Kandasamy (1998)13), Lim (1997)4), Rahman (1998, 1999)14),15), Fukuoka (1998)16), Ohmoto (1998)17) and Kuhnle (1999)18).

Most experimental studies concerning local scour around spur-dikes have used flow depths that were less than the height of the spur-dike model. The previous submerged groins studies mentioned here were considered groins in series with constant overtopping ratio (h/d).

The focus of this study was on characterizing local scour around submerged spur-dike in general and the maximum depth of scour in particular. Attention was focused mainly on the dimensions of the spur-dike (overtopping ratio & opening ratio) and the depth of flow upstream of the spur-dike.

2. PURPOSE AND LIMITATIONS

The purpose of this investigation was to study the variation of the local scour under the following limitations:

- A single submerged spur-dike placed at the left sidewall of the flume with angle equal 90° to the flow direction was considered.
- The opening ratios ($\alpha = \frac{Bh - bd}{Bh}$) used were varied from 0.77 to 0.98.
- The overtopping ratios (h/d) used were varied

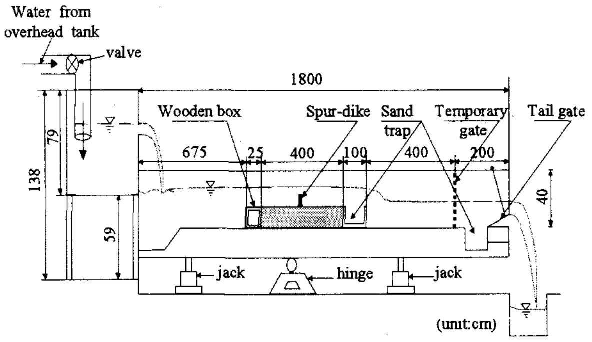

Fig. 1 Details of the experimental set-up

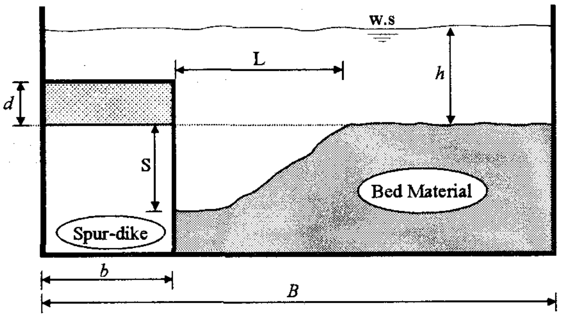

Fig. 2 Cross section at the nose of the spur-dike

Table 1 Flow characteristics and boundary conditions

Case No.	Run No.	d (cm)	b (cm)	h (cm)	Q (m^3/s)	h/d	α	S (cm)
1	1-1	2.5	5	5	0.0073	2.0	0.94	7.04
	1-2	2.5	5	6	0.0090	2.4	0.95	6.88
	1-3	2.5	5	7	0.0104	2.8	0.96	5.58
	1-4	2.5	5	8	0.0120	3.2	0.96	5.77
	1-5	2.5	5	10	0.0145	4.0	0.97	5.75
	1-6	2.5	5	13	0.0187	5.2	0.98	5.39
2	2-1	2.5	10	5	0.0073	2.0	0.88	8.87
	2-2	2.5	10	6	0.0090	2.4	0.90	9.79
	2-3	2.5	10	7	0.0104	2.8	0.91	8.17
	2-4	2.5	10	8	0.0120	3.2	0.92	8.29
	2-5	2.5	10	10	0.0145	4.0	0.94	7.70
	2-6	2.5	10	13	0.0187	5.2	0.95	6.28
3	3-1	2.5	15	5	0.0073	2.0	0.81	12.01
	3-2	2.5	15	6	0.0090	2.4	0.84	9.49
	3-3	2.5	15	7	0.0104	2.8	0.87	10.78
	3-4	2.5	15	8	0.0120	3.2	0.88	8.95
	3-5	2.5	15	10	0.0145	4.0	0.91	7.85
	3-6	2.5	15	13	0.0187	5.2	0.93	6.90
4	4-1	5.0	10	6	0.0090	1.2	0.79	13.23
	4-2	5.0	10	8	0.0120	1.6	0.84	11.50
	4-3	5.0	10	10	0.0145	2.0	0.88	11.28
5	5-1	7.5	10	8	0.0120	1.07	0.77	13.20
	5-2	7.5	10	10	0.0145	1.33	0.81	13.67

from 1.07 to 5.2.

