International Journal of GEOMATE, Oct., 2022, Vol.23, Issue 98, pp.100-108
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2022.98.3506
Geotechnique, Construction Materials and Environment

PHYSICAL MODEL AND VALIDATION OF LOCAL SCOUR PATTERN DOWNSTREAM OF TRAPEZOIDAL THRESHOLD

*Nanang Saiful Rizal[1] and Ilham Saifudin[2]

[1]Department of Civil Engineering, University of Muhammadiyah Jember, Jl Karimata 49, Jember, Indonesia
[2]Department of Informatic Engineering, University of Muhammadiyah Jember, Jl Karimata 49, Indonesia

*Corresponding Author, Received: 28 June 2022, Revised: 25 July 2022, Accepted: 09 Oct. 2022

ABSTRACT: Trapezoidal thresholds are often used to measure discharge in irrigation canals. A trapezoidal sharp threshold can be made with a slope (n) varying from $n_1 = 1$, $n_2 = 0.5$ and $n_3 = 0.1$. Discharge measurement with this method is not only easy, but also has good accuracy, especially for irrigation water distribution. However, the weakness in the downstream threshold can occur in local scour. To observe the local scour pattern downstream of the trapezoidal threshold, a physical model test was conducted in the laboratory. Forty (40) experiments were carried out on 3 variations of the slope of the trapezoidal frame wall and using 2 channel base materials. From the results of this study, the equations for scouring length (Ls) and scour depth (ds) are obtained which are influenced by downstream water height (H), grain diameter (d50), froude number (Fr), and threshold wall slope. After validating the resulting model using a slope of $n_4 = 0.6$ and $n_5 = 0.3$, a relative error rate of 18.7% was obtained (NSE = 0.1, MAE = 0.2 and RMSE = 1.4).

Keywords: Local scour, Trapezoid threshold, Scour length, Scour depth, Grain diameter, Froude number

1. INTRODUCTION

Trapezoidal thresholds are widely used to measure discharge in irrigation canals, besides that, they are also used as sediment-retaining structures in mountain lava flows. The installation of the threshold greatly affects the hydraulic behavior of the flow. Hydraulic flows including downstream scour impacts have been investigated by previous researchers. As for the study of the flow behavior above the weir, there have been several studies have been completed [1−7] that used dimensional analysis to study the flow process above the threshold and downstream of the sharp edge. Some previous researchers focused on the value of the discharge coefficient only, even though the installation of a threshold can also cause water jumps. The water jump has actually been muted by the stilling pond but it can still cause local scour downstream. In this regard, several studies have led to the study of local scour downstream. To maintain the river against the erosion of the river walls and protect the degradation of the riverbed and regulate the flow of the river, it is necessary to build an energy absorber pond downstream of the river [8-11]. The potential for local scour downstream of the stilling weir pond will be high, especially during flooding [12], so it is important to study the local scour patterns that occur downstream of the weir so that the damage can be minimized. The studied local scour, found that the depth of the upstream scour was independent of the slope of the downstream weir [13]. The threshold with an angle of 120° can minimize scour compared to other angles [14]

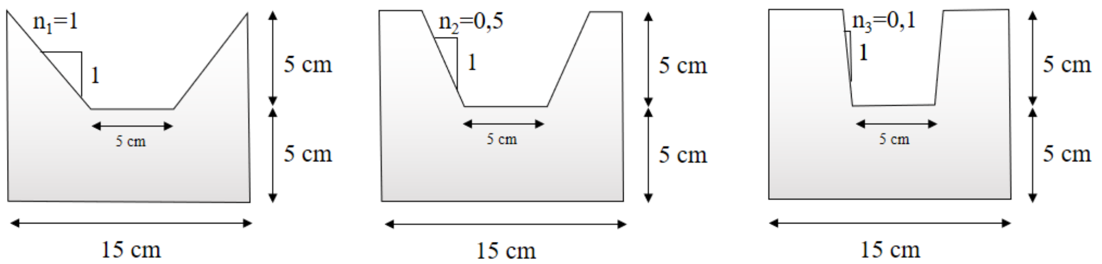
Variations in the width of the threshold greatly affect the scour behavior that occurs [15], the wider the threshold, the smaller the length and depth of scouring, and vice versa. If the threshold is triangular, recommend an angle of 45° and 60° because can reduce local scour events that occur. In principle, scour is a natural behavior that occurs due to the installation or construction of the Sebeih weir [16], but if the scour is too deep and long, it can endanger the stability of the dam, especially against overturning and shear. The carried out experimental studies on weirs to enable accurate measurement of very low and very high discharge rates [17]. In previous studies, many have focused on the triangular threshold. In the study of flow above the threshold, we have succeeded in identifying the discharge coefficient (Cd) including the scouring process that occurs at the triangular shape threshold. Variables that change are discharge, channel slope, and threshold angle. At some channel slopes, it shows that the scouring process that occurs can affect the discharge coefficient [18, 19] from their experiments showed a very good agreement with the theory, by obtaining an average discharge coefficient value for each weir which varied from 0.61 to 0.62.

At the square threshold, the relationship between the Reynolds number and the magnitude of the discharge coefficient and Reynolds number has been obtained in a physical model test. [20], the same was done and succeeded in developing an equation of discharge above the threshold with an error rate of 4% [21], have investigated the flow above triangular and trapezoidal thresholds [22]. The main objective of this research is to find the factors that influence the flow characteristics above the threshold and succeeded in finding that the froude number and the geometric shape of the threshold greatly affect the flow characteristics at a threshold [23]. It has also investigated flow at sharp thresholds with experiments in the laboratory and showed the same result that the froude number and geometric shape of the cross-section greatly affect the flow characteristics above the threshold, after experimentally finding scour downstream of a curved lintel [24].

