

CHAPTER 187

Large Scale Laboratory Tests of Dune Erosion

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Introduction

An ongoing research program at North Carolina State University (NCSU) has investigated the viability of a mechanics based swash induced dune erosion model. Early work includes both small scale laboratory and field experiments. The overall objective of the experiments was to determine the relationship between the swash characteristics and dune erosion under a variety of conditions. A linear relationship between the specific swash force (per unit width of the dune) as defined by the bore depth and velocity, and the specific volume eroded has been documented for an individual swash (in the lab), Overton et al. (1988) and for a series of swash events (in the field) Fisher et al. (1987). Problems of scale, dune material and manner of construction in the field led to a series of experiments in the large wave tank at Oregon State University (OSU). The objective of the OSU tests was to investigate the relationship between the swash force and the volume eroded for two prototype scale dunes of different sand grain size.

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Experimental Design and Setup

The experiments were designed to simulate dune erosion under storm conditions at prototype scale. The experimental design and procedure summarized in the following are described in detail in Stone (1989). The OSU wave tank has a length of 104 m, a width of 3.7 m and a height of 4.6 m and is equipped with a programmable wave generator. The permanent bottom of the flume is flat with a 3.6 m step at one end. In order to accommodate the beach and dune requirements, the tank was modified in two ways. One, a beach with a 1:10 slope was installed. Two, side walls were constructed at the location of the dune to increase the height of the tank to 2.5 m. This would allow for the dune to be built with a height of approximately 2 meters.

Two dunes were constructed on the step portion of the tank as shown schematically in Figure 1. The economics of testing dictated that the dunes were built during the initial tank modification and setup phase of the experiments. Therefore, two dunes were built with a depth along the length of the tank of approximately 4 m with a plywood barrier placed at point B to separate the two. Similar material, fine sands, with median sand grain sizes, d_{50} , of 0.32 mm and 0.23 mm were used for construction. This material was locally available river sand. Dunes were constructed by placing sand in the

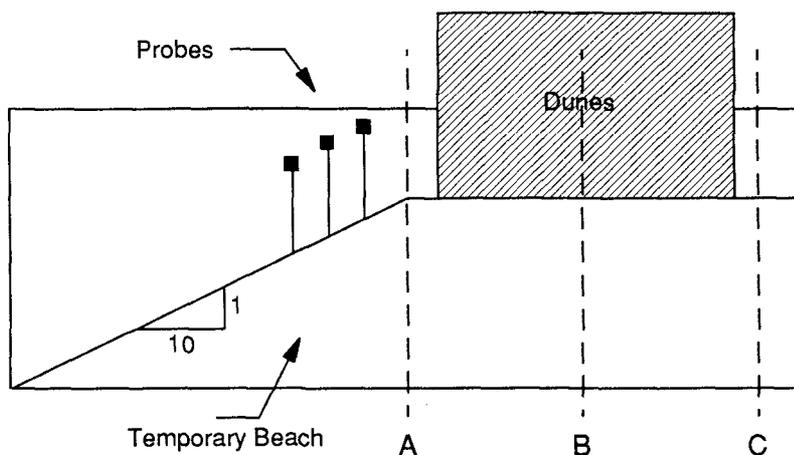


Figure 1. Schematic of the experimental setup.

flume with the aid of a Bobcat front-end loader. Sand was added to the flume in 30 cm layers. A vibrating compactor was then used to consolidate the material. The compactor was run across the top of the dune at least twice for each layer. This procedure was repeated until the dunes were approximately 1.5 m high.

Swash data was collected by three capacitance type wave gages placed on the beach in front of the dune. The probe closest to the dune was set 2.5 m away so that as the dune began to erode and collapse the dune material would not bury the probe. Bore depth was determined from the record at this probe. The subsequent probes, intended for use in determining the velocity of the leading edge of the bore, were placed 1 m apart, Figure 1.

Dune position was documented by a 35 mm camera before, during and after each experiment. Each photograph of the dune included the profile of the dune face and a 60 cm by 60 cm standard grid to determine scale. Specific volume eroded for a given event is defined as the difference in area between the original dune position and subsequent position at the defined interval of time.

Each experiment proceeded as follows. The pre-test beach and dune profile was surveyed. Instrumentation was calibrated and synchronized. Pre-test dune position was documented on film. Waves were generated which eroded the dune face. The experiment continued until sufficient erosion was recorded, at which time the wave generator was shut down. Post-test profiles and position of the dune were then determined.

