EFFECTS OF LANDWARD SLOPE ROUGHNESS ON SCOURING PHENOMENA DOWNSTREAM OF EMBANKMENT TOE

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1. INTRODUCTION

On the crest of embankment, the overtopping flow has high potential energy. As it flows down the embankment slope this energy turns into kinetic energy. This overtopping high velocity flow, attacks as a jet on the downstream bed. The downstream bed reduces the mean flow velocity, increase the pressure and cause a hydraulic jump to occur. This action causes scouring to occur, that later reduces the stability of the embankment. The leeward slope and toe of the coastal dike at Iwanuma city collapsed after the 2011 Great East Japan tsunami. Similarly, during flash floods in Afghanistan many hydraulic structures have collapsed due to this bed scouring. Embankments, in addition to be a popular method to manage floods or tsunami related damages it also has agricultural and flood management related benefits. Therefore, scouring at the toe of an embankment is a significant issue that needs to be reduced.

Scouring is a function of flow velocity, flow depth, flow attack angle, channel profile, channel bed slope and bed particle properties. Scouring occurs when the shear stress of flow exceeds the critical value of bed particle movement. Wakes, vortices and skin friction drag are other factors that aggravate scouring. Tanaka & Sato (2015) conducted field survey after the 2011 Great East Japan tsunami and concluded that the scoured depth and length from the toe of the embankment is related to the energy head and momentum at the crest of the embankment. Reduction of this energy head and momentum can reduce the scour depth and length. Studies have also shown the benefit of stepped type of spillways, showing capability to dissipate energy (Guenther et al., 2013). Guenther, Felder, & Chanson, (2013) performed a physical study on stepped spillway configuration. Their study showed different flow regimes depending upon the dimensionless flow rate d_c/h; where d_c represents critical flow depth on the crest of the embankment and h is the step height. The critical flow depth at the crest of the embankment $(d_c) = \sqrt[3]{q^2/g}$, where q is the flow rate per unit width (m^2s^{-1}), g is the gravitational acceleration (9.81 ms^{-2}). The flow patterns observed were nappe ($d_c/h < 0.5$), transition ($0.5 < d_c/h < 0.9$) and skimming flow ($d_c/h > 0.9$) (Guenther et al., 2013) (Fig. 1 a).

The advantages of stepped type of embankment, compared to a smooth slope embankment is that it can be cost-effective (Chanson, 2015). Stepped type embankment has shown capability to reduce the energy of the overtopping flow, but the effect to scouring is unknown. Therefore, the objective of this study was to, as an initial stage, compare the scour profile of a smooth sloped embankment model with a stepped sloped embankment model.

2. METHODOLOGY

Experiments were conducted using a laboratory flume channel (5 m long, 0.7 m wide and 0.5 m height with a slope of 1:500). Two embankment models were made by changing the landward slope. One is smooth slope (SS) and the other is a horizontal stepped slope (HSS) (Fig. 1 b). The erosive soil downstream of the embankment, had a median grain size diameter (d_{50}) of 0.0045 m. It was assumed that this d_{50} condition allows for a clear-water scour experiment.

Four overtopping depths were investigated in this study. The overflow duration was set for 900 s. The embankment height (H_E= 0.145 m) and the overtopping flow depth (d_{OT} 0.026, 0.037, 0.098, and 0.046 m, respectively) were made dimensionless (d_{OT}/H_E = 0.18, 0.25, 0.28 and 0.32, respectively). The flow depth and velocity prior to measuring the scouring were measured by a point gauge and Particle Image Velocimetry (PIV), respectively. Scour profile was measured along the channel by a laser displacement gauge (KEYENCE LK-500). The scour profile was measured transversely and longitudinally, at 0.05 by 0.1 m points respectively, along the flume channel.

