SAND EROSION AT THE TOE OF A GABION-PROTECTED DUNE FACE

Alex Chapman, B.A.Sc.
IAESTE Trainee
Delft University of Technology

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INTRODUCTION

In coastal regions lying at or below sea level, there is a need for protection from the destructive forces unleashed by storms. Nature often provides this protection in the form of dunes, which are formed gradually by coastal geomorphological processes.

Under normal circumstances, wave action takes place only in the foreshore region; this leaves the dune untouched for most of the time. During extreme weather events, however, very high water levels can occur which may allow direct wave action on the face of the dune and thus erosion of the dune itself. If this erosion progresses to the point where overtopping takes place, the dune can be completely washed away and the lands beyond laid waste by flooding.

Thus, it is apparent that protection of dunes from erosion is of great importance. Various methods have been developed in order to provide this protection; they can be classified as either rigid or flexible structures.

Rigid structures are primarily in the form of retaining walls, and are either pile-type (with or without tie-backs) or gravity-type. Pile-type walls are generally effective for this purpose, but can be quite expensive to construct. Gravity-type walls may prove ineffective due to the process of erosion, which can cause undermining and subsequent base failure. Another disadvantage of both types of rigid structures is a significant alteration to the natural profile of the beach, which may be undesirable aesthetically.

Flexible structures provide an attractive alternative. In particular, wire-mesh gabions have been employed for this purpose. Their low capital cost, ease of construction, low maintenance requirements, and durability have all contributed to their success.
ABSTRACT

The purpose of this research project was to study the manner in which erosion takes place at the toe of a dune slope protected by gabions, and to examine the response of the gabions to this erosion. A sand slope overlaid by model gabions was subjected to wave attack in a hydraulic flume, and periodic measurements of the bottom profile were taken. The results showed that the gabions performed well, and continued to provide protection to the slope even after a considerable amount of erosion and resulting deflection had taken place.

THE MODEL GABION SYSTEM

The experiments were performed using a wave flume in the Hydraulics Laboratory of the Delft University of Technology, using a model-to-prototype scale of 1:20.

The first task was to design a model system which would provide the best representation of the behavior of a prototypical gabion installation. The following design aspects were taken into consideration:

- Sand-tightness
- Stability under wave attack
- Erosion at the toe
- Deformation at the toe

Each aspect will be discussed separately.

Sand-Tightness

In order for a gabion revetment to be effective, the sand of the dune must be prevented from migrating into the gabion and thence into the open water. This is done in practice by laying a sheet of geotextile on the dune face before the gabions are constructed, and similarly this was done in the model. The geotextile was Stabilenka polyester with a tensile strength of 200 kN/m
and ultimate strain of 10%.

In the experiment, however, it was also possible for the sand to escape around the edges of the geotextile sheet at the sides of the flume; this process led to failure of the model in initial testing. It was prevented by digging a narrow gap between the wall of the flume and the sand at the sides of the dune face, tucking the edges of the geotextile sheet into this gap, and packing down the sand again so that the folded-over edge of the sheet was pressed tight against the wall of the flume.

For the purposes of this experiment, the failure mode caused by sand out-migration at the sides of the geotextile sheet was not of interest. However, this phenomenon may merit considerable concern; before the problem was corrected, rapid erosion in the splash zone of the model led with disturbing swiftness to failure of the slope. It is therefore recommended that, in prototypical installations, measures be taken to prevent the escape of sand in this manner.

Stability Under Wave Attack

The modes of failure encountered in previous research were, in order of frequency, sliding, uplift, and (in the case of thin mattresses) buckling. Sliding failure is likely caused by incipient uplift (Brown, 1979), so these failure modes are essentially caused by the same mechanism.

It is stated in this report that a gabion system at a slope shallower than 1:2 would generally be stable against sliding, so it was decided to use a slope of 1:3 for this experiment. Using Equation 6.4:

$$H = 2.8 \, R \, \cot \alpha$$

Using $$\cot \alpha = 3$$ and $$R = 25 \text{mm}$$, the value obtained for $$H$$ is 21 cm. As it proved impossible to generate a non-breaking wave greater than about 13 cm in height, the tests which were performed fell well within the bounds of stability dictated by this equation.

The forces producing uplift in a prototypical gabion arise from fluid motion in the spaces between the fill stones. In order to duplicate this process in the model, it was necessary to scale
the bulk density and the permeability according to Froude.

Erosion at the Toe
The size of the sand particles used in the experiment was scaled based on the settling velocity, with a prototype value of $d_{so}=240\mu m$. Using a relation derived by Vellinga (1986), the $d_{so}$ value of the model was $110\mu m$.

The depth of sand covering the floor of the flume was 20cm. This was adequate to show the progress of erosion over a significant period of time.