- A constant bed shear stress was considered in all cases ($\tau_* = 0.079$).

3. EXPERIMENTS

(1) Experimental set-up

The experiments were conducted in a tilting steel flume 0.4m wide, 0.4m deep and 18m long. The flume is supported in the center at one point and on the ends by two screw jacks that allow the channel slope to be adjusted. The central 8m of the flume is equipped with transparent walls. The water is supplied to the system from a constant head, overhead tank through a 0.2m diameter delivery pipe. A valve fitted in the delivery pipe controls the discharge. Flow rate in the flume was measured using a triangular weir that was calibrated prior to the experiment. One size of sand was used in the experiments reported herein. The mean size of the sand was measured to be 0.75mm. A uniform bed material was set 7m downstream of the entrance, and covered 4m with a thickness of 0.15m in all cases of the experiments. Acrylic sheets were used to model different spur-dikes, which locates in the middle of the sand bed area 9m downstream of the entrance with angle equal 90° to the flow direction. Bed surface profiles were measured using electric resistance bed profiler, and the measurements recorded with under flow condition. The details of the experimental set-up and cross section at the nose of the spur-dike are shown in **Fig. 1** and **Fig. 2** respectively.

(2) Experimental conditions

On the study of bed characteristics and maximum scour around submerged spur-dikes, the following are the basic conditions set for the study:

- The study was carried out with uniform bed material having the mean diameter of 0.75mm.
- The Froude number of the flow was kept below 1.0, in this series of experiments it was varied from 0.32 to 0.52.
- Shear velocity ($u_* = \sqrt{ghI_e}$) at 50cm upstream the spur-dike was kept constant in all cases with value 0.031 m/s. Energy gradient (I_e) was measured using Manning formula.
- The discharge was varied from 0.0073 to 0.0187 m^3/s, which gives flow depth varied from 5 to 13cm.
- The heights of the spur-dike above the bed material were 2.5, 5 and 7.5cm. The thickness of the spur-dike was 1.5cm in all cases and the spur-dikes projected a perpendicular distance of 5,10 and 15cm into the channel.

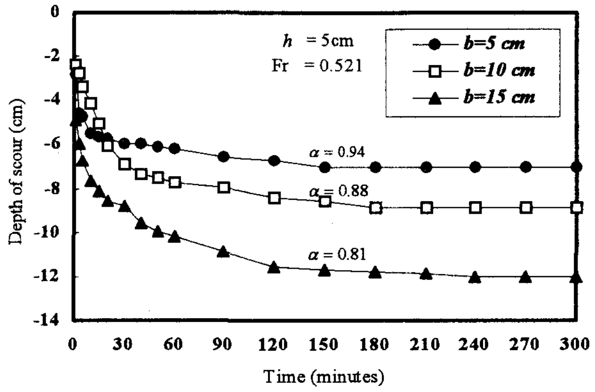

Fig. 3 Development of scour hole

- The slope of the bed surface was 1/2500, and Manning roughness was 0.014 in all cases.

The experimental conditions and the flow characteristics are summarized in **Table 1**.

(3) Experimental procedure

Before the beginning of the experiments, the flume was examined to adjust the required slope that gives the uniform flow conditions far upstream. The suitable longitudinal surface slope was found to be 1/2500. A single spur-dike was fixed to the left sidewall of the flume in the appointed position. A 15cm thick bed material was laid into the flume and leveled to make the sand bed surface parallel to the channel bottom. The sliding point gauge was used to check the horizontal bed surface at different locations. Before each run the tailgate was adjusted to a suitable level to give a considered flow depth, which keep the shear velocity constant in all cases with different discharges. A temporary wooden gate was set 16m downstream of the entrance to keep the flow rate constant without any disturbance to the bed material before each run. The runs started by slowly allowing the water to flow over the horizontal bed until it reaches to the height of the temporary gate. The discharge valve was slowly adjusted to give a supply of the flow required for each run. Then a temporary gate was opened slowly and completely, so that there was no effect in the flow and the bed surface level, and almost no scour happened before achieving the desired water depth; thereafter the timer was switched on.