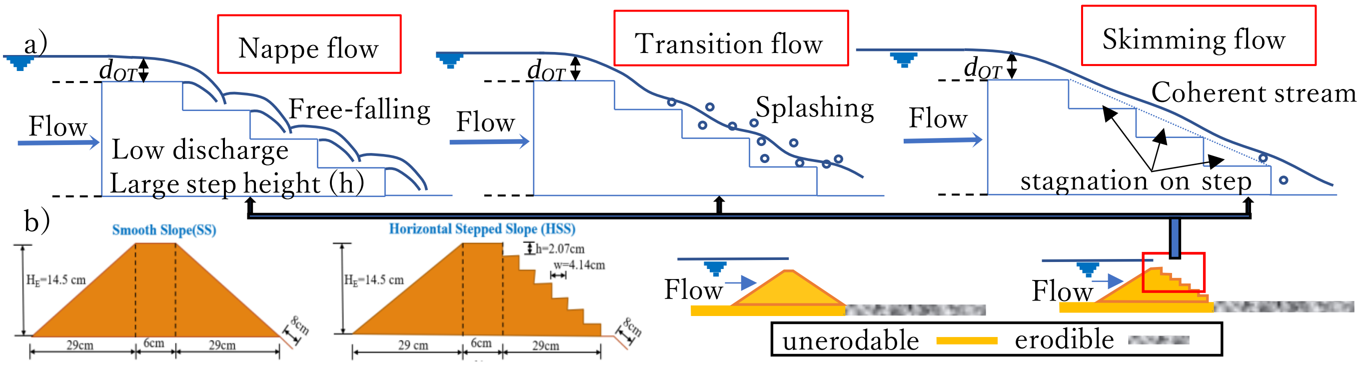

Figure 1 a) Flow structures observed on a stepped slope embankment b) Experiment configuration

3. RESULTS AND DISCUSSION

The investigated HSS embankment model showed a skimming flow structure. Guenther et al. (2013) showed that the skimming flow is characterized under the condition $d_c/h > 0.9$. In this study, skimming flow with slight undulation was observed in HSS embankment. The d_c/h of HSS for the minimum discharge was 1.1, which is more than 0.9.

Ground profile after experiment is plotted in Fig. 2 a). The scoured particles from the toe of the embankment accumulated downstream of the submerged hydraulic jump in both types of embankments investigated. Moreover, video footage showed that the scour depth (S_D) and scour length (S_L) versus time, respectively follow a logarithmic profile showing significant change in the first 120 s of the experiment. It was observed that in the condition of the HSS the initial scouring rate was lesser compared to the SS type (Fig. 2 b) and c)). In the $d_{OT}/H_E = 0.32$, in SS in 20 s reached 33% of its maximum S_D while HSS reached 28% of its maximum S_D. Meanwhile the S_L in SS in 20 s was 38% while HSS was 34% of its respective maximum. Indicating a time difference to reach the maximum S_D and S_L, where SS reached its maximum faster.