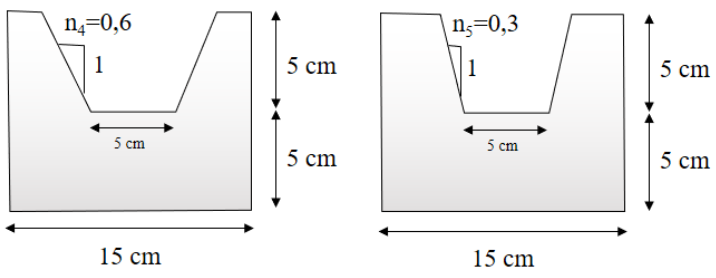
They experimentally concluded that the use of an apron downstream can reduce the maximum scour depth [25], and also experimentally found that the height of the threshold and apron required to prevent scour was 25% [26]. Concave scour behavior will also occur at the trapezoidal threshold, so research is needed to examine the depth and length of local scour including the installation of an apron on the downstream side to make it easier to examine the local scour behavior that occurs. The trapezoidal threshold is the right measuring structure for measuring the discharge that enters the irrigation canal, because it can measure the discharge in larger quantities, is easier to apply in the field, and has a fairly good measurement accuracy. The purpose of this study was to evaluate local scour that occurred downstream of the trapezoidal threshold with a slope of n_1 = 1 and then the results were compared with the slope of a more upright slope, namely n_2 = 0.5 and n_3 = 0.1. At 1 slope of the trapezoidal threshold, 4 variations of flow discharge will be flowed on a fine subgrade type and then repeated with 4 variations of flow discharge on a slightly coarse subgrade. Furthermore, 40 experiments (3 variations of the trapezoidal ridge slope and 2 variations of the slope of the slope for validation, 4 variations of flow discharge, and 2 variations of the channel subgrade) will be sought for their relationship to local scour events that occur (length and depth of local scour).

2. MATERIALS AND METHODS

This research was conducted at the Hydraulics Laboratory of the Civil Engineering Study Program, Faculty of Engineering, Muhammadiyah University of Jember, Indonesia. The flume channel has a length of 410 cm, a width of 15 cm, and a height of 24 cm made of mica material with a thickness of 5 mm. The flume line is equipped with a point gauge and a current meter. 5-point gauges function to measure the water level and depth of the scour, while the current meter is to measure the speed that occurs at several points downstream that experience scour. The flume channel is also equipped with an upper and lower reservoir as well as a water pump to regulate the flow circulation so that it is stable and according to the needs of 4 variations of experimental discharge. The trapezoidal threshold is made of mica with a thickness of 5 mm, a height of 50 mm, and a bottom width of 50 mm. There are 3 trapezoidal threshold models made for the experiment, namely the slope of the slope n_1 = 1.0, n_2 = 0.5 and n_3 = 0.1 while maintaining a base width of 50 mm (figure 1). The water level tested above the trapezoidal threshold refers to the variation of flow discharge Q_1 = 14.5 cm^3/s, Q_2 = 13.0 cm^3/s), Q_3 = 11.2 cm^3/s and Q_4 = 10.5 cm^3/s. fine sand (d_{50} = 1.18 mm), coarse sand (d_{50} = 2.36 cm).



a. Threshold model for physical model test (n_1 = 1, n_2 = 0.5 and n_3 = 0.1)



b. Threshold model for validation test (n_4 = 0.6 and n_5 = 0.3)

Fig.1 The geometric shape of the trapezoidal threshold in research

At the beginning of the study, a series of trials were carried out to determine the length of time for scour monitoring of the 2 basic materials used and the length of the material that would potentially experience local scour. This was done with 6 trials, on 2 variations of the trapezoidal threshold shape (n_1 = 1 and n_2 = 0.5) with 2 different materials whose results are plotted in the table presented in Figure 2.

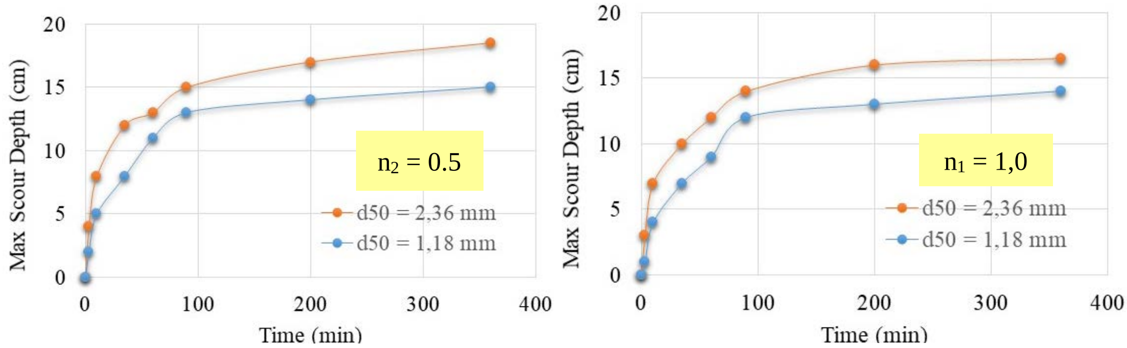


Fig. 2 The relationship between scour depth with time-based on fine sand and coarse sand

