# Erosion Prediction on Irrigation Reservoir Embankments

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## Abstract
Laboratory experiments and numerical simulations using XBEACH were carried out in order to understand the causes of wave induced erosion of earthen embankments and provide accurate prediction methods. A one-dimensional numerical wave tank was created using the XBEACH non-hydrostatic mode to simulate the erosion and retreat of a sand embankment due to regular waves. The numerical wave tank simulations were compared with the laboratory experiments that were carried out in a wave tank at the USDA-ARS National Sedimentation Laboratory to study wave erosion of a sand embankment ($D_{50}$ = 0.5 mm). The results showed that the XBEACH model approximately predicted the erosion profile and its progression, except during the initial formation of the beach slope. The simulation results were also compared with an analytical model. It was concluded that XBEACH is an adequate tool for predicting retreat in sandy soil embankments for individual storm events. This paper summarizes the key findings of the laboratory and numerical experiments.

## Introduction

Groundwater is the primary source for irrigation in the Lower Mississippi River Basin (Delta) which has resulted in significant depletion of the Mississippi River Valley Alluvial Aquifer (MRVAA). A widely adapted method to reduce the dependence on groundwater resources is the use of irrigation reservoirs and tailwater recovery systems (Figure 1). The embankments of the irrigation reservoirs are built using locally available soils and typically left unprotected, which makes them susceptible to erosion due to wind generated waves and surface runoff.

Shoreline morphology in wave dominated environments is a result of complex interactions between waves and wave relatefd currents, and the shoreline material. Wave induced shoreline erosion and dune recession is well documented in the literature. Reviews of the previous studies on dune erosion can be found in Komar (1976), Vellinga (1986) and Van Rijn (1993 and 2011). Many analytical and numerical models have been developed in order to understand and predict shoreline morphodynamics during storm events. Applicability of these models to wave erosion of earthen embankments is limited because of differences in material types and scaling (Ozeren et al., 2021).

In this study, laboratory experiments and numerical simulations using XBEACH, an open-source coastal modeling software developed by Deltares, were carried out in order to understand the causes of wave induced erosion of earthen embankments and provide accurate prediction methods. In what follows, the key findings of numerical and laboratory experiments are summarized.

**Figure 1.** An irrigation reservoir near Shelby, MS

## Laboratory Experiments

Laboratory experiments were carried out in a 20.6 m long, 0.7 m wide, and 1.2 m deep laboratory wave tank at the USDA-ARS, National Sedimentation Laboratory in Oxford, Mississippi (Figure 2). The model embankments were constructed using sand with a median diameter of $D_{50}$ = 0.5 mm. A standardized packing procedure was used to establish the steep model embankment in the wave tank. Before packing, the residual moisture content of the sand was approximately 8% - 24%. The sand was then placed on the down-wave end of the wave tank in 5 cm thick layers. Each layer was packed with a roller. The final height of the model embankments was 0.5 m. Particle size distribution and packed bulk density of the model embankments were measured for each experiment.

The experiments consisted of varying regular wave heights with a constant wave period of $T$ = 1.2 s and still water depth of $h$ = 30 cm (Table 1). Each model embankment was exposed to waves for 10-minute-long intervals with 3 minutes resting period in between. The evolution of the embankment profile was monitored using photogrammetric methods. The embankment and water surface profiles were digitized using automated edge detection algorithms (Ozeren et al. 2021).

**Table 1.** List of laboratory experiments.

| Experiment | Measured wave height, $H$ (m) | Number of 10 min cycles | Initial profile |
|---|---|---|---|
| 190411 - AR-H060T1201 | 0.061 | 172 | |
| 190424 - AR-H060T1202 | 0.060 | 100 | |
| 190514 - AR-H060T1203 | 0.060 | 100 | |
| 190521 - AR-H034T1201 | 0.034 | 100 | |
| 190522 - PE-H060T1201 | 0.060 | 100 | Eroded profile (190521) |
| 190523 - PE-H083T1201 | 0.083 | 100 | Eroded profile (190522) |
| 190605 - AR-H075T1201 | 0.075 | 100 | |
| 190619 - AR-H034T1202 | 0.034 | 100 | |
| 190702 - AR-H060T1204 | 0.061 | 100 | |