The bed readings at the nose of the spur-dike were taken at various time intervals to get the rate of scour. The run was continued until the bed reading at the nose of the spur-dike changed so slowly with time nearly up to 300min. After recording the maximum scour depth, a temporary gate inserted again so that the scour pattern was not disturbed. Measurements of scour were taken at close intervals around the spur-dike and at less-closer spacing far upstream and downstream of the flume. After completing one run, the flume then was prepared for another run with same procedures. 5 experimental cases with 23 experimental runs were conducted having different initial arrangements.

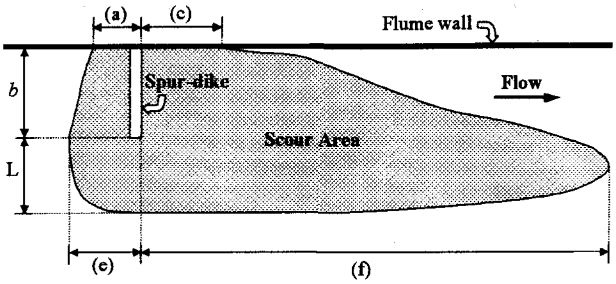

Fig. 4 Geometry of scour hole

Table 2 Geometry of scour as ratio of spur-dike length

Case No.	Run No.	*b* (cm)	L (cm)	L/S	L/*b*	S/*b*	(a)/*b*	(c)/*b*	(e)/*b*	(f)/*b*
1	1-1	5	10	1.42	2.00	1.41	2.8	1.6	2.4	4.6
	1-2	5	10	1.45	2.00	1.38	2.6	3.0	2.2	8.4
	1-3	5	9	1.61	1.80	1.12	2.4	0.6	2.0	2.4
	1-4	5	8	1.39	1.60	1.15	2.5	0.6	2.0	1.8
	1-5	5	7	1.22	1.40	1.15	2.4	0.6	2.0	2.2
	1-6	5	7	1.30	1.40	1.08	2.4	0.0	2.0	2.4
2	2-1	10	12	1.35	1.20	0.89	1.9	0.7	1.5	10.0
	2-2	10	13	1.33	1.30	0.98	2.0	0.9	1.7	4.5
	2-3	10	11	1.35	1.10	0.82	1.8	0.1	1.6	4.1
	2-4	10	11	1.33	1.10	0.83	1.7	0.2	1.5	2.1
	2-5	10	10	1.30	1.00	0.77	1.8	0.0	1.4	2.8
	2-6	10	7	1.12	0.70	0.63	1.3	0.0	1.2	2.5
3	3-1	15	21	1.75	1.40	0.80	1.7	0.1	1.5	6.7
	3-2	15	15	1.58	1.00	0.63	1.3	0.0	1.1	6.7
	3-3	15	16	1.48	1.07	0.72	1.5	0.0	1.3	4.2
	3-4	15	11	1.23	0.73	0.60	1.2	0.0	1.0	2.3
	3-5	15	9	1.15	0.60	0.52	1.0	0.0	0.9	1.9
	3-6	15	6	0.87	0.40	0.46	1.0	0.0	0.7	0.3

4. RESULTS AND ANALYSIS

(1) Development of scour hole

The scour depths as a function of time for various opening ratios are shown in **Fig. 3**. It was found that maximum scour depth was attained after 150min in case of high opening ratio ($\alpha = 0.94$) and after 240min at $\alpha = 0.81$. Then the observing of the scour depth was too slow towards to the equilibrium phase after time nearly up to 300min. That variance in maximum scour depths observed in each case was because of the different parameters examined in each investigation.