Based on the results in Figure 2, the basic material of the channel will be installed on the flume with a length of 410 cm and the testing time is only 25 minutes. The testing procedure is as follows: 1) The trapezoidal threshold variation that has been made is carefully installed on the flume and placed at a distance of 50 mm from the upstream of the flume. 2) The selected base material is mounted on the flume and its elevation is leveled with the apron (50 mm depth, Figure 2.) with high accuracy measured by a point gauge with a maximum deviation tolerance of +0.1 mm. 3) Make sure the threshold is tight, there are no leaks and the apron and basic materials are flat, then the point gauge and current meterady to be used to measure and are in the predetermined position. 4) The discharge flows according to the experimental design and is controlled by a stop faucet. 5) Flow velocity is measured using a current meter with +1% accuracy. 6) The faucet stop is adjusted gradually until discharge Q_1 = 14.5 cm^3/s. 7) The time for the test to start. 8) After 25 minutes (no significant change in layer profile), measurements of velocity, scour depth and local scour length were recorded. 9) The pump is turned off and all materials are returned to their original position flush with the apron. 10) The above steps were repeated for discharge Q_1 = 14.5 cm^3/s, Q_2 = 13.0 cm^3/s), Q_3 = 11.2 cm^3/s and Q_4 = 10.5 cm^3/s for 2 different types of channel bottom material (d_{50} = 1.18 mm and d_{50} = 2.36 cm) with 3 different variations of the trapezoidal threshold (n_1 = 1.0, n_2 = 0.5 and n_3 = 0.1).

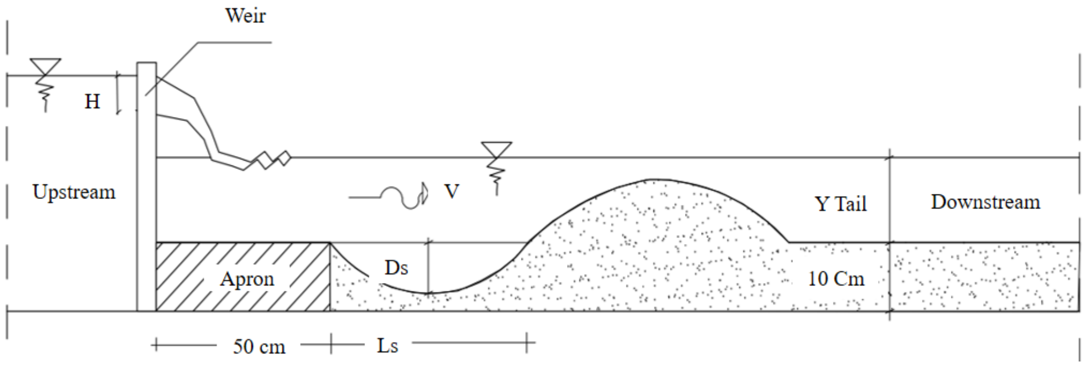


Fig.3 Schematic diagram of longitudinal scour pattern (scour height and scour length)

3. ANALYSIS AND DISCUSSION

To analyze the scour process at the downstream weir of the trapezoidal threshold, some of the variables reviewed are: H = water level above the trapezoidal threshold, ytail = water depth downstream, Q = flow rate in the channel, V = average flow velocity downstream flume, g = acceleration of gravity, V = dynamic viscosity of water, d50 = average particle diameter, Lap = apron length, H = water height above the threshold, S = flume bottom slope, ds = scour depth, B = flume width, Ls = scour length (Figure 3). The relationship between length (Ls) and depth (ds) scour, is expressed by the following :

$$Ø(P,B,L_{ap},Y,H,d_{50},g,V,\rho_s,Q,\rho,S_o,\mu,n)=0 \quad (1)$$

According to the discussion above, the variables A, B, O, s, n1 and Lap are considered constant variables, so that Equation (1) can be presented as follows:

$$\frac{d_s}{y} = n\left(\frac{H}{y},\frac{d_{50}}{y},\frac{V}{\sqrt{gy}},\frac{\rho Q}{d\mu},n_1\right) \quad (2)$$

If : $V/\sqrt{gy}$ = Froude's number, $Q/d\mu$ = Reynolds number at flow system, If Reynolds number is negligible, then the equation becomes:

$$\frac{d_s}{y} = n\left(\frac{H}{y}, \frac{d_{50}}{y}, Fr, n_1\right) \quad (3)$$

Forty experimental experiments using three different trapezoidal threshold slope models have been carried out. The physical model test was carried out by varying several independent variables, namely the slope of the trapezoidal threshold (n), the water level above the threshold (H), and the type of channel bottom material (d_{50}). At the location for measuring the speed and depth of scour as well as the longitudinal profile of local scour in the flume channel in the laboratory (Figure 4), the flow velocity, local scour length and local scour depth was measured and then made into a data set to calculate and analyze its relationship to the 4 variations in water level above. trapezoidal threshold and the 2 types of channel base materials used. Furthermore, an equation is made to obtain the relationship between local scour length (Ls) and local scour depth (ds) for these 3 variables. As a result of the flow through the threshold, it has caused local scour along the bottom of the channel downstream. The results of observations of scour (length and depth of local scour) on fine and coarse sand with various flow rates are presented in Figure 5. There are 4 variations of discharge used, namely: Q_1 = 14.5 cm^3/s, Q_2 = 13.0 cm^3/s, Q_3 = 11.2 cm^3/s and Q_4 = 10.5 cm^3/s.