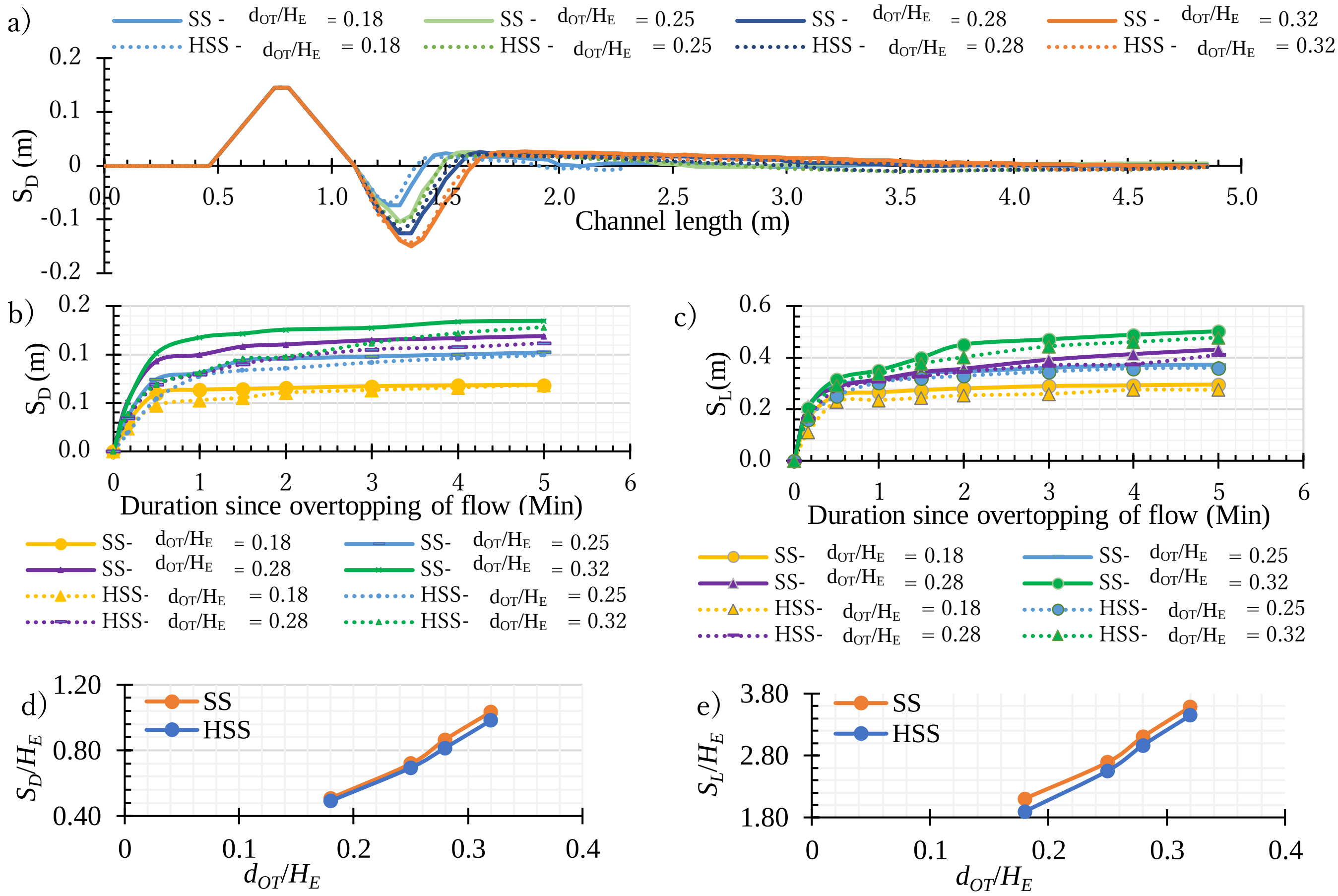

Figure 2 a) Central of flume channel bed profile after the SS and HSS embankment in different flow depth conditions b) Scour depth (S_D) versus time c) Scour length (S_L) versus time d) S_D/H_E versus d_{OT}/H_E, e) S_L/H_E versus d_{OT}/H_E

Fig. 2 d) and e) compares d_{OT}/H_E with the ratio of S_L or S_D with H_E, respectively. Fig. 2 d) and e) shows that both SS and HSS embankment, S_D and S_L increased with increasing d_{OT}/H_E. However, it was observed that an HSS embankment model had a lower S_D and S_L. In d_{OT}/H_E of 0.28, S_D/H_E for SS was 0.87 while for HSS it was 0.82. Similarly, for S_L/H_E against d_{OT}/H_E of 0.28, SS was 3.1 and HSS was 2.97.

4. CONCLUSION

The experiment results showed that flow structure on embankment slope directly affected downstream scouring. A stepped slope embankment (HSS), compared to smooth slope embankment (SS), reduced the scoured depth (S_D) around 3.4%-5.9% and scoured length (S_L) around 3.8%-9.8%. The $d_{OT}/H_E = 0.18$ in HSS was skimming type flow, a d_c/h of 1.1, greater than 0.9. Therefore, further study on a modified stepped structure is encouraged i.e. increasing the step height or changing the roughness of the step (gabion boxes placed on a stepped embankment). This could further encourage energy dissipation, as well encourage the flow to change towards nappe type flow, which can hopefully further reduce the S_D and S_L values.

REFERENCES

Chanson, H. (2015, June 23). Embankment overtopping protection systems. *Acta Geotechnica*, Vol. 10, pp. 305–318.

Guenther, P., Felder, S., & Chanson, H. (2013). Flow aeration, cavity processes and energy dissipation on flat and pooled stepped spillways for embankments. *Environmental Fluid Mechanics*, *13*(5), 503–525.

Tanaka, N., & Sato, M. (2015). Scoured depth and length of pools and ditches generated by overtopping flow from embankments during the 2011 Great East Japan Tsunami. *Ocean Engineering*, *109*, 72–82.