STUDY ON EROSION OF COASTAL DIKE CONSISTS OF NON-COHESIVE FINE SAND UNDER TSUNAMI OVERFLOW

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1. INTRODUCTION

The safety of coastal communities under devastative events like tsunami has been a primary concern for a long time. Generally, coastal areas are protected against such natural disasters by natural and man-made barriers such as sand dunes, dikes and sea-walls. Therefore, paying careful attention on stability and resilience of such structures under severe conditions is very important. Coastal dikes are one of the major defensive structures against tsunami, and the destruction and failure of coastal dikes in the recent major tsunami events (i.e. 2004 Indian Ocean tsunami and 2011 East Japan Tohoku earthquake and tsunami) have raised the necessity of improvements and modifications to their existing design procedures. Thus, having clear and in-depth understanding about the failure patterns and characteristics of failure under different construction conditions is vital, in order to design coastal dikes to resist throughout the period of tsunami overflow. This study overlooks the eroding behavior of coastal dike under tsunami overflow and capability of numerically simulating the erosion process and the evolution of dike surface profile.

2. EXPERIMENTAL STUDY

A series of experiment studies has been conducted to assess the eroding behavior of coastal dikes constructed with different embankment materials [Honda et al. (2014)], and in the current paper, experimental and numerical simulation results are discussed for the case considering non-cohesive fine sand as an embankment material. Fig.1 shows the set-up for the laboratory model experiments which were carried out in the wave flume (47m long, 0.8m wide and 1.6m deep) in to 1:25 Froude scale. In the experiments, tsunami overflow was generated with an steady inflow to the flume and discharge of the overflow was determined as to maintain a flow depth of 4cm at the leeward crest of the dike under the stable condition. The dike was constructed with 1:2 slopes on the either side and with cautiously compacted layers of 5cm in thickness, up to a total height of 0.2m. The median grain size (d_{50}) of the sand particles used in the model construction was 0.26mm. The evolution of the dike surface profile under tsunami overflow was captured using a video camera which was placed outside the flume and facing normal to the flume wall.

3. NUMERICAL STUDY

Numerical simulation of the physical experiment was carried out as a two-dimensional study, mainly considering the profile of the experiment set-up and utilization of computational load. Three-dimensional coupled fluid-sediment interaction model developed by Nakamura and Yim (2011) was adopted for the simulation study. The model employs large-eddy simulation model as main solver, which is based on continuity and momentum equations for incompressible viscous air-water multi-phase flow that consider seepage flow in porous media and variations in sediment bed profile. It also consists of a volume of fluid (VOF) module for tracking air-water interface and, a sediment transport module which computes, the evolution of the surface profile for a sediment bed and distribution of suspended sediment concentration. Nakamura and Mizutani (2014) successfully employed this numerical model to analyze the local scouring due to

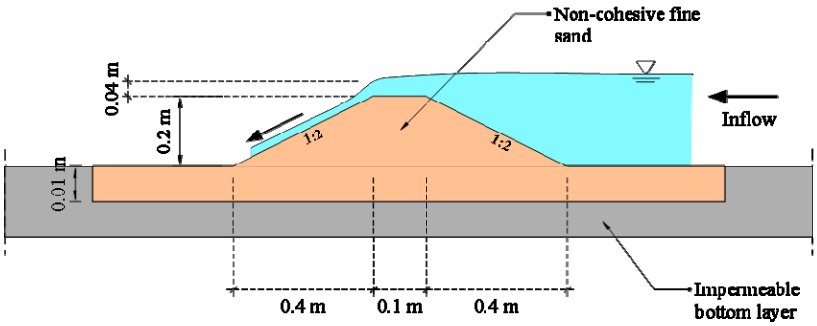

Fig.1 Sketch of experiment set-up

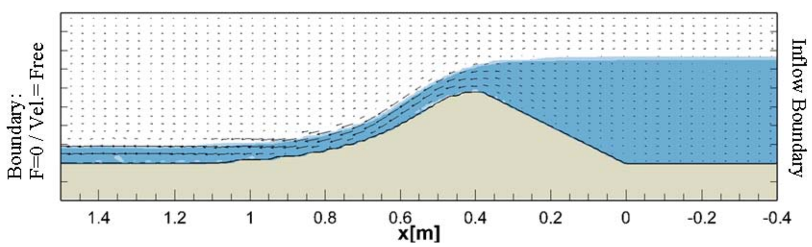

Fig. 2 Vector plot of flow velocity in numerical simulation. (t=20s)