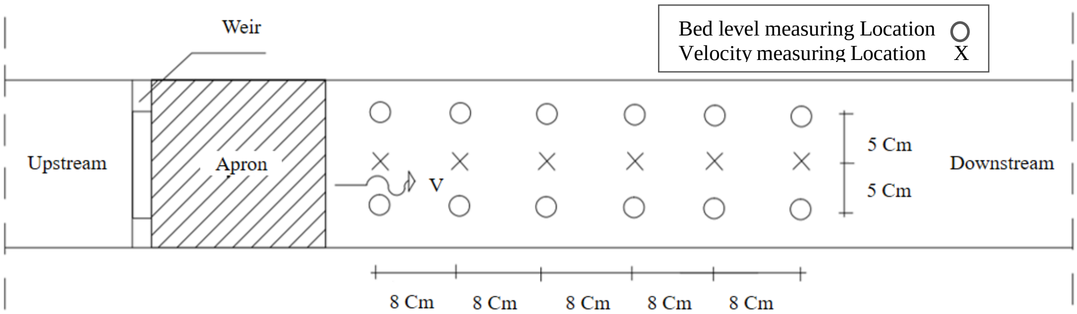


Fig. 4 Locations for measuring the speed and depth of scour as well as the longitudinal profile of the scour.

There are differences in the length and depth of local scour, in addition to being influenced by changes in the grain diameter of the base material as well as changes in discharge and changes in wall slope from the trapezoidal threshold which is presented in Figure 5 while the graph is presented in Figure 6. It can be seen that the scour length (Ls) is getting higher with increasing value. the slope of the trapezoid threshold wall (n) occurs both at d_{50} = 1.18 mm and d_{50} = 2.36 mm with a flow rate of 14.5 cm^3/s. Likewise, the scour depth (ds) increases with the increasing slope value of the trapezoidal threshold wall (n) this occurs both at d_{50} = 1.18 mm and d_{50} = 2.36 mm with a flow rate of 14.5 cm^3/s.

