

EXPERIMENTAL AND NUMERICAL STUDY OF THE HYDRO-SEDIMENTARY DYNAMICS ON THE LAND SIDE OF A COASTAL DIKE

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INTRODUCTION

Coastal dikes are commonly found coastal defense structures in many tsunami-prone areas. They have proven effective in safeguarding coastal communities and valuable coastal assets during tsunamis and other extreme wave events. Nevertheless, the presence of such structures in the coastal area significantly influences the hydro-sedimentary dynamics of the neighboring coastal region. Moreover, wave overtopping on these protective structures lead to local erosion, referred to as scour. Scour has direct relationship on the stability of the structure, causes infrastructure damage, and poses risks to people on the landward side.

Recognising that tsunami-induced scour plays a pivotal role in structural failures, examining into the mechanisms of scour is crucial for shaping future design standards. This research can contribute to the creation of resilient design guidelines and effective mitigation strategies, as highlighted by McGovern et al. (2019). In spite of numerous numerical studies addressing scour patterns, only a few studies have considered the influence of coastal dike geometry on tsunami-induced scour at the landside. Consequently, this research paper focus on numerically examining the hydro-sedimentary dynamics occurring at the leeward side of a coastal dike. The study incorporates the tsunami-induced scour predictive model established by Jayaratne et al. (2016), which was developed through extensive laboratory experiments and validated using a hydrodynamic model based on the Reynolds-Averaged Navier-Stokes (RANS) approach, as well as a sediment transport model founded on the turbulence-averaged Eulerian two-phase flow equations.

EXPERIMENTAL MODELLING

Jayaratne et al. (2016) employed both field data from the 2011 Tohoku tsunami and laboratory experimental data collected at the University of East London to develop a practical predictive model for estimating scour depth at the landside of a coastal dike. The field survey team conducted measurements of scour trench depth and extent, assessed the structural geometry of partially or fully collapsed structures, captured digital photos and videos, recorded survey location coordinates, and gathered soil samples from damaged structures in Fukushima and Miyagi prefectures.

Laboratory experiments were performed at the University of East London using a hydraulic flume measuring 8.6 m in length, 0.305 m in width, and 0.315 m in depth. The experiments utilised three scaled coastal dike models (see Table 1) at 1:50, all featuring consistent structure heights of 0.1 m but with varying seaward and landward slopes. A 0.113 m layer of sand was placed immediately landward of the model dike to assess the trench depth and extent of

the scour profile. The sand used in the landward area had an average grain diameter (d_{50}) of 0.35 mm.

Table 1: Model dike dimensions

Dike name	Crest width (cm)	Seaward slope (-)	Landward slope (-)
A	10	1: 1	1: 1
B	15	1: 2.25	1: 0.7
C	2.4	1: 3	1: 1.4

To maintain consistency, the water depth behind the dam break gate (h_w) was kept at 0.3 m throughout the experimental programme. The water depth at downstream, referred to as h_d in the seaward of the dike, was varied to three distinct hydraulic conditions (1.5, 3.0 and 5.0 cm). A high-speed video camera was used to record the tsunami wave propagation following the opening of the dam as it approached the dike, and the subsequent scour process. Frame-by-frame analysis of the video footage was employed for in-depth scour examination, including the detection of fluid velocity.

Five pressure sensors, each digitised at a frequency of 25 kHz, were positioned in five distinct locations within the model dikes. After the wave had passed through the model dikes and the scour process had occurred, the final scour depth on the landward of the model dike was measured using a high-precision point gauge and video image analysis.

NUMERICAL MODELLING

The study employs the ANSYS Fluent, a computational fluid dynamics (CFD) modeling suite, to simulate incompressible 2D fluid flow resulting from a dam break wave. In this research, an unstructured mesh was applied to the beach slope and coastal dike areas, while a structured mesh was utilised in other regions of the investigated domain. Mesh sizes ranged from $\Delta x = \Delta y = 0.00001$ m to 0.01 m, maintaining a minimum orthogonal quality of 0.97 due to product limitations. The impact of friction on the flow was not taken into consideration. Figure 1 illustrates the various model sections utilised for establishing boundary conditions in the numerical model.