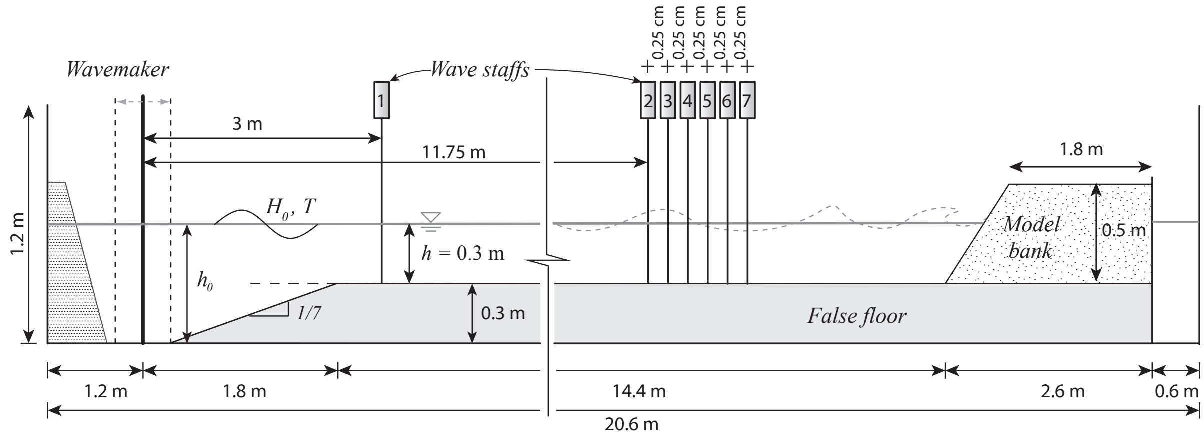


**Figure 2.** Definition sketch of the experimental setup

# XBEACH Model

XBEACH is a process-based coastal morphodynamic model that can simulate one-dimensional and horizontal two-dimensional nearshore hydrodynamics of surface waves and wave-induced currents coupled with non-cohesive sediment transport, avalanching of dune fronts and morphological change. The model has been extensively validated against laboratory and field studies and applied to modeling a large variety of coastal erosion problems from storm event time scale to longer timescales (Roelvink et al., 2009, Eichentopf et al. 2019). Their results showed that XBEACH agreed reasonably with various analytical solutions and was well suited for simulating complex profiles and first- and second-order wave generation. In this study, a section of the laboratory wave tank setup was simulated using the nonhydrostatic mode of XBEACH on a 1-dimensional computational domain. The computational domain was discretized with regular mesh of varying grid spacing between $\Delta x = 5$ mm near the model embankment and $\Delta x = 100$ mm offshore (Figure 3). The digitized embankment profiles of the laboratory experiments were used to define the initial embankment profile in the numerical model, and the wave tank floor was represented with a non-erodible boundary.

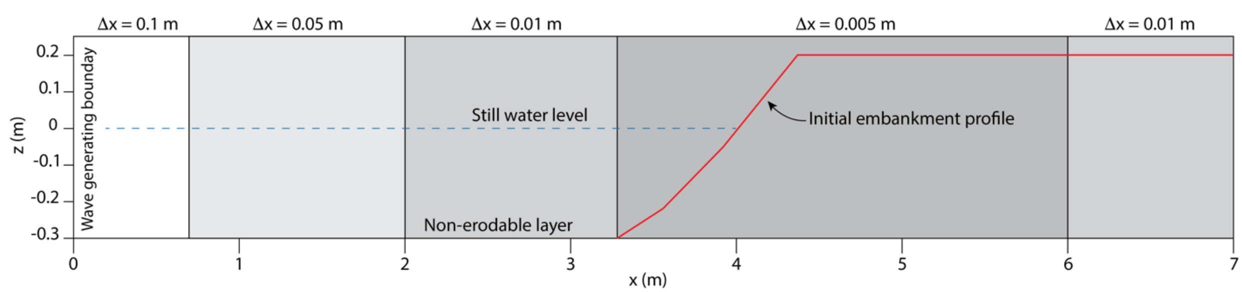


**Figure 3.** Computational domain for the XBEACH simulations

Initial water depth was 0.3 m for all simulations as in the laboratory experiments. A constant wave period, $T_{rep}$ = 1.2 s and root-mean-square wave heights, $H_{rms}$ = 3.4 cm, 6.0 cm, and 8.0 cm were defined at the offshore boundary. The sediment density was $\rho s$ = 2650 kg/m³, the porosity was 0.445 the median diameter was $D_{50}$ = 0.5 mm, and critical slopes in the wet and dry regions were set to 0.4887 and 1.37 based on what was measured during the laboratory experiments.

# Results and Discussions

The measured profiles of the laboratory experiments were compared with the XBEACH simulations corresponding to the same times. Figure 4 shows a comparison of the simulated profiles with the picture from one of the laboratory experiments. Measured and simulated embankment profiles at different times are compared for three different wave heights in Figure 5b. The Brier Skill Score (BSS) was used to characterize the performance of the XBEACH model for profile change (van Rijn et al., 2003). The results show that the XBEACH model sufficiently predicted the erosion profile and its progression, except during the initial formation of the beach slope.