(2) Geometry of scour hole

Geometry of scour hole is presented in **Fig. 4** and

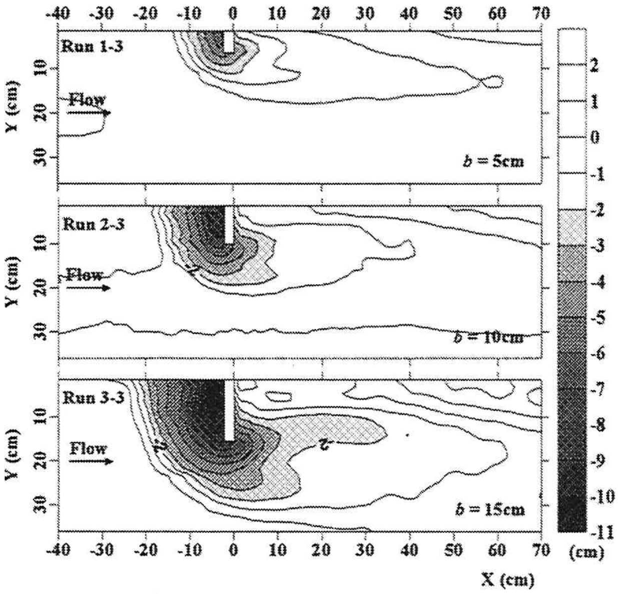

Fig. 5 Scour pattern around dikes with different lengths (b)

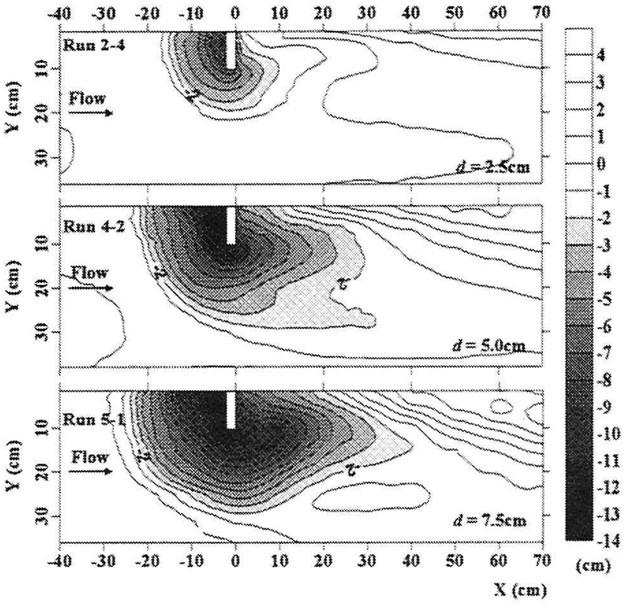

Fig. 6 Scour pattern around dikes with different dike heights (d)

Table 2. In all cases, the observed maximum scour depth located upstream the spur-dike and close to the channel's sidewall. The scour hole upstream of the spur-dike was conical in shape, whereas downstream, it was elongated and had a shallower slope. It was further found that the width of the scour hole (L) in front of the spur-dike had consistent correlation with the maximum scour depth (S). The value of (L/S) varied from 0.87 to 1.75 and had systematic correlation with the overtopping ratio, opening ratio and the Froude number. However, the average value of (L/S) was about 1.4, which gives a slope very close to the angle of repose of the sand used in the channel bed (30°). The ratios of the maximum width L/b, and the maximum scour depth S/b tend to be larger for the 5cm length spur-dikes. Upstream extents (a)/b & (e)/b ratios of scour holes do not vary greatly with different flow depths (h) in each case. However, these ratios tend to be smaller for the 15cm long spur-dike. The distance of the starting point of the scour hole downstream of the spur-dike near to the sidewall (c)/b is seen to go to zero for some runs with high overtopping flow ratios (h/d) and almost all runs of case 3. This means that bank erosion will not be a problem under these conditions in downstream area, but it may occur in upstream area as observed in (a)/b ratios. Downstream scour length ratios (f)/b has large values for the runs with low overtopping ratios (h/d) in each case. That was the effect of the dimensions of the spur-dike model used in each investigation.

(3) Scour pattern for different parameters

Scour pattern around spur-dikes with different lengths (b), different heights (d) and different flow depths (h) are shown in **Fig.5**, **Fig.6** and **Fig. 7** respectively. Elevations are in cm, contour interval is 1cm, and elevation of initial bed surface was 0.0 and elevations less than –2cm are shaded.

