WAVE STORM INDUCED DUNE EROSION AND OVERWASH IN LARGE-SCALE FLUME EXPERIMENTS

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Large-scale physical model tests are ongoing at CIEM wave flume of the Polytechnic University of Catalonia. This paper presents some aspects of the study aimed to analyze the effect of wave storm events on dune erosion and overwash processes. Two different regimes of storm attack on the sandy beach/dune system are investigated: a collision regime with swash and run-up to the dune face and an overwash regime with wave run-up overtopping the dune crest (Sallenger et al. 2003). Eight run tests are performed with a combination of four irregular wave conditions and two different water depths. Detailed measurements in time and space of profile evolution, hydrodynamics, sediment concentration, overtopping rate and photogrammetric survey are carried out.

1. INTRODUCTION

Disaster due to storm surge and waves in the era of global warming and accelerated sea level rise are the major threats to coastal nations such as the U.S., Japan, the Netherlands, Italy and Portugal. Dunes and beaches have been successful coastal protectors for centuries due to their ability to defend to storm impact. However, storm-driven surge, wind and waves can cause severe dune erosion with large-scale morphology changes, damages to infrastructures and loss of human lives. Failure of the dunes takes place when the rate of dune erosion is so large that flooding of the lowlands behind them occurs. Sallenger et al. (2003) defines four regimes of storm attack on a beach/dune system:
1) swash regime with wave run-up confined to the foreshore;
2) collision regime with swash and run-up to the dune face;
3) overwash regime with wave run-up overtopping the dune crest;
4) breaching and inundation regime.

Herein, the attention is focused on dune erosion processes during storm events in the collision regime and in overwash regime. In one case, the incoming storm waves break frequently, resulting in large components running up the dune face. Sand is dragged down the slope by the down-rush causing erosion of the beach and dune with the undermining of the dune toe. Part of the dune face collapses and lumps of sediments slide downwards to form a bar/step. Experiments on dune erosion using scale models have been performed by Vellinga (1986), Deltares/Delft Hydraulics (2004, 2006a,b, 2007), Van Gent et al. (2008). Similar experiments have been done in Germany (Dette & Uliczska 1987, Newe et al. 1999) focusing on German coastal conditions and in the USA (Kraus & Smith 1994) focusing on USA coasts. In the other case, when the waves have sufficient energy to overtop the dune crest, overwash occurs and the sediment is eroded over the top of the dune and transported to be deposited on the backshore. Although qualitative observations of the overwash processes and overwash related coastal hazards have long been discussed in coastal engineering literature (Donnelly et al. 2006), relatively few laboratory studies on dune overwash have been conducted (Williams 1978, Hancock 1994, Hancock & Kobayashi 1994, Kobayashi et al. 1996) and comprehensive physical and field data sets are still lacking. The paper first addresses the description of the model set-up, the test program and the instrument deployment. The paper ends with the presentation of some preliminary results.

2. SET-UP OF PHYSICAL MODEL AND TEST PROGRAMME

The experiments are conducted at the CIEM wave flume of the Polytechnic University of Catalonia. The dimensions of the CIEM wave flume (100 m length, 3 m wide and 5 m depth) allow to perform nearly prototype-scale experiments with a movable bed beach. The initial cross-shore profile is assumed to match a field dune beach profile, named "Canto do Marco", located north of Figueira da Foz, along the Atlantic coast of Portugal (Figure 1).

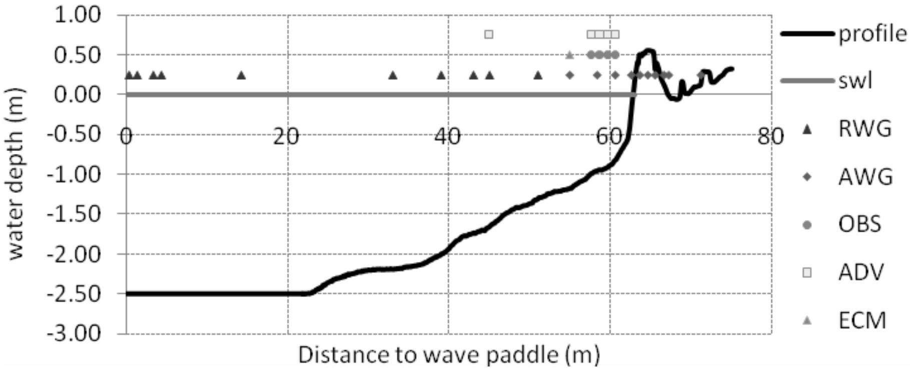


Figure 1. Initial profile and instruments locations

The sand in the flume is well sorted and its mean diameter is 0.246 mm with measured fall velocity of 34 mm/s. A wedge-type wave paddle is used to generate irregular waves, based on Jonswap spectrum ($\gamma = 3.3$). Table 1 summarizes the test programme with the adopted water depths and wave conditions at the wave paddle.