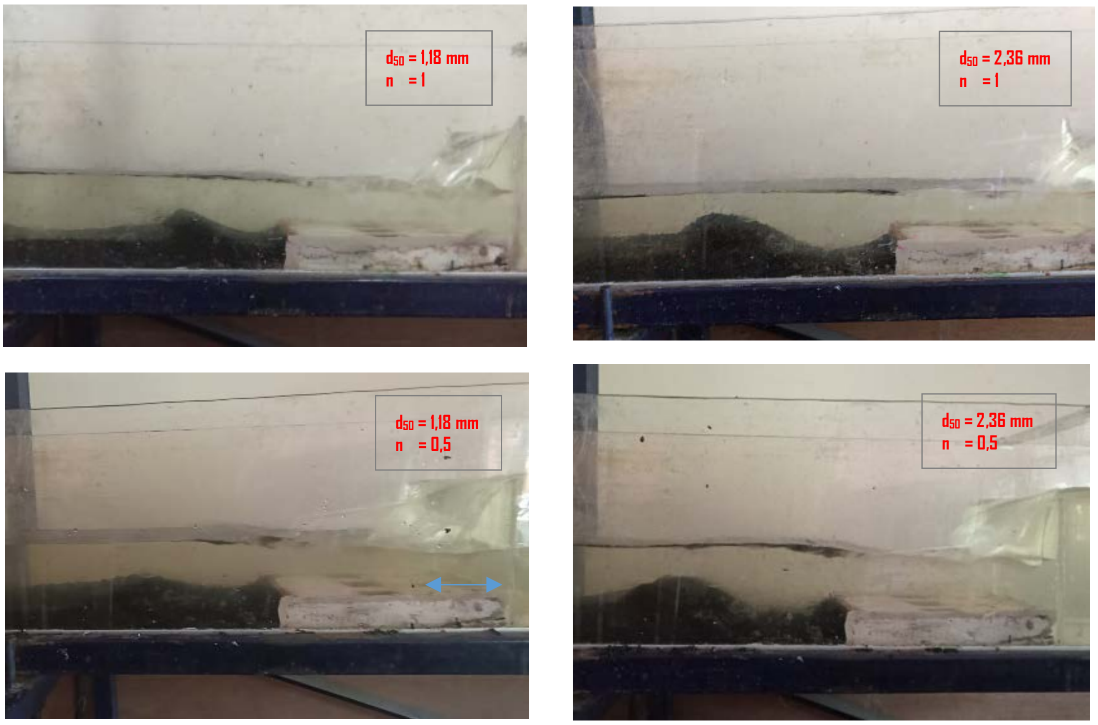


Fig. 5a Local scour on coarse and fine sand when Q = 14.5 cm3/s

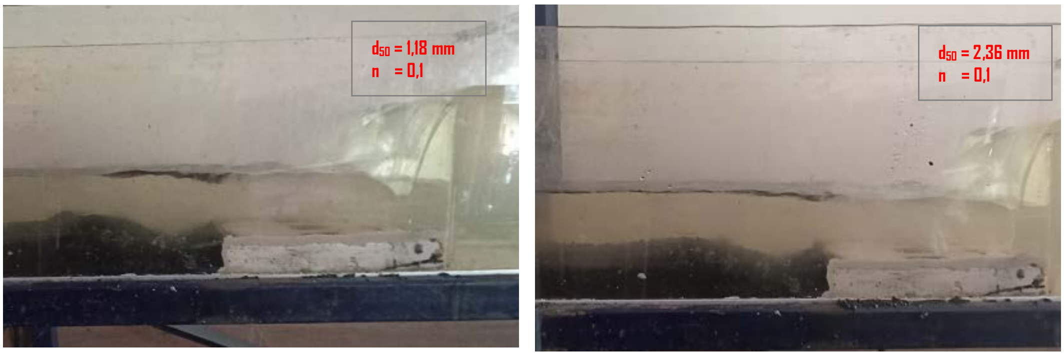


Fig. 5b Local scour on coarse and fine sand when Q = 14.5 cm^3/s

From Figure 5, it can also be seen that the local scour length (Ls) and local scour depth (ds) is strongly influenced by the slope of the trapezoidal threshold wall. Furthermore, it is necessary to make a relationship between the scour length (Ls) and downstream water height (H), grain diameter (d_{50}), Froude number (Fr), and threshold wall slope (n). This also applies to the scour depth (ds) and it is necessary to review the relationship between the slope of the trapezoidal threshold wall.The water level at the peak of the threshold and downstream as well as the local scour (ds) was measured with a point gauge, while the flow velocity was measured using a current meter. The figures for measuring the length and depth of local scour are plotted based on the measurement points presented in Figures 6 and 7. The trend of the local scour curve for coarse sand materials is initially the scour length (Ls) up to a distance of 150 mm and then decreases gradually with a decrease in discharge up to a length of 80 mm then tends to be stable or remains increasingly downstream. A similar curve trend was found in the base material of fine sand, the trend of the local scour length curve (Ls) was initially up to a distance of 150 mm and then decreased gradually with a decrease in discharge to a length of 60 mm. The trend of the local scour curve for coarse sand is initially the scour depth (ds) up to 140 mm and then it decreases gradually with a decrease in discharge up to 40 mm and then tends to be stable or remains more downstream. A similar curve trend was found in the base material of fine sand, the trend of the local scour depth (ds) curve was initially up to 60 mm then decreased gradually with a decrease in discharge only up to 30 mm. From the figures in the scour and the scour length at several variations of discharge, it is shown that the coarse sand material is easily scoured (deeper scour and longer scour). As a result, a lot of coarse sand material shifts downstream so that the downstream sediment collision becomes larger than the fine sand material eventually causing siltation.

