THE EFFECT OF SUBMERGED WATER DEPTH ON SHEAR STRESS ACTING ON THE BED AND DOWNSTREM SLOPE OF LEVEE DUE TO OVERTOPPING

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1. INTRODUCTION

Bed shear stress has been an important subject to be quantified in many researches since it has a close relation to the scour around hydraulic structures. Therefore, many researchers have studied the method of investigating bed shear stress from direct measurement to modeling. Moreover, scouring at the downstream slope of the levee caused by the overtopping flow is also a vital topic. Therefore, the aim of this research is to investigate the influence of submerged water depth on; (1) the distribution and the reduction of bed shear stress, and (2) the stability of levee downstream slope by analyzing the force of water flow acting on the levee downstream slope.

2. EXPERIMENT PREPARATION AND MEASUREMENT PROCEDURE

The experiment was conducted in a 4m-long and 0.4m-width flume. Fig. 1 shows the experimental setup with a levee being upstream of the flume which had the height (H) of 10cm and a downstream slope (S) of 1:1.33. Water overtops the levee with the depth h_1 to a wooden rigid bed at the height of 10cm from the levee top. Downstream end of the rigid bed is a wooden sill to generate submerged conditions (h_3) for the experiment.

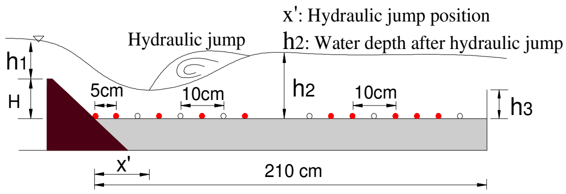

Fig.1. Schematic of experiment setup

The shear stress apparatus used in the experiment is S10W-2 (SSK Co. Ltd). This apparatus can measure shear force acting on the bed directly. The starting point of the shear stress measurement was 10cm from the toe. The distance between two adjacent points in the area near the toe was 10cm and a larger distance was considered for the remained area as shown by open circles in Fig. 1. Water depths were measured by using a point gauge with the accuracy of ±0.1mm. The starting position of the water depth measurement was at the toe of the levee slope and the gap between two neighboring positions was 5cm as shown by red circles in Fig. 1 (some points are at the same positions with shear stress measurement). During the experiment, videos were taken to determine the type and location of hydraulic jump.

3. RESULTS AND DISCUSSION

3.1 Hydraulic jump position and classification

Location of hydraulic jump nearest to the embankment (defined as x' in Fig. 1) depends not only on overtopping depth, but also on submerged water depth as shown in Fig. 2. With small overtopping depth, the location x' is close the toe and vice versa. In contrary, the smaller the submerged water depth is, the further the location x' is. Moreover, submerged water depth strongly affects hydraulic jump type. Specifically, undular hydraulic jump occurs with high submergence ($h_3/H > 0.4$); while strong hydraulic jump appears when having a low submerged water depth ($h_3/H < 0.2$) at downstream section (Fig. 3). In summary, high overtopping depth combined with low submergence results in strong hydraulic jump with the location of being far away from the levee toe.

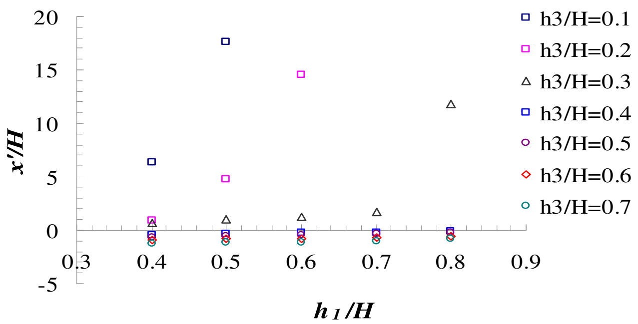

Fig.2. Location of hydraulic jump in relation to h_1/H

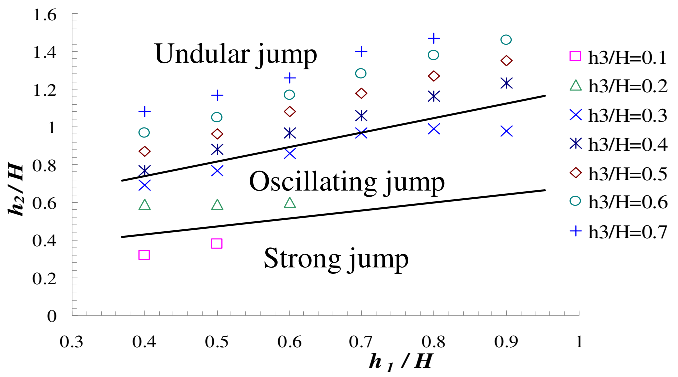

Fig.3. Classification of hydraulic jump occurred in this study

3.2 Shear stress distribution

Fig. 4 shows that shear stress decreases from the toe along the channel. The results also show that high overtopping depth,

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i.e. high flow energy, leads to a large value of bed shear stress. Whilst, hydraulic jump reduces shear stress significantly. Obviously, in front of hydraulic jump, shear stress is high and rapidly drops to a very small value due to energy dissipation within hydraulic jump.