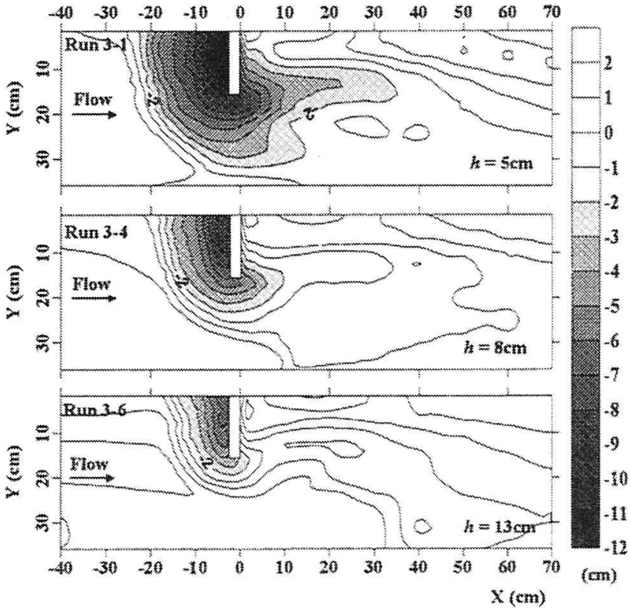

Fig. 7 Scour pattern around dikes with different flow depths (h)

The runs with larger spur-dike length, higher spur-dike height and lower flow depth produced scour area wider than the one with smaller spur-dike length, height and higher flow depth. The larger opening ratios (α) caused small scour area and the bank erosion downstream the spur-dike hardly can occur. In all runs, the upstream portion of the scour hole has the approximate form of an inverted cone. The vortex of the cone represents the greatest depth of scour and it is found to locate upstream the spur-dike close to the sidewall of the channel. Whereas downstream, the elongated scour area was related to the spur-dike length, height and the flow depth in each run.

Also, it is observed that the transport of sediment was limited only around the spur-dikes, and the deposition area was located downstream the spur-dike towards the sidewall. The ratio between the volume of scour hole and the volume of the bed deposition was in good balance in all runs.

5. EFFECT OF VARIABLES

In the previous studies no one consider the height of the spur-dike (*d*) as it was always above the flow depth. So that, the governing factor in this study will be the height of the spur-dike (*d*) above the original bed as an important factor in overtopping flows.

(1) Effect of opening ratio (α)

The relation between (S/*d*) with opening ratio (α) is plotted in **Fig. 8**. For all runs of small spur-dike heights (*d* = 2.5cm) the relationship could be present by straight line of an adverse slope. While for runs with large spur-dike height (*d* = 5.0 and 7.5cm) the relationship could present by almost horizontal straight line with a little difference in (S/*d*) observed ratios. That leads to find out two different phases of scouring process according to the height of the spur-dike and its ratios with other parameters.

(2) Effect of overtopping ratio (*h/d*) and (*b*/*h*)

The variations of (S/*d*) with overtopping ratio (*h/d*) are plotted in **Fig. 9**. In first three cases, at the same values of (*h/d*) the observed (S/*d*) ratios were different because of the difference in spur-dike length in each case, and it was found that the small overtopping ratio produces large scour depth. Even in case 5, the observed scour depth was the biggest among all other cases, however (S/*d*) value was the smallest.

The relation between (S/*d*) with (*b*/*h*) is plotted in **Fig. 10**. It can be seen that *b*/*h* has clear dependence on the height of the spur-dike (*d*) as the value of *b*/*h* increased with increasing of S/*d* ratios when *d* = 2.5cm. The relationship can be presented by a set of positive curves except in case 5, which has the larger value of spur-dike height (*d* = 7.5cm).

From discussing the effect of the three parameters above (α, *h*/*d* and *b*/*h*), it seems that when S/*d* has values less than 2.0 (as in case 5) the relation almost represented by an opposite direction to all other values.

The differences observed in the maximum scour depth in each case of study could be interpreted as a resulting from the actual values of effective shear stress at the nose of the spur-dike. So that, measuring the velocity distribution around the spur-dike under the same conditions will be useful to spot and analyse the effective parameters on the local scour around submerged spur-dikes.

