Large scale physical model tests on sand filled geotextile tubes and containers

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ABSTRACT: To test the stability of sand filled geotextile containers and sand filled geotextile tubes under wave attack, tests were performed in the Delta flume of Deltares on a scale of approximately 1:4. Wave conditions were varied up to 1.5 m significant wave height in the model. The difference between the sand filled geotextile tube and container models in these tests is the filling degree, which is on average 45% for geotextile containers and up to 80% for geotextile tubes. The higher filling degree leads to higher stresses in the geotextile of the tubes compared to the stresses in the geotextile of the containers. The tests on geotextile containers showed that before rolling or sliding of the containers occurs, the migration of the sand in the container is a dominant failure mechanism that leads to damage of the structure. This mechanism leads to loosening of the sand in the sand filled geotextile container as could be determined by hand cone penetration tests before and after the tests. Due to this mechanism the stability numbers found in this research are lower than the stability numbers found in small scale model tests. The tests on sand filled geotextile tubes show the influence of the percentage of fill on the stability.The paper describes the test set-up and the results of the tests. The failure mechanisms for sand filled geotextile tubes and containers differ due to differences in filling degree. Sand migration inside the sand filled geotextile element may decrease its stability when the filling degree is less than approximately 60%

1 INTRODUCTION

Geotextile elements such as geotextile tubes or containers are considered more and more as a serious alternative for traditional coastal protection units such as rock or concrete armour.

Geotextile containers are placed with a split barge. The container has to pass through the opening of the barge during dumping. This results in a percentage of fill of around 45% at maximum, where the percentage of fill is defined as the actual fill divided by the maximum fill that is possible given the circumference of the geotextile. With a larger percentage of fill it is difficult to pass through the opening of the barge and the loading on the geotextile during dumping increases significantly.

Geotextile tubes are placed by pumping a sand-water mixture into a prefabricated ‘tube’ of geotextile. The water leaves the tube through the pores of the geotextile, the sand is trapped in the tubes. This leads to a filling degree between 60 and 90 %.

Geotextile tubes and geotextile containers can be used in several layouts in hydraulic structures such as breakwaters, dikes, dams and groynes but can also be used for land reclamations or temporal structures. These structures are in several cases under a significant wave load and might become unstable and therefore loose their function. Therefore, it is important to know the wave load and failure mechanisms of a structure consisting of geotextile tubes or geotextile containers. Design formulas are mostly based on small scale model tests (Pilarczyk, 2000 and CUR, 2006), although it was already shown in by Venis (1968) that scaling could be problematic. Therefore some large scale model tests were performed on both geotextile containers and tubes.

2 SCOPE OF STUDY

Two series of large scale physical model tests have been carried out to test the stability of tubes and containers under wave attack.

The first test series, performed in spring 2007, was on the stability of geotextile containers. A stack of geotextile containers was tested for two water levels and different wave heights.

The second test series, performed in autumn 2008, was on the stability of geotextile tubes. Variations in this test series were (i) the type of stack, (ii) the filling degree, (iii) the size and (iv) the application of a trench to simulate that the tube is partly settled in the supporting layer of sand.

In this paper the observed failure mechanisms are described and compared with the failure mechanisms that are described in literature.

3 BRIEF REVIEW

3.1 Theoretical analysis on failure mechanisms

In Lawson (2008) nine failure mechanisms are discussed. Six failure mechanisms are related with external loads. These are sliding instability, overturning instability, bearing instability, global instability, scour of the foundation and foundation settlement. Three failure mechanisms are internal: geotextile skin rupture, erosion of fill though the geotextile skin and deformation of the contained fill. The effect of deformation is described in Recio & Oumeraci (2009a).

An almost forgotten failure mechanism is described in Venis (1968). Venis performed several test with various sizes of sandbags under current attack. He found that the point at where the sandbag started to shift was almost independent of the model scale. At a certain velocity, u_{crit}, the sand in the bags started to migrate and the bags became unstable. This mechanism only occurred when applying larger sand bags. This is illustrated in Figure 1. He concluded out that Froude law scaling is not applicable with respect to the stability of the sand bags due this mechanism.