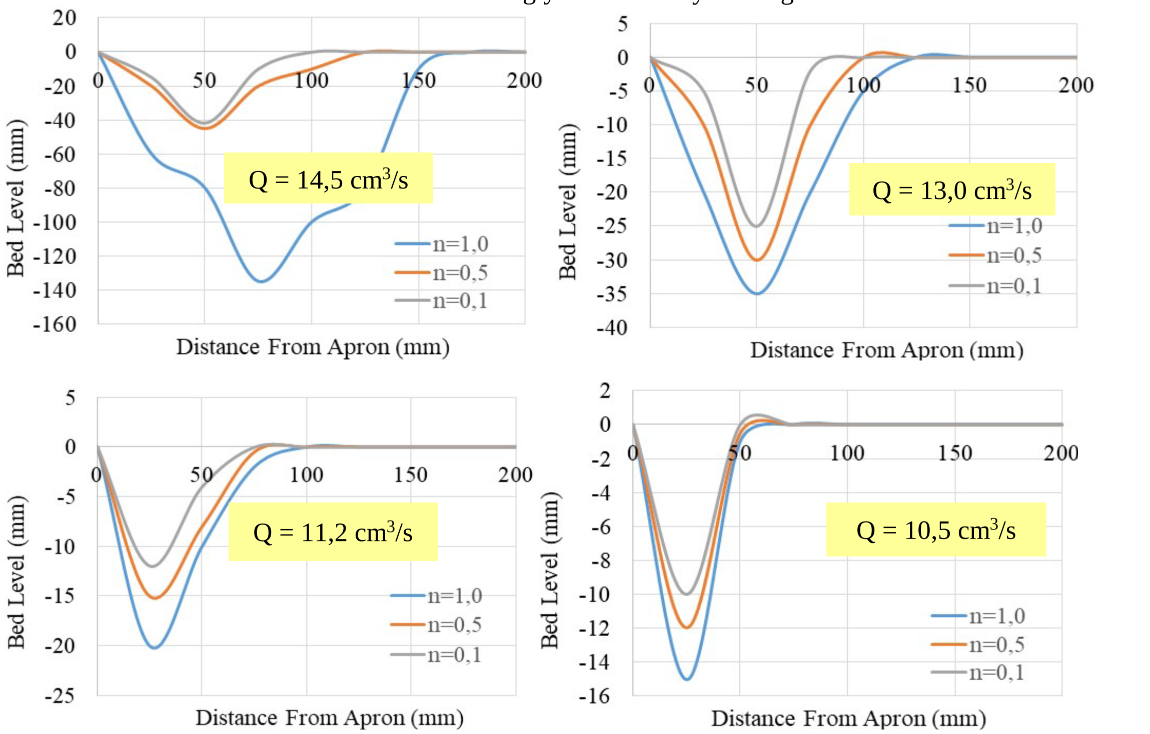


Fig.6 Longitudinal profile of local scour on coarse sand d_{50} = 2.36 mm

As in Figure 6 for coarse sand d_{50} = 2.36 mm, at the largest discharge (Q = 14.5 cm^3/s) there is a significant difference in scour length and scour depth between the slope of the threshold n1 = 1 and n_2 = 0.5 and n_3 = 0.1. As for the flow rate Q = 14.5 cm^3/s, the local scour is the highest then gradually with the smaller the slope of the trapezoidal threshold wall, the local scour length and local scour depth will smaller. At the of flow rate Q_2 = 13.0 cm^3/s, Q_3 = 11.2 cm^3/s and Q_4 = 10.5 cm^3/s, the scour pattern is almost the same or uniform. At the time of disch,arge Q_4 = 10.5 cm^3/s the scour length is only 50 mm with a scour depth of only 10 mm, this indicates that the trapezoidal threshold compared to the rectangular sill has a greater risk of scour downstream. This is because at the trapezoidal threshold, the flow is wider and the higher the jump edge, the bigger the jump. So the trigger for local scour is the flow at the edge of the threshold because it has the highest hydraulic jump. Likewise with the flow in fine sand d_{50} = 1.18 mm, the scouring pattern is presented in Figure 7, when the highest flow rate is Q_1 = 14.5 cm^3/s, the scour pattern is almost the same as Q_2 = 13 cm^3/s, although there are slight deviations. The scouring pattern for n_3 = 0.1. While at Q_3 = 11.2 cm^3/s the scouring pattern is almost the same as Q_4 = 10.5 cm^3/s, but there is still a significant difference in scour length and scour depth between the threshold slope n_1 = 1 with n_2 = 0.5 and n_3 = 0.1. Similar to coarse sand sediments, at the time of discharge Q4 = 10.5 cm^3/s even the scour length is only 50 mm with a very small scour depth that is almost undetectable. So from this desdesireioption can be concluded that the flow pattern when passing the threshold light greatly affects the scour pattern that will occur downstream of the trapezium threshold. When compared to Figures 6 and 7, the scour pattern is influenced by the discharge factor and flow flow conditions, the grain diameter of the base material is also very decisive.

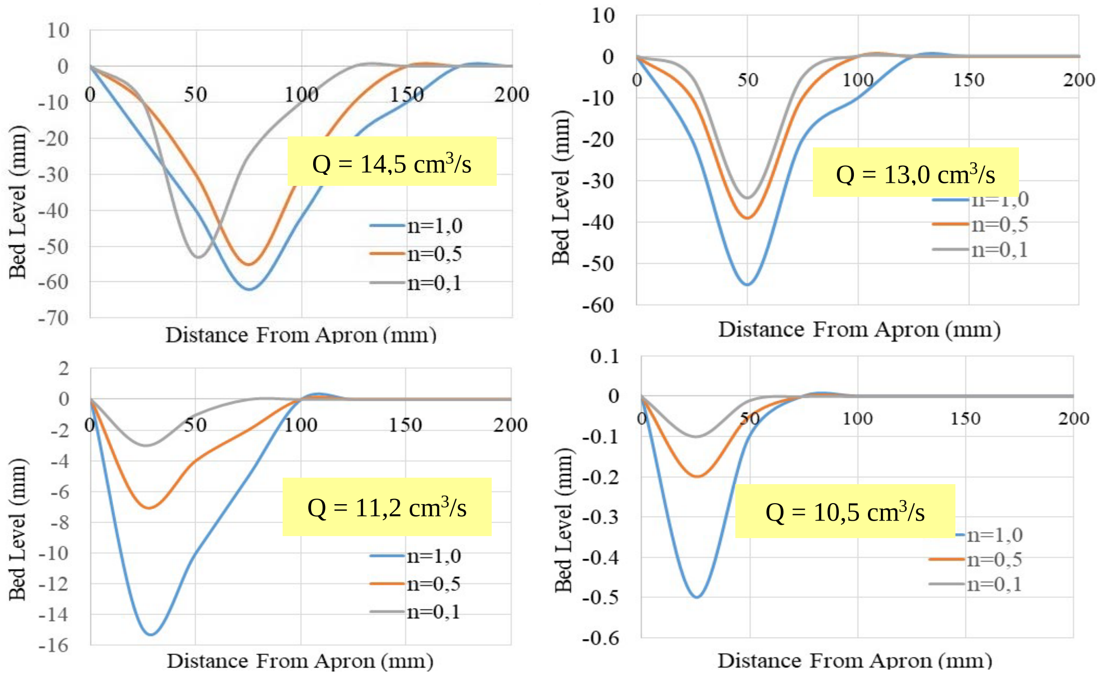


Fig. 7 Longitudinal profile of local scour on fine sand d50 = 1.18 mm

The trend of differences in the base material is very visible in the difference in the length and depth of scour. At the beginning of the flow, the water will fill the soil cavities, if the grain diameter is large, the voids will be filled with water. Coarse sand has more soil voids than fine sand because the diameter of the grains is quite large, so the total density is smaller than that of sand so that when hydrodynamic force is applied, the water will be easy to move or scour. From Figures 6 and 7, it can also be seen that the greater the slope of the trapezoidal threshold the more water flow will be edged. The higher edge of the waterfall is bigger, which means the jump is bigger. So the trigger for erosion is probably the flow at the edge of the threshold because it has the highest hydraulic jump. The longer and deeper the hydraulic jump, the greater the potential for local scour. To detect this, it is necessary to study the flow velocity when the water jumps and the Froude number that occurs when the water is about to jump, visualization of this condition is presented in Figure 8. When compared to Figure 8, we can see the scour pattern from above when the slope of the threshold wall is n_2 = 0.5 and n_3 = 0.1. The flow path is strongly influenced by the shape of the talud, the wider the peak of the threshold, the wider the flow and when spreading automatically, the scour width will be longer. This occurs in both fine sand and coarse sand as the base material. However, when it spreads, it has the potential to increase the length of the scour, but as it spreads the discharge becomes smaller in the middle so that the depth of the middle scour gets smaller. But in general, the larger the value of n, the longer the scour and the deeper the scour. So it is necessary to review the speed and Froude number when the water has experienced a jump. On the edge of the highest jump, is the initial trigger for scouring. Eventually gets longer and deeper as shown in Figure 8.