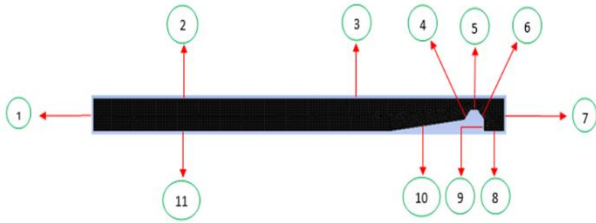


Figure 1 - Different model sections set up in ANSYS Fluent Software [(1) Left wall; (2) Inlet; (3) Free surface; (4) Seaward slope; (5) Crest; (6) Landward slope; (7) Right wall; (8) Bottom wall; (9) Back wall; (10) Beach slope; and (11) Bottom left wall].

The Volume of Fluid (VOF) method with Piecewise Linear Interface Calculation (PLIC), a technique pioneered by Youngs in 1982, was employed to represent the interface between the air and water phases. To address the substantial computational demands associated with fine grids near the near-wall region, a scalable wall function was implemented. This function effectively addresses complex factors, such as viscous effects inherent in turbulent flows, such as those occurring in tsunamis.

RESULTS AND DISCUSSION

The pressure values obtained from the sensors in the experimental test programme and from the numerical model tests are plotted in Fig. 2.

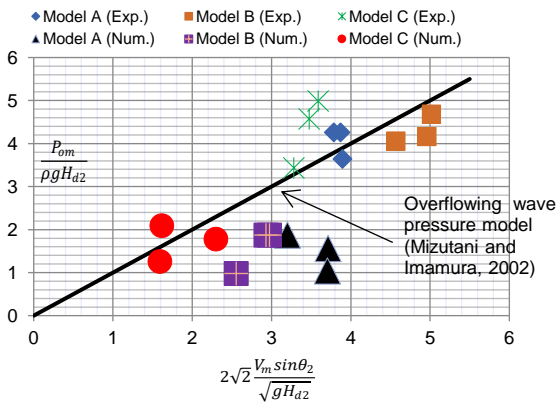


Figure 2 - The correlation between wave pressure due to overflow and flow parameters as observed in experimental and numerical simulations (P_{om} =maximum wave overflowing pressure, H_{d2} =Landward height of the dike, V_m =maximum flow velocity, θ_2 =landward slope of the model).

Figure 2 suggests that the experimental results aligned closely with the overflowing wave equation proposed by Mizutani and Imamura (2002). Notably, the values predicted by the numerical analysis did not show the same proximity as of the experimental results. Nevertheless, the predicted values from the numerical model were observed to be situated in proximity to the line representing overflowing wave pressure.

Scour depth data from experiments and numerical model simulations were plotted against the scour depth

predictive model results (see Fig. 3).

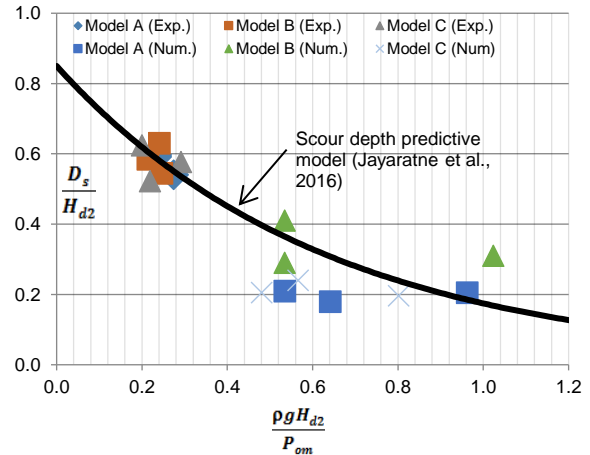


Figure 3 - Relationship between non-dimensional scour depth and the maximum wave overflowing pressure in laboratory (Exp.) and numerical (Num.) investigations (D_s =scour depth).

According to Fig. 3, it can be concluded that the scour depths obtained from the numerical study were notably less than those observed in the experimental data. This could be primarily due to the generation of lower overflowing wave pressures in the numerical model. This discrepancy may be attributed to the initial conditions or parameters used in the numerical analysis.

The outcomes of this study unveil a clear connection between shear stress, the representative scour depth, and its horizontal position from the landward toe. Additionally, the Root Mean Square Error (RMSE) was used to juxtapose the scour depths derived from this investigation with those predicted by Jayaratne et al. (2016), demonstrating a reasonable level of agreement.

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