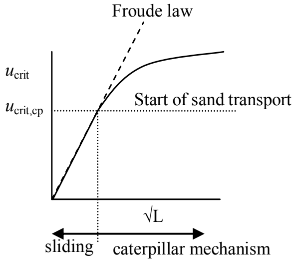

Figure 1. The Froude scaling law and the importance of sand transport within the geotextile element according to Venis (1968)

3.2 Stability formulas

Several physical small-scale model tests have been reported and concluding stability formulas are summarized in Pilarczyk (2000) and CUR (2006). The derived stability parameters are usually based on Froude scaling laws, in eg. $H_s/\Delta D$ = constant or $H_s/\Delta b$ = constant, where H_s =significant wave height, b the width of the geotextile element, D the height, Δ =relative density of the geotextile elements $((\rho_{\mathrm{sand}}-\rho_{\mathrm{water}})/\rho_{\mathrm{water}})$ and ρ = density. These stability parameters do not include deformations of the elements or sand transport within the elements.

Recio & Oumeraci (2009b) reported stability formulas including deformation of the elements. They described a mechanism in which the sand within the container is redistributed, allowing a part of the geotextile container to be lifted up and down and therefore lateral displacement and finally failure of the structure occurs.

4 EMPIRICAL SET-UP AND TESTING PROGRAM

A series of experiments on the stability of geotextile containers as well as on geotextile tubes have been performed. Both test series were performed in the Delta flume of Deltares. This flume has a length of 235 m, a width of 5 m and a depth of 7 m. At one end of the flume irregular waves with a JONSWAP spectrum and a wave steepness, based on the peak wave period, of $s_{0,p}$ = 0.03 was created, at the other end a structure made of geotextile elements was build. At all the test series a Geolon® PE180L geotextile was used, thus only woven geotextile containers were tested. The geotextiles had an opening size O_{90} = 0.170 mm. The experiments had a duration of around 1000 waves or until damage occurred. If no damage occurred during a test, a new test with a higher wave height was started.

4.1 *Tests on geotextile containers*

The geotextile containers had a width (parallel to the direction of the flume) of b = 2.75 m, a length (perpendicular to the direction of the flume) of L = 5 m and an average thickness of D = 0.55 m. The filling percentage, defined as described before, was 44%. A stack of geotextile containers was placed on an existing 1:3 concrete slope. The seaward slope of the containers was 1:2. Above the containers, that formed a berm with a width of approximately 6 m, a smooth 1:3 slope was present. Two different water levels were tested; one series where the water level was equal to the top of the upper geotextile container and one series where the waterlevel was 0.75 H_s above the top of the upper container. The arrangement of the test set-ups is shown in Figure 2.

4.2 *Tests on geotextile tubes*

A concrete elevation with a height of 3.60 m and a slope angle of 1:2.5 was constructed in the flume. On top of this plateau the geotextile tubes were placed. Seven different layouts were tested. With these seven layouts four subsets were made: (i) the type of stack, (ii) the filling degree, (iii) the diameter of the tube and (iv) the application of a trench. Subset (i) consists of three test series: a single tube, two tubes placed beside each other and two tubes placed besides each other with a third tube place on top, a so-called 2-1 stack. On the landward side a trench was placed to block potential sliding in landward direction. Subset (ii) consisted of three test series where the filling degree was 55 %, 75 % and 90 %. Subset (iii) consisted of 2 test series: a diameter of 1.14 m and a diameter of 1.50 m. Subset (iv) consisted of two test series: a series with a trench and a series without a trench. The layout of the seven test series are shown in Figure 3.

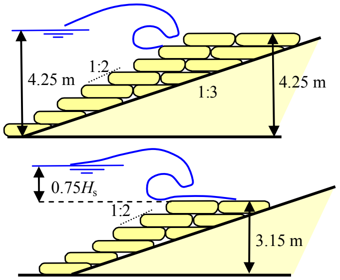

Figure 2. Arrangement of test set-up of geotextile containers

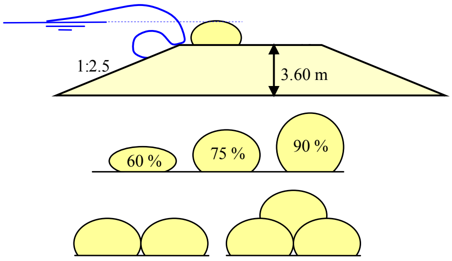

Figure 3. Arrangements of test set up of geotextile tubes

The tubes were constructed by filling a prefabricated geotextile with a sand-water mixture, just like in a prototype situation, see Figure 5. An impression of a test with geotextile tubes is given in Figure 4.