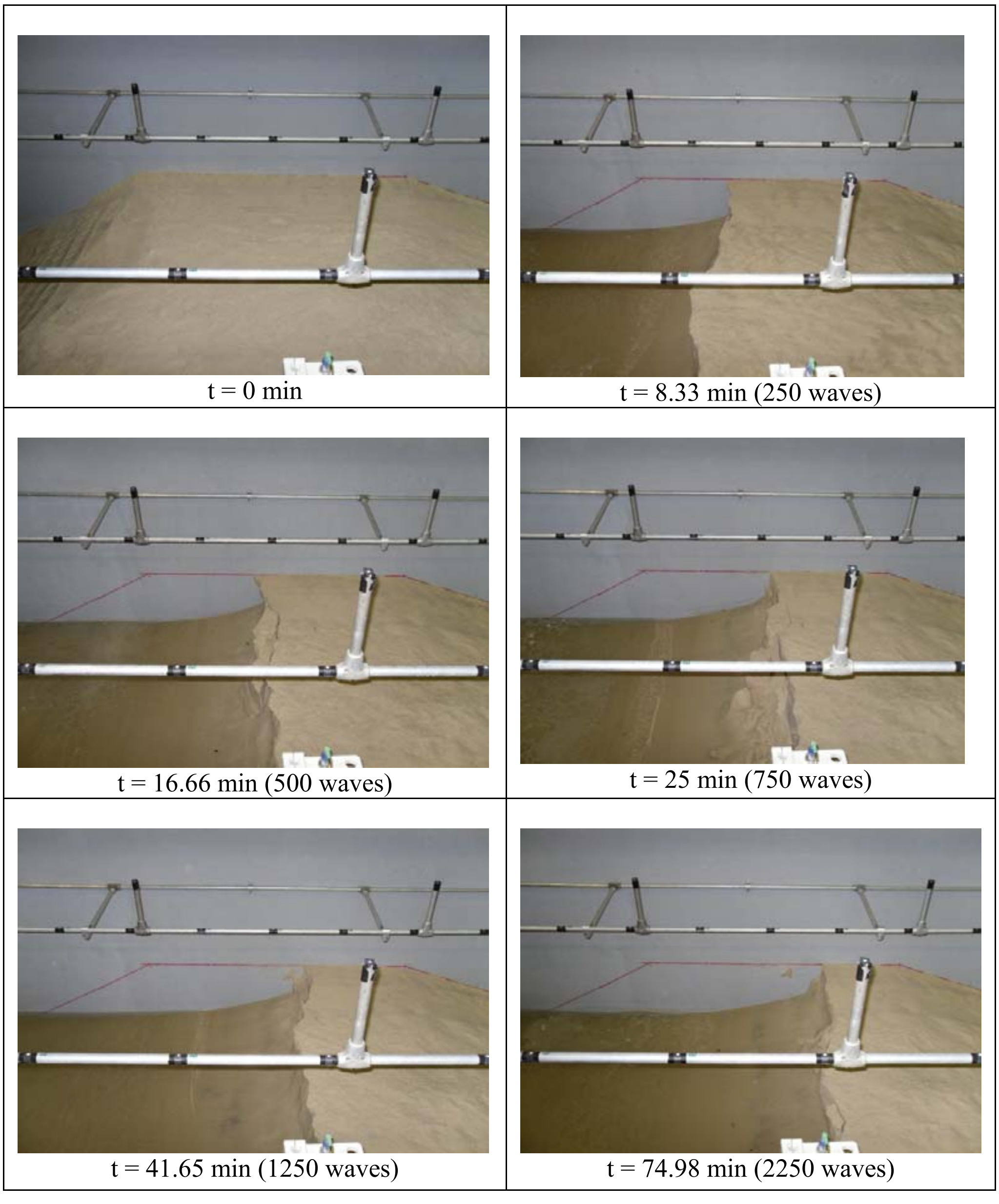
Table 1. Test programme with wave conditions at the wave paddle