Deformation at the Toe
Previous research into the mechanical properties of the gabion has indicated that its deflection behavior does not obey conventional elastic theory. When supported at the ends and allowed to deflect under its own weight, the observed deflection corresponded to a circular arc. The radius of this arc is related to the fill rate.

Designing a model gabion which would adequately reproduce this behavior was indeed challenging. The 1:20 scale with a prototype of dimensions 4.0x2.0x0.5m called for a unit with dimensions of 200x100x25mm. An initial design using wire flymesh proved to be far too rigid; the sides of the model unit contributed considerable stiffness. Another similar design using synthetic mesh was found to be too fragile.

The final design for the gabion model was a single unit representing a set of five prototypical gabions. The unit consisted of a base of Enkamat geotextile measuring 500x200mm, and a covering of 370$\mu m$ nylon screen mesh. The interior was filled with stones with diameters from 8mm to 18mm, and the edges were fastened with staples. To provide confinement and to simulate the five individual compartments of the prototype, 0.32mm nylon line was laced between the top and bottom of the model and tied off. This design provided excellent representation of the permeability, density, and deflection characteristics of the prototype.
EXPERIMENTAL PROCEDURE

The set-up of the wave flume is shown in Figure 1 (see Appendix). The bed of the flume was covered with sand to a depth of 20cm. At the end farthest from the wave generator, a dune face was built on a slope of 1:3. The face of the slope was covered with the geotextile and tucked in at the edges as described above. The model gabions were then placed on the slope and stapled together.

In the last trial, this arrangement was modified so that the geotextile extended horizontally 20cm from the toe of the slope. An additional model gabion unit was placed on this section.

Six trials were performed; the slope was rebuilt and the bed re-levelled after each. The first four trials were used to ascertain the combination of wave period, wave height, and water depth which would produce the most rapid erosion. In the last two trials, this information was used on the two alternative arrangements and the testing was continued for a longer length of time. The period and height of the incoming wave were measured with one wave probe.

During the course of each trial, measurements were taken hourly. The measurements consisted of three bottom profiles: one taken along the flume centreline using a point gauge, and one at each side using a grid scale drawn on the glass of the flume wall. The results obtained from the centreline profiles provided the clearest representation, as the presence of the folded-over geotextile at the wall of the flume made it rather difficult to determine exactly where the level of sand was. Centreline profile plots for each trial are contained in the Appendix, showing the conditions at the start and the end of the trial. For Trials #5 and #6, a profile taken half-way through the trial is also included, providing some illustration of the change in the rate of erosion as the trials progressed.

As well, photographs were taken hourly during the last two trials. Included in the Appendix are photos taken at the start, half-way through, and at the end of these trials.
DISCUSSION OF RESULTS

The pattern of erosion remained fairly consistent during all of the trials. Sand was transported away from the region immediately in front of the toe of the slope, and then was gradually deposited farther out toward open water. The sandbar thus formed would then gradually cause the incoming waves (which had previously retained their form right until the point of impact with the slope) to break after they passed by, thus reducing the amount of wave energy reaching the slope. The rate of erosion was observed to decrease as the trial progressed.

The gabions themselves performed very well. Even after considerable erosion had taken place, they continued to retain the slope; in Trial #5, after 24 hours of testing, the gabion closest to the toe of the slope was still stable even though it was lying on an angle of nearly 45 degrees from the horizontal. It was observed that some downslope movement of the gabions had occurred, but the amount of this movement was quite small.

The alternative arrangement, used in Trial #6, showed some interesting results. Over the course of 29 hours of testing, this gabion deflected from a horizontal position to an angle of about 27 degrees. When compared to the performance of the toe gabion in Trial #5, it can be seen that the extra gabion used in Trial #6 provided some additional protection.
CONCLUSIONS

Wire mesh gabions provide an inexpensive and effective system for the protection of coastal sand dunes. The patterns of erosion observed in the experimental stage of this project show a distinct tendency to create a protective sandbar, which dissipates wave energy and slows down the rate of erosion. The gabions preserved the slope while the eroded material was deposited to form this barrier. The addition of another set of gabions lying horizontally at the toe of the slope was found to provide even more protection to the slope.

However, it should be noted that this experiment represents only a two-dimensional situation, and the effect of cross-current was not simulated. Further research will be required in order to ascertain whether the sandbar-formation process will continue where longshore transport also exists.
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* In Trial #4, the water depth D was 30cm. For all other trials D = 20cm.
Figure 1 - Model Set-up
Trial 1

H = 13 cm, T = 2.44 s
Trial 2

H = 13 cm, T = 1.14 s

Initial + Final
Trial 3

H=7.5cm, T=2.07s
Trial 4

H=6.5cm, T=2.07s, D=30cm

Vertical Position

Initial

Final
Trial 5

H=13cm, T=2.45s

Initial

Half-time

Final
Trial 6

$H=12.5\text{cm}, T=2.44\text{s}$

Vertical Position

Initial

Half-time

Final

Horizontal Position