The laboratory experiments showed that for both sand embankments in this study and earthen embankments reported in Ozeren et al. (2021), the steep initial profile was eroded in a relatively short time by discrete block failures, which was not captured by the numerical model. After the first few 10-min wave cycles, the embankment profiles predicted by XBEACH agreed well with the laboratory measurements.

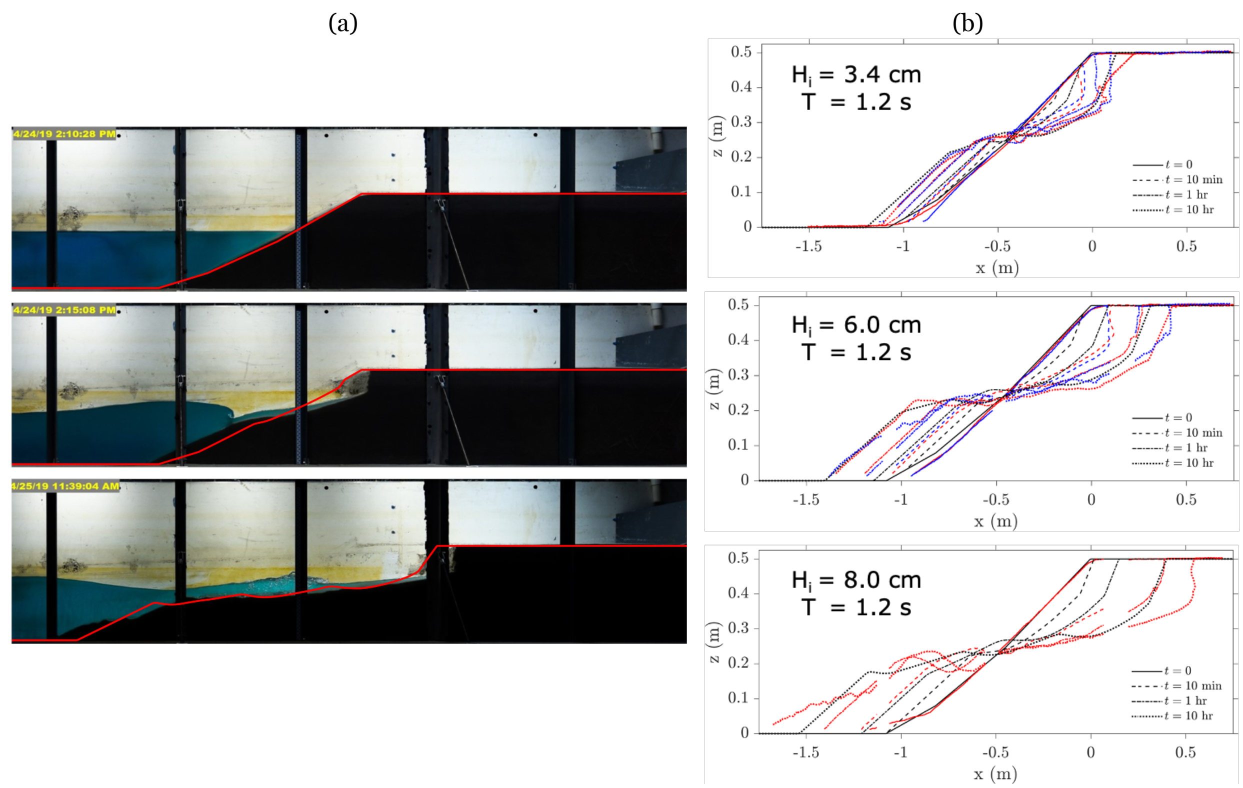


**Figure 4.** (a) A comparison of pictures taken during the experiment AR-H060T1202 and the corresponding XBEACH simulations, and (b) comparison of the simulated and measured profiles. Measured profiles are shown in red and blue, and simulated profiles are shown in black

Figure 5 compares dimensionless erosion volume derived from laboratory measurements for sand and earthen embankments, as well as XBEACH simulations. The dimensionless variables are based on the analytical model in Ozeren et al. (2021). Although the recession rates of both sand and earthen embankments were similar, the earthen embankment had a much larger erosion volume than the sand embankment initially, but the sand embankment reached an equilibrium profile much quicker and at a steeper beach slope than the earthen embankment. In general, initial erosion was underestimated by XBEACH.