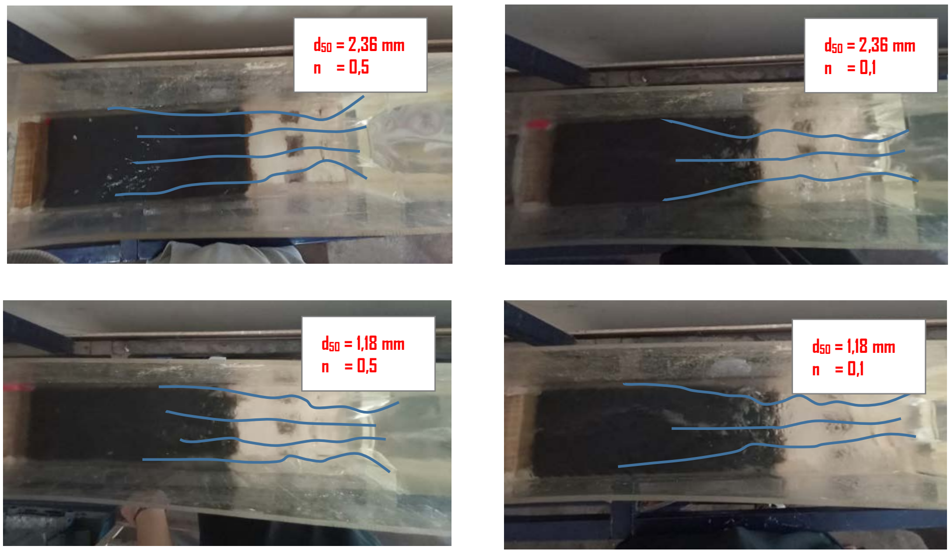


Fig.8 Top view of local scour flow and pattern at Q_1 = 14.5 cm^3/s

4. MODELING AND VALIDATION

After modeling the trapezoidal sill installation with variations in the slope of the trapezoidal sill wall (n_1 = 1, n_2 = 0.5, and n_3 = 0.1) using 2 channel base materials (d_{50} = 1.18 mm and d_{50} = 2.36 mm) with 4 variations of flow rate obtained a linear regression equation that shows the relationship between the slope of the slope of the scour length and the local scour depth that occurs. To obtain a model is done by using multiple linear equations with scour depth (ds) and scour length as variable y. Then the water level above the threshold (H) ais the site A1 variable, the base material diameter (d_{50}) is the A2 variable, the froude number (Fr) is the A3 variable, and the threshold slope (m)is the A4 variable. By using a statistical software program the results obtained are :

a). Local scour depth (ds)

$$\frac{ds}{y} = \frac{1{,}04\,H}{y} - \frac{2{,}31\,d_{50}}{y} - 0{,}45\,Fr + 125{,}83\,n + 5{,}92$$

b). Local scour length (Ls)

$$\frac{Ls}{y} = \frac{0{,}46\,H}{y} - \frac{1{,}07\,d_{50}}{y} - 0{,}05\,Fr - 4{,}51\,n + 1{,}35$$

The modeling results were further validated by testing the physical model using a trapezoidal threshold which has a slope of n_4 = 0.6 and n_5 = 0.3 using 2 channel base materials (d_{50} = 1.18 mm and d_{50} = 2.36 mm) with 4 discharge variations. flow whose results are presented in Figure 9. Figure 9 shows that there is still a difference between the theoretical calculation of the LS and ds values with the results of the physical model test. From the results of the validation of the above equation using n4 = 0.6 and n5 = 0.3, for the local scour depth equation (ds) has a relative error of 18.7% (NSE = 0.1, MAE = 0.2 and RMSE = 1 ,4) while for the local scour length equation (Ls) the relative error is 19.3% (NSE = 0.3, MAE = 0.7 and RMSE = 4.8).

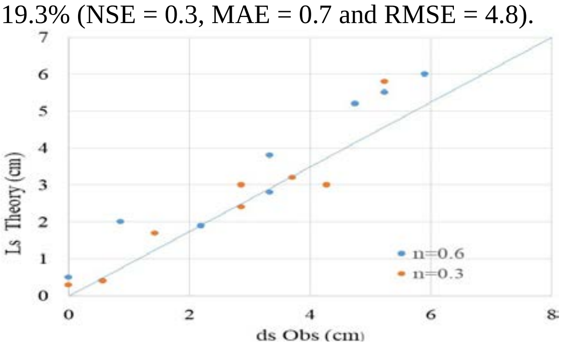


Fig. 9 Comparison of Observational and Theoretical Ds and Ls with n_4 = 0.6 and n_5 = 0.3.

5. CONCLUSION

Experimental study of the influence of the slope of the slope on the trapezoidal threshold on local scour events that occur. This event must be a concern in the design of waterworks because it can cause instability of the channel or river downstream so the length and depth of local scour need to be anticipated. The local scour event is an accumulation of the influence of the shape of the threshold, the bottom condition of the channel, and, the low behavior. The more inclined the trapezoidal threshold slope, the greater the scour occurs. Likewise, when the discharge increases, the greater the scouring event occurs, including the channel bottom material. The coarser the channel bottom material, the greater the potential for scouring to occur. This is because at, the beginning of the flow, the water will fill the soil cavities, if the grain diameter is large, the voids will be filled with water. In fine sand, there are more voids in the soil than in coarse sand, because the diameter of the grains is large enough, so the total specific gravity is smaller than in sand so that when hydrodynamic forces are applied, the water will easily experience local movement or scour.