At small opening ratio (α), the average velocity becomes bigger at the spur-dike location, so that the observed scour depth increases under this condition.

At longer spur dike (*b*) and lower flow depth (*h*), the over flow decrease while the side flow increase with high velocity which leads to more scouring process to be occur at the nose of the spur-dike.

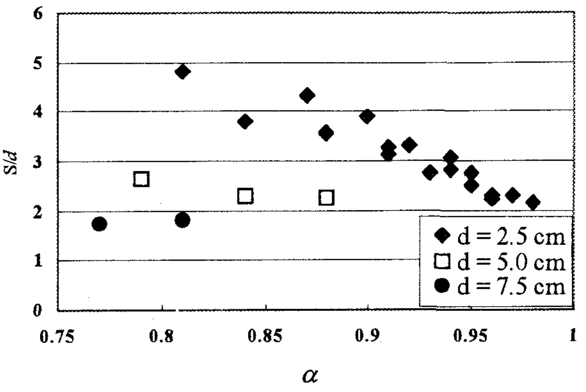

Fig. 8 Variation of (S/*d*) with (α)

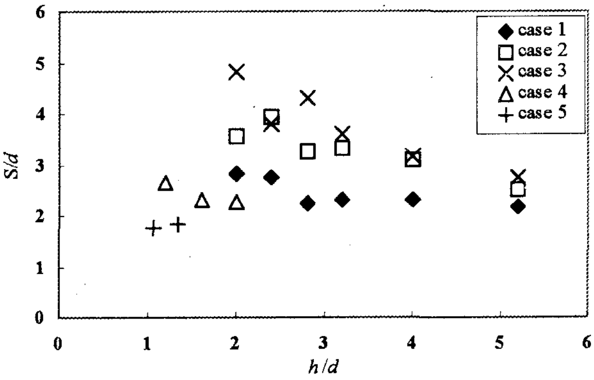

Fig. 9 Variation of (S/*d*) with (*h/d*)

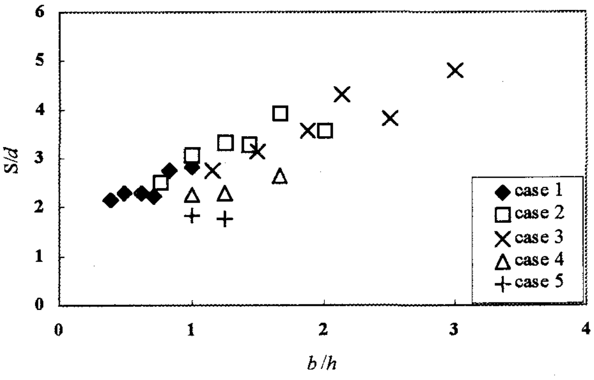

Fig. 10 Variation of (S/*d*) with (*b/h*)

6. CONCLUSIONS

In movable bed condition, the following points can be concluded from the results discussed in this investigation:

- Local scour around submerged spur-dikes is significantly affected by the overtopping ratio and the opening ratio.
- The longer spur-dike length & the lower flow depth produced scour area wider than the shorter spur-dike length & the higher flow depth.
- The larger opening ratios (α) caused relatively small scour area and the bank erosion downstream the spur-dike hardly can occur.
- The data collected in this investigation can be useful for the development of numerical models of scour around submerged spur-dikes.

Investigate the local scour around repelling (60°) and attracting (120°) spur-dikes are expected to study near future to find out the effect of the inclination angle of the spur-dike with the flow direction on the scouring process.

NOTATION

The following symbols are used in this paper:

$\alpha = (\frac{Bh - bd}{Bh})$, opening ratio.

I_e : energy gradient.

B : width of the flume.

h : flow depth.

b : length of the spur-dike in the lateral direction.

d : height of the spur-dike above the original bed.

S : maximum scour depth.

Q : flow rate in volume.

L : width of scour hole in front of the spur-dike.

X : longitudinal distance from spur-dike directing to downstream.

Y : lateral distance from the flume sidewall.

(a): upstream scour length at the flume sidewall.

(c): downstream scour length at the flume sidewall.

(e): upstream scour length within the flume width.

(f): downstream scour length within the flume width.

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