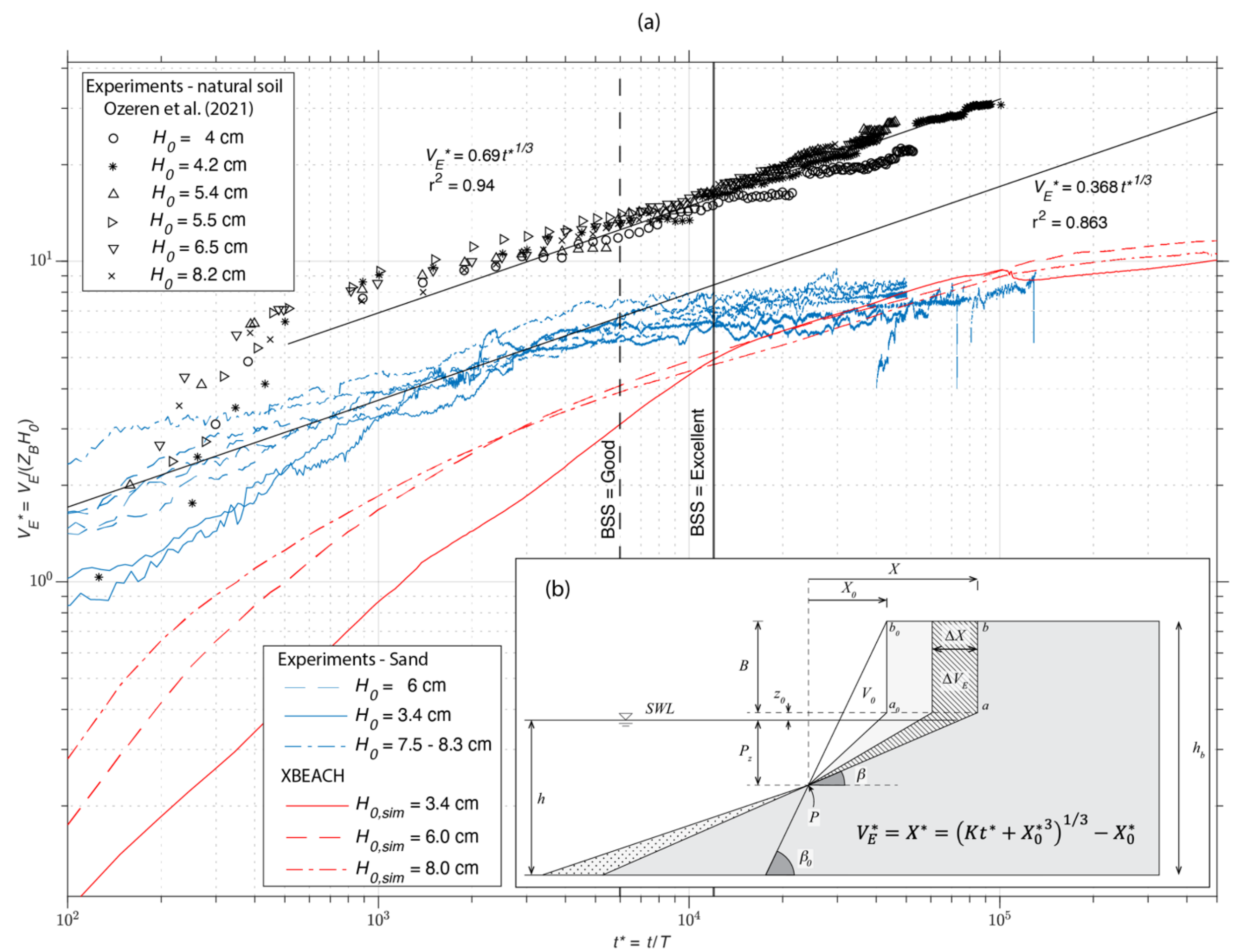


**Figure 5.** Dimensionless time evolution of (a) erosion volume ($V_E$, $Z_B$, $H_0$, $t^*$, $t$, $T$) compared with the analytical solution (Ozeren et al., 2021) and XBEACH simulations; (b) Description of the analytical model and key variables used. A detailed description of the variables can be found in Ozeren et al., 2021

# Conclusions

Laboratory experiments and numerical simulations using XBEACH were carried out in order to understand the processes observed during the wave induced erosion of reservoir embankments and to provide improved prediction methods. The results showed sand and earthen embankments eroded at similar rates, but the sand embankment reached an equilibrium profile much more quickly than the earthen embankment. The XBEACH model approximately predicted the erosion profile and its progression, except during the initial formation of the beach slope. It was concluded that XBEACH is an adequate tool for predicting retreat in sandy soil embankments for individual storm events and can be extended to multiple storms. The experiments in this study were limited to a fixed water depth and wave period. Additional experiments with a range of wave periods as well as irregular waves will provide additional data to better tune the numerical model and improve the understanding of morphodynamic response of reservoir embankments to wave action.

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