Eleven experiments were successfully conducted. The conditions of each test are given in Table 1. Five of the tests were on dune one ($d_{50} = 0.32$) and six on dune two ($d_{50} = 0.23$). The wave height and the wave period were held constant for the duration of an individual test, however, the beach slope and distance from the dune altered with the subsequent erosion and adjustment of the beach. The test wave heights ranged from 0.46 m to 1.02 m while the wave period ranged from 5 secs to 10 secs. Four tests, numbers 6, 8, 7 and 9, conducted on dune two, had the same wave conditions in order to look at the repeatability of results. With each test, the horizontal distance from the mean water level and the dune changed as the dune eroded, however the tank was filled several times to bring the water level back within range. This distance varied between approximately 0.9 m and 3.0 m.

Test #	Wave Period (secs)	Wave Height (m)	Beach Slope	Distance from Dune (m)	Grain Size (mm)
1	7.0	0.86	0.18	2.18	0.32
2	7.0	0.61	0.10	0.92	0.32
3	10.0	0.46	0.12	1.92	0.32
4	5.0	0.91	0.12	2.32	0.32
5	7.0	0.91	0.12	0.98	0.32
6	7.0	0.61	0.10	2.03	0.23
7	10.0	0.46	0.13	2.50	0.23
8	7.0	0.61	0.14	2.48	0.23
9	10.0	0.46	0.19	2.88	0.23
10	7.0	1.02	0.18	3.15	0.23
11	7.0	0.46	0.14	3.11	0.23

Table 1. Test conditions.

Data Reduction

The experimental data were analyzed for two parameters, specific swash force and specific volume of dune eroded. Earlier work, both small scale laboratory and field work, indicates that a linear relationship exists between these two factors, (Fisher, 1987 and Overton, 1988). Specific swash force is quantified as

$$SF = \rho v^2 d \quad (1)$$

where ρ is the density of the water, v is the leading edge velocity of the swash and d is the depth of swash immediately after impact with the dune. These data were determined from the records of the three capacitance swash gages placed on the beach in front of the dune. A sample of this data is shown in Figure 2. For each time history for an individual swash the following characteristics are observed. One, a dramatic increase in the water depth marks the time that the swash hits the probe. The rule of thumb used was if the depth increased 3 cm in 0.1 seconds it was assumed that a swash was on the beach. Because the probes were buried in the beach approximately 30 cm, the background reading in the absence of a swash indicates the moisture in the sand. Two, the depth of the swash increases and then levels off. This plateau is taken to be the maximum depth of the swash before the backwash moves down the beach and interferes with the signal. Three, there is a subsequent rapid increase and decay in the depth which signifies the

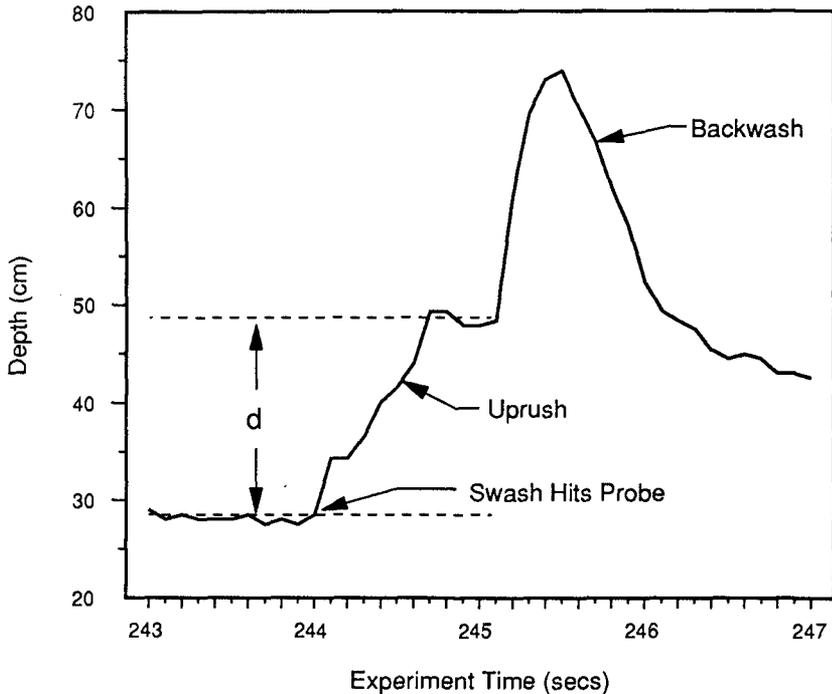


Figure 2. Swash depth versus time at the dune.

passing of the backwash. The depth of swash required in computing the specific force is the difference between the background depth and the depth of the plateau before backwash, Figure 2.