REFERENCES

1. Kindsvater R.W. Discharge characteristics of rectangular thin-plate weirs, Trans. Am. Soc. Civil Eng. Vol.124, 1959, p.772–822.
2. Ackers P., White W.R., Perkins J.A., Harrison. Weirs and Flumes for Flow Measurement, Wiley, New York, 1978.
3. Swamee P.K., Ojha C.S.P., Kumar S. Discharge equation for rectangular slots, J. Hydraulic Eng. ASCE, Vol.124, No.9, 1998, p.973–974.
4. Borghei S.M., Jalili M.R., Ghodsian M.. Discharge coefficient for sharp-crested side weir in subcritical flow, J Hydraulic Eng. ASCE, Vol. 125, No.10, 1999, p.1051–1056.
5. Clemmens A.J., Wahl T.L., BOS MG., Replogle J.A.. Water measurement with flumes and weirs, International Institute for Land Reclamation and Improvement (ILRI) Publication 58, Wageningen, The Netherlands, 2001.
6. Iaydin A., Metinger., Hincal O.. Measurement of small discharges in open channels by slit weir, J. Hydraulic Eng. ASCE Vol.128, No.2, 2002, p.234–237.
7. V. FERRO. New theoretical solution of the stage-discharge relationship for sharp-crested and broad weirs, J. Irrig. Drain. Eng. ASCE, Vol. 138, No.3, 2012, p.257–265.
8. Breusers, H.N.C.; Raudkivi, A.J., Scouring, Balkema: Rotterdam., The Netherlands, 1991.
9. Guan D., Melville B., Friedrich H.. Bed load influence on scour at submerged weirs. Pp. 1-9, In Proceedings of the 35th World Congress of IAHR, Chengdu, China, 2013.
10. Guan D., Melville B.W., Friedrich H.. Flow Patterns and Turbulence Structures in a Scour Hole Downstream of a Submerged Weir., J. Hydraul. Eng. Vol. 140, 2014, p. 68–76.
11. Wang L., Melville B.W., Whittaker C.N., Guan D. Effects of a downstream submerged weir on local scour at bridge piers. Hydro Res. Vol. 20, 2018, p.101–109.
12. Tregnaghi M., Marion A., Coleman S., Tait S.. Effect of Flood Recession on Scouring at Bed Sills. J. Hydraul. Eng, Vol. 136, 2010, p.204–213.
13. Wang LU., Bruce W. M., Dawei G., Colin N. W.. Local scour at downstream sloped submerged weirs, J. of Hyd. Eng. (ASCE)., Vol. 144, No. 8, 2018, p.1–12.
14. Al-Husseini T. R., Al-Madhhachi A. T., Naser ZA.. Laboratory experiments and numerical model of local scour around submerged sharp-crested weirs, J. of King Saud Univ. – Eng. Sci, Vol 32, No.3, 2019, p. 167-176.
15. Martinez J., Reca, Morillas M.Y., Lopez J.G.. Design and calibration of a compound sharp-crested weir, J. Hydraulic Eng. ASCE Vol.131, No.2, 2005, p.112–116.
16. Sobeih M.F., Helal E.Y., Nassralla T.H., Abdelaziz AA.. Scour depth downstream weir with openings, Int. J. Civil Struct. Eng. Vol. 1, No.3, 2012, p.259–270.
17. Ramamurthy A., Qu J., Zhai C., Vo D.. Multislit weir characteristics, J. Irrig. Drain. Eng. ASCE Vol. 133, No.22, 2007, pp.198.
18. Murthy K., Giridhar D.. Inverted V-notch: practical proportional weir, J. Irrig. Drain. Eng. ASCE. Vol. 115, No.6, 1989, p.1035–1050.
19. Johnson M.C. Discharge coefficient analysis for flat-topped and sharp-crested weirs, Irrig. Sci. Vol.19, 2000, p.133–137.
20. Ramamurthy A., Kai J., Han S.. V-Shaped Multislit Weirs, J. Irrig. Drain. Eng. ASCE., Vol.139, No.7, 2013, pp 582–585.
21. Al-Hamid A.A., Negm A.A.M., Al-Ibrahim A.M.. Discharge Equation for Proposed Self-Cleaning Device, J. King Saud Univ., Vol.9, No.1, 1996, pp. 13-24.
22. Hayawii H.A.A., Yahia A.A.A., Hayawii G.A.A.. Free Combined Flow over a Triangular Weir and under Rectangular Gate, Damascus Univ., Journal of Engineering, Vol.24, No. 1, 2008, P 9-22.
23. Saman J.M.V., Mazaheri M.. Combined Flow over Weir and under Gate, Journal of Hydraulic Engineering, ASCE, Vol. 135, No.3, 2009, p.103–114.

24. Shenouda A.GH. Scour Length Downstream Curved Weirs, M.Sc. Thesis, Aswan Faculty of Engineering, South Valley University, Egypt, 2008.
25. Al_Hamid A.A., Husain D., Negm A.A.M.. Discharge Equation for Simultaneous Flow over Rectangular Weirs and Below Inverted Triangular Weirs, Arab gulf journal of scientific research., Vol 14 (3), 1996, p. 595-607.
26. Ali N. A. The proper location of the floor sill with scouring reach downstream of the heading-up structure, J. of Eng. Scie. (JES), Faculty of Eng. Assiut Univ., Vol. 23, No.2, 1995, p.1–12.