TEST	Water Depth (m)	h_{dune} (m)	$H_{s,0}$ (m)	T_p (s)	s_p
A	2.35	0.65	0.25	2.5	0.026
B	2.35	0.65	0.33	2.5	0.034
C	2.35	0.65	0.33	3.0	0.024
D	2.35	0.65	0.33	3.5	0.017
E	2.50	0.50	0.25	2.5	0.026
F	2.50	0.50	0.33	2.5	0.034
G	2.50	0.50	0.33	3.0	0.024
H	2.50	0.50	0.33	3.5	0.017

Detailed measurements of water surface elevation, flow velocities and sediment concentration along the flume are carried out during each test (Figure 1). In particular, eleven resistant wave gauges (RWG) and four acoustic wave gauges (AWG) are used to measure the time series of free surface elevation above SWL, with five resistant wave gauges adopted to separate incident and reflected waves. Five Acoustic Doppler Velocimeter (ADV) are used to measure fluid velocities in the water column. Eight Optical Backscatter Sensor (OBS) are placed at four transects, at the locations where the velocity measurements, to allow a correlation between the velocity and concentration observations. Four spherical S-type Electromagnetic Current Meter (ECM) measure instantaneous flow velocities at a fixed transect in the flume. Bed profile measurements are carried out using a mechanical profiler. Each test is temporarily interrupted to carry out the bed profile measurements at fixed time intervals. Photogrammetric survey is carried out in order to evaluate topographic changes due to overwash action in the rear side of the dune. High resolution digital cameras and software for stereogrammetry (James et al. 2006) are used in the experiments, with estimated accuracy of ~1 mm. To carry out overtopping measurements five ultrasonic sensors are installed, with a vertical difference of 25 cm from the crest of the dune, from the front side of the crest to the rear side of the dune. From the signal acquisition are obtained information on the flow depth of the overtopping tongue (Bosman et al. 2008). In addition, is used an overtopping tank to calibrate the signal of the ultrasonic sensors and to measure overtopping volume. The overtopping tank is equipped with a pump and a sensor inside to monitor the water level in real time. On the top of it, a sediment trap is placed attached to a weight measuring system. The load of sediment is measured in time. The overtopping tank is also equipped with a wooden board to channel the incoming flow inside it. To avoid erosion, when the overtopping tongue crosses the intersection between the dune and the wooden board, a heavy duty plastic sheet is placed between the end of the board and the dune. This sheet is attached to the board surface near the edge, extended far enough into the dune so that it is not exposed and removed by wave action. Finally, six pressure cells are installed fixed in the dune. These pressure cells give more information about the pressure of the overtopping tongue. The signal can be also used if the ultrasonic meters are out of range.

3. VISUAL OBSERVATIONS ON DUNE EROSION PROCESS

Detailed observations during the ongoing experiments in the large-scale CIEM wave flume show the occurrence of two different processes:
1) regular sliding and retreating of the dune face when it has become too steep and formation of a bar/step at the toe of the dune;
2) overwash with wave run-up overtopping the dune crest.
Figure 2 shows an example of process type 1) with the development of the dune erosion volume during the test E.



t = 0 min; t = 8.33 min (250 waves)
t = 16.66 min (500 waves); t = 25 min (750 waves)
t = 41.65 min (1250 waves); t = 74.98 min (2250 waves)

Figure 2. Development of dune erosion volume during test E

The incident waves reach the dune face and run over it. As a result, the dune front becomes steeper till it is nearly vertical or even overhanging. As a consequence, the dune face retreats under waves impacting it. Episodically, the dune face collapses and big lumps of sediment fall or slide down the dune face on the beach in front of the dune. This sand is picked up by swash and surf zone processes that move the sediment seaward to form a bar/step. It appears evident that at the beginning of the test the erosion rate is significantly larger than at the end of the test. Another interesting aspect to be considered in the analysis is due to the impact (wave collision) of incoming breaking waves and outgoing reflected broken waves generating a large amount of turbulence.

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