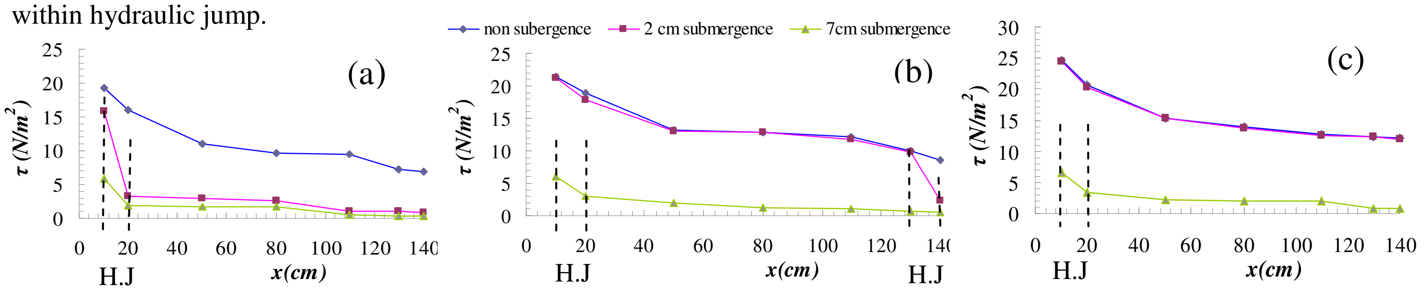

Fig.4. (a) Shear stress fluctuation- (a) 4cm overtopping, (b) 6cm overtopping, (c) 8cm overtopping; H.J: Hydraulic jump.

It is well-known that due to the effect of submerged condition, shear stress is smaller than that without submergence and that situation can be proved in Fig. 5 as shear stress reduction in y-axis. In addition, shear stress is much reduced when increasing submerged water depth at downstream section. For instance, with the ratio h_1/H =0.4, shear stress of $h_3/H=0.2$ is more than 3 times larger than that of h_3/H =0.7. This phenomenon can be explained that submerged water depth dissipates flow energy by generating hydraulic jump, which significantly reduces bed shear stress.

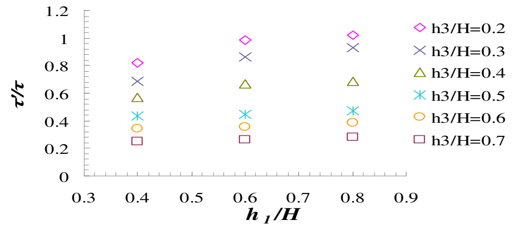

Fig.5. Shear stress reduction of fixed bed

3.3 Effect of submerged water depth on the force acting on the levee downstream slope

The force of water flow (F_{act}) acting on the levee downstream slope was calculated by using the momentum conservation equation within the control volume shown in Fig.6. The external forces acting on the control volume in horizontal direction include static pressure force F_1 and F_2, shear force at fixed bed F_3, and acting force F'_4. By applying the equation, the acting force can be expressed as $F'_4 = F_2 + F_3 + \rho.q(v_2 - v_1) - F_1$, where ρ: density of water (kg/m^3), q: flow discharge in a unit channel width (m^2/s), and v_1, v_2: flow velocities at section 1-1 and 2-2 in Fig.5, respectively. Then, acting force in the slope direction was calculated as $F_4 = F'_4/cos\theta$.

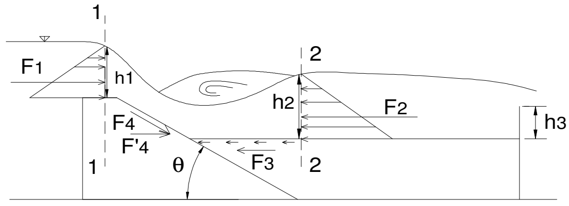

Fig.6. Forces acting on the control volume

Fig. 7 shows the effect of submerged water depth on force acting on the levee downstream slope. Interestingly, instead of decreasing the acting force by increasing submerged water depth conventionally, when submerged water depth is more than 2cm (h_3/H > 0.2), the acting force does not follow that rule. This phenomenon can be explained that undular hydraulic jump generated under high submerged water depths appears right after the levee slope; as a result, the water volume under the undular jump leads to the increase of the force acting on the slope. The similar phenomenon can be also seen in the research of Kells et al. (2001), in which they concluded that increasing tail-water depth leads to the increase of scour region behind the sluice gate. Therefore, in this research, h_3/H = 0.2 (h_3 = 2cm) is considered as the optimum value. Although more studies are needed for generalizing, the design to enhance the stability of the levee downstream slope should take the existence of this kind of optimum value into account.

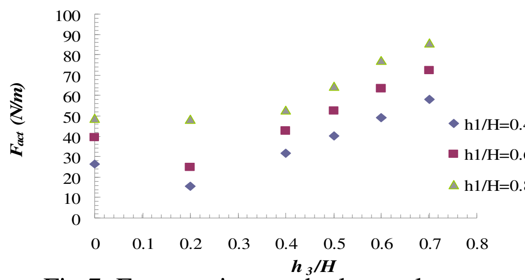

Fig.7. Force acting on the levee slope

4. CONCLUSION

The results can be summarized as following

1. The optimum value of submergence on the stability of levee dowstream slope is h_3/H = 0.2. When the submergence is larger than that optimum value, the acting force is increasing and vice versa.
2. Shear stress is gradually reduced along the channel because of the friction from the bed and it is decreasing with increasing submerged water depth due to energy dissipation within hydraulic jump.

ACKNOWLEDGEMENTS

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REFERENCE

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