Figure 4. Impression of test with geotextile tubes

Figure 5. Filling of a geotextile tube (besides the flume)

5 TEST RESULTS AND DISCUSSION

5.1 *Geotextile containers*

The stability of the containers was lower than expected based on the empirical data derived from small-scale model tests. It appeared that heavy sand transport in the containers occurred and that, besides sliding of an element, a so called caterpillar mechanism of the upper container occurred. This caterpillar mechanism is caused by the sand transport in the geotextile container. It is very likely that the sand transport is caused by the significant wave run-down that occurred due to the presence of the upper smooth berm. Taking in mind the theory described by Venis (1968) it is concluded that the Froude scaling law and the derived dimensionless empirical parameters such as $H_s/\Delta D$ cannot be applied in all cases. The sand transport within the containers reduces the stability of the geotextile containers and gives an upper limit with respect to the wave height or flow velocity. This upper limit is assumed to be depended on several parameters such as the porosity and stiffness of the geotextile, characteristics of the external loading and filling percentage of the element. How these parameters influence the moment when the caterpillar movement starts, could not be investigated within the current research programme.

5.2 *Geotextile tubes*

All layouts except the 2-1 stack were displaced due to sliding of an individual element. Significant deformation of the tubes did not take place except for the tube which was filled for 55%. This tube was significantly deformed. Failure of the 2-1 stack occurred due to a seaward sliding mechanism of the tube on top and the tube which was placed on the seaward side of the stack.

Parameters that influence the stability against sliding are the external forces, usually represented by the wave height and wave period, and the strength parameters such as the weights and the friction between the element and its subsurface.

Failure due to sand migration within the elements did not occur.

5.3 *Comparison between existing literature and results of the physical model tests*

The theory described by Venis (1968) is not used in the present day stability formulae of geotextile tubes and geotextile containers. However, the experiments on the stability of geotextile containers showed that this mechanism is in some specific cases a significant failure mechanism, especially when the filling degree is low (45%).

5.4 *Scaling with respect to sand transport in the geotextile containers*

In reality the geotextile containers are approximately four times larger than those tested in the Delta flume. An important aspect of the scaling of the stability is the sand transport in the geotextile containers. Therefore, the theory of Venis (1968) is used and extended. The maximum critical velocity described by Venis is very likely to be independent at the model scale. This implies that the scaling with respect to sand transport was 1:1.

However, this does not imply that the sand transport within the containers is not dependent on other aspects of the element such as the used materials and the shape of the geotextile. It is assumed that the sand movement is caused by a flapping geotextile. This flapping is caused by several external forces such as (breaking) waves or currents, which generate turbulence. The intensity of the flapping of the geotextile depends on the shape of the element. If the geotextile is strongly curved around the sand and the tensile stress is sufficiently high it is hardly possible for the geotextile to flap. A relatively large force is needed to lift the geotextile since the geotextile is able to give a counterforce. A relatively small external load is needed to lift the geotextile at an element which is not curved. This is precisely what is observed at the experiments. Strong sand migration occurred at the geotextile containers which are slightly curved and did not occur at the (strongly curved) tubes.

6 CONCLUSIONS

The following conclusions are drawn from the present study:

- A potential failure mechanism, when applying geotextile containers under wave attack, is the caterpillar mechanism, which is caused by sand movement inside the geotextile container.
- The caterpillar mechanism and significant migration of sand inside the element hardly occurred at the experiments with geotextile tubes, likely due to the higher filling degree of tubes compared with containers.
- It is very likely that the sand movement inside a geotextile element is not dependent on the size of the element (assuming not very small experimental set-ups). This implies that the scaling with respect to the caterpillar mechanism is 1:1. In other words; in a prototype situation start of displacement would occur at the same wave heights as in the large scale experimental set-up in the Delta flume.
- The migration of sand within a geotextile element is strongly dependent on the curvature of the element
- Placement of geotextile containers in the zone where waves break should be avoided, because of the limited filling degree that can be achieved. Outside this zone the containers can be applied.
- According to our tests the filling degree of sand filled geotextile elements in the breaker zone have to be around 60% or higher to avoid failure due to sand migration (caterpillar mechanism).

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