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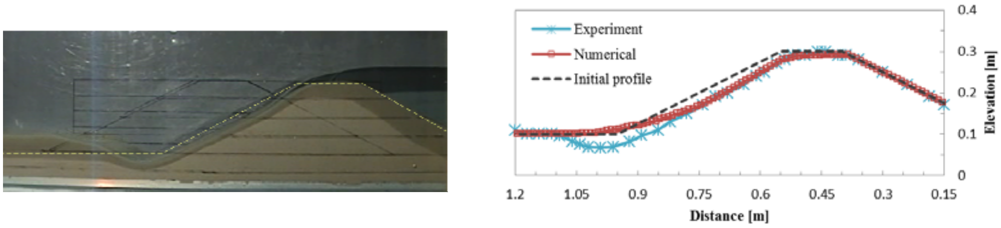
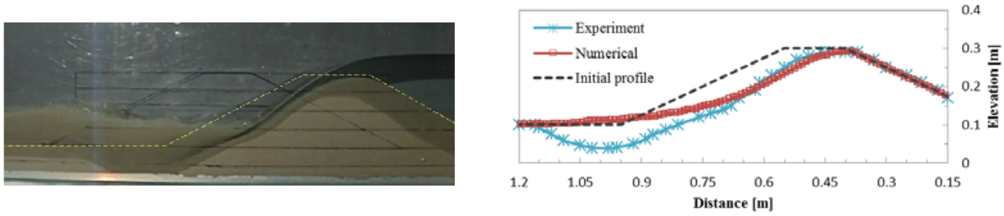
tsunami overflow for an impermeable coastal dike and highlighted the importance of considering the effects of infiltration/exfiltration in the sediment calculation for higher accuracy of results. A timed capture of computation domain, indicating flow behavior over the dike during the numerical simulation is shown in Fig. 2. A uniform mesh size of 10mm was applied in all directions throughout the dike area in the simulation domain, and gradually increasing mesh sizes were effectively utilized as damping zones in both landward and seaward sides of the computation domain.



(a) after 10s



(b) after 20s

Fig. 3 Snapshots of experiment (Left) and comparison of experiment and numerical results (Right) for dike surface profile

4. RESULTS & DISCUSSION

The snapshots of tsunami overflow in the experiment at 10s and 20s (t=0 as the time at the start of overflow) are shown in the Fig.3, together with the comparison of numerical and experiment results at the particular times. In the experiment, following the initial overflow of incoming tsunami, erosion started on the leeward surface of the dike, and top leeward edge of the dike gradually moved to seaward with the progress of local erosion. At the same time a hydraulic jump occurred close to the bottom of leeward slope, which increased the turbulence at the location, enhancing the local scouring process [Fig. 3(b)]. It is clear from the Fig. 3 that erosion of the leeward surface of the dike which occurred due to the overflow of tsunami is well reproduce by the numerical simulation except for the area of local scouring at the bottom of the leeward slope. This discrepancy is presumed to be a result of locating the outflow boundary relatively closer to the leeward end of the dike in aim of reducing the computational cost, which prevented the occurrence of hydraulic jump. Moreover, the comparison of temporal variation of the dike surface displacement (Δd) along the vertical direction at the location of initial leeward crest, for experiment and numerical cases is shown in Fig. 4. It can be seen from the figure that surface evolution is well captured by the numerical model.

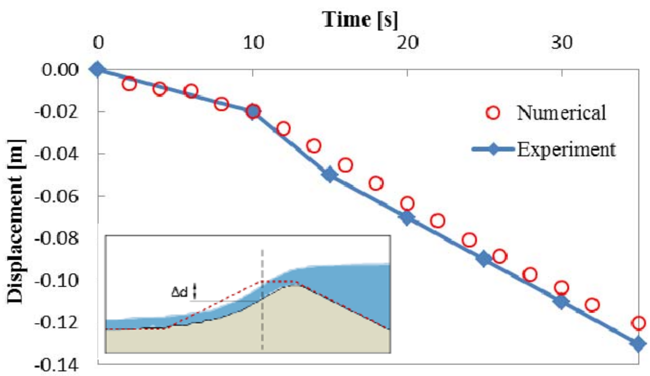


Fig. 4 Comparison of the vertical displacement of the surface at the location of leeward crest

5. CONCLUSIONS

Eroding behavior of a coastal dike which consists of non-cohesive fine sand, under tsunami overflow, was studied through both experiment and numerical simulation. Local erosion in the leeward slope of the dike and the local scouring at the bottom of the leeward slope are identified as dominant factors for the failure of the dike.

Numerical simulation considering the effects of in/exfiltration well reproduced the local erosion of the dike and the rate of erosion. Especially the evolution of the dike surface profile together with the movement of the temporal crest positions was effectively captured by the numerical simulation. Local scouring at the bottom of the leeward slope was under estimated in the simulation, which is presumed to be occurred due to the applied boundary conditions considering the reduction of computation cost. Further studies are recommended to improve the simulation process and to extend the analysis for dikes constructed with cohesive materials.

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