The velocity of the leading edge of the swash is determined by identifying the time at which the bore hits the first and last probes on the beach. An example of this data is given in Figure 3. The characteristic shape of each depth time history is above. The feature required for the determination of velocity is the time the bore hits the probe. From this, the velocity is calculated based on the distance traveled between two swash probes (2 m) and the time of travel, dt .

The force for each bore was calculated using Equation 1. While quantifying the force for an individual bore is possible, it was not always possible to measure the amount eroded due to that loading. Therefore, the summation of the force in a given interval of time versus the volume of dune eroded in the same time

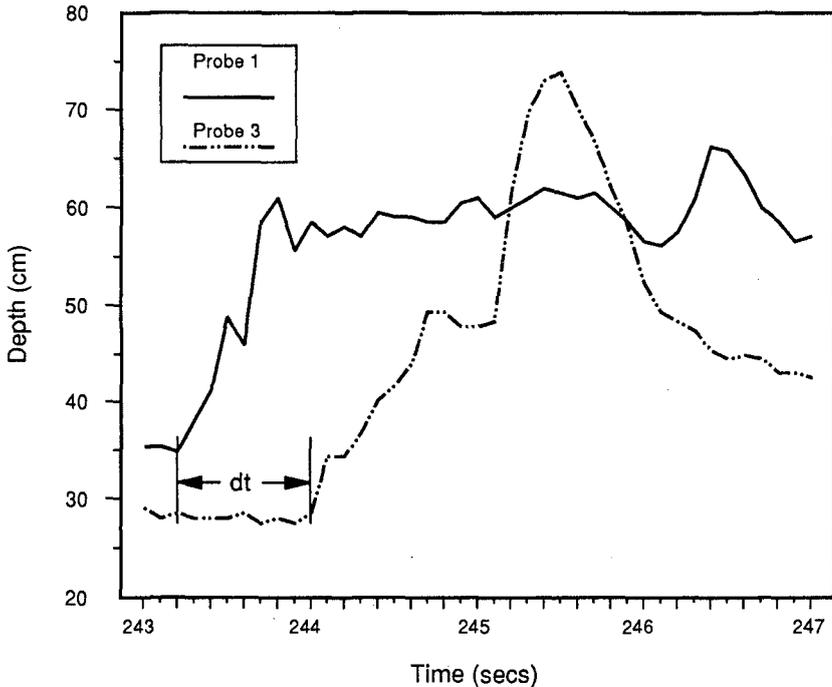


Figure 3. Depth versus time at two probes placed 1 m apart.

interval becomes the quantity evaluated. The duration of an experiment is the time between the first swash that hit the dune and the last slide taken to document the position of the dune.

Specific volume eroded was determined from the before and after profiles of the dune face as recorded on 35 mm film. Pre-test profiles were shot to record the initial dune face position. Then, during the test, photos were shot at a minimum of three minute intervals for the duration of the test. The time of the shot was recorded either in the field book or on the photo by the data back on the camera. This enabled not only before and after quantification of the dune position but the progressive erosion as well. In order to differentiate between beach erosion and dune erosion, the initial face of the dune was used to define the seaward extent of the dune. Regardless of the orientation of the material as the dune failed and the beach readjusted, the volume lost from the dune was determined as material lost landward of the original dune face. Obviously, the numerical value

of the volume eroded could vary with the interpretation of the differentiation of dune and beach material.

In order to quantify the data, the black and white 35 mm film was developed and mounted as slides. These slides were projected and the dune image traced in order to digitize volumes. The reference grid included in each frame was used to determine the scale. The original plan was to record the erosion by photography on both sides of the flume; however, due to equipment malfunction a complete set of data on one side of the flume only was available. Therefore, the numbers used in the analysis represent one side of the dune and the assumption is that the erosion was uniform across the dune face.

Results

The results of the experiments, as quantified by specific force and erosion, are given in Table 2.

TEST NUMBER	SWASH FORCE (kN/m)	VOLUME ERODED (m ³ /m)
1	90.6	0.20
2	195.5	0.39
3	101.3	0.05
4	133.0	0.16
5	233.6	0.54
6	158.4	0.25
7	50.0	0.10
8	187.8	0.29
9	54.0	0.08
10	258.0	0.37
11	93.0	0.23

Table 2. Specific swash force and volume eroded.

The data were analyzed with three objectives in mind. One, were the experiments valid with respect to reproducibility? Two, would the linear relationship established in the earlier work hold up for prototype wave and dune conditions? Three, would grain size effect this relationship?

In order to examine the first question, two experiments were conducted with identical offshore wave conditions. Experiments 6 and 8 were conducted with a 7 second period and a wave height of 0.61 meters. Results from these tests presented in Table 2 indicate that conditions in experiment 8 netted a higher force and a correspondingly higher volume eroded than in experiment 6. This can be accounted for by the duration of the experiment. Experiment 8 was approximately 200 seconds longer than experiment 6. Given the wave period, this represents approximately 28 additional swashes that attacked the dune. Using intermediate photography, it was possible to analyze experiments 6 and 8 at durations of 499 and 509 seconds, respectively. Therefore, the specific force and the specific volume eroded for these intervals were 126.4 kN/m and 123.5 kN/m and 0.190 m³/m and 0.184 m³/m, respectively, representing a 4% difference in results. Likewise for experiments 7 and 9, in which in which the measurable difference between experimental results is a specific force of 4 kN/m and a specific volume eroded of 0.02 m³/m. It is felt that these measures indicate the reproducibility of the experimental conditions and results.

The linearity of the relationship is examined by plotting and analyzing the data. The data were first analyzed as two distinct sets, characterized by sand grain size. Separately, the hypothesis of a linear relationship holds as these data fit with r squared values of 0.74 and 0.86 for sand grain size 0.32 and 0.23 respectively. Given this, the question was asked if the data could support the conclusion that these two lines (relationships) were unique, i.e., that based on these tests that sand grain size had a significant impact on the results. In order to answer this question a test for parallelism was performed. It was hypothesized that the relationships were parallel (and thus the same). Statistically, this hypothesis could not be rejected. This indicated that the data did not support the hypothesis that the force erosion relationship could be distinguished by sand grain size. Thus, Figure 4 presents the data and the line which best fits the data presented as a single dataset. Forcing the line through the origin (no force, no erosion), the slope of the best fit line is 0.00174. This correlates with an r squared value of 0.78.

Conclusions

The results from the large scale laboratory experiments at OSU support the hypothesis that the volume

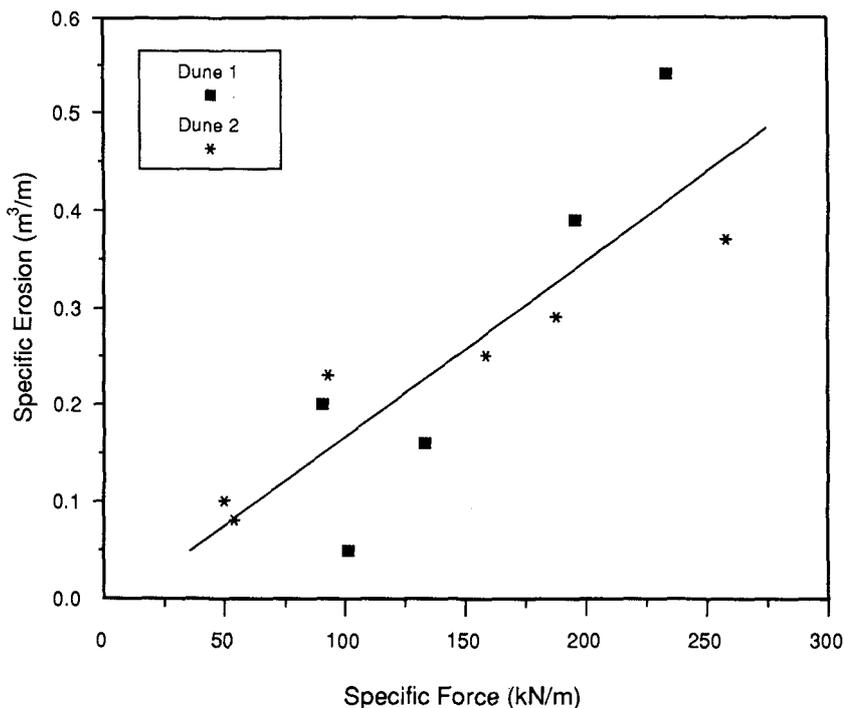


Figure 4. Specific force versus specific volume eroded.

of dune eroded during swash attack is linearly related to the summation of the swash force during that event.

However, the investigation into the effect of sand grain size is incomplete based on these experiments. While the data do not show that sand grain size is important, several aspects of the experiments which could influence this should be kept in mind. One, this conclusion is based on a limited number of experiments: a dataset of five for dune one and a dataset of six for dune two. Perhaps a more significant factor is that while the sands were distinguished by different d_{50} 's, they both could be classified as fine sands. Thus, the effect of sand grain size on the force erosion relationship cannot be determined at this level.

References

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