SAND-FILLED GEOTEXTILE CONTAINERS FOR SHORE PROTECTION

by

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ABSTRACT

In search for soft, sustainable and easily reversible coastal protection measures a concept was found which was already applied to close a dike line during the end of the 1950. Since that time sand containers have mainly been used as temporary protection or safety measures because long-term constructions were not feasible due to the lack of reliable design formulae for the assessment of the hydraulic stability of geotextile sand containers under wave loads. Hydraulic model investigations were carried out at Leichtweiß-Institute for Hydraulic Engineering (LWI) of the Technical University of Braunschweig, Germany to establish reliable stability formulae for sand containers applied as dune protection subject to storm waves.

1 INTRODUCTION

New shore protection structures, especially at sandy coasts, are increasingly required to have less ecological and visual impacts than conventional structures such as dikes and revetments. However, due to the increasing storminess associated with climate changes some of the existing dunes must be protected. Furthermore, these reinforcement protection measures have to be cost effective which implies the use of local material without any heavy equipment, especially when the required infrastructure is not available.

A potential measure in this respect is the use of geotextiles for the strengthening of dunes as storm protection structures or as a revetment by themselves. One concept is the use of sand-filled geocontainers as has been used in a pilot project at Rerik and Glowe on the island of Rugia (Baltic Sea) in Germany, but also all around the world as for example in Australia or Gambia. The investigations described in this paper focus on these types of geotextile structures.

The containers which have been commonly used as a temporary measure are evolving toward a real alternative to hard rock revetments due to the improved geotextile materials. In areas where no rock material is available an advantage of geocontainers is that local sand can be used as filling material. Therefore, transport costs and subsequent ecological impacts can be reduced. Also a reduction in construction costs can be achieved because geocontainers up to a certain size will not need any heavy equipment to be handled. In addition, structures made of geocontainers are reversible and do not affect the marine landscape as this is the case for conventional revetments and other hard structures. In fact, the actual dune core is covered by sand which is only washed away in case of a severe storm. Moreover structures made of geocontainers are very flexible allowing to adapt to differential settlements.

For the first time world-wide geotextile sand containers were used in 1957 for dike repair in Holland (Zitscher, 1971). Since then sand containers are more frequently used in hydraulic engineering and coastal protection. While they were formerly used as temporary measures (e.g. dike repair) they are now increasingly used as long-term protection measures. Geocontainers are used as scour protection (storm surge barrier at the Eider in 1993 with 48000 sand containers), groynes (Maroochy Groyne Aus-

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tralia, 2001 with 650 sand containers), as revetment against beach and dune erosion (Island of Rugia (Glowe) 2002 with 2000 sand containern), as well as artificial detached reefs (Narrowneck Reef, Australia 2001).

2 OBJECTIVES

The main objective for the increased use of geocontainers as a permanent shore protection measure is the lacking knowledge related to their hydraulic performance and stability which has led to quite different sizes used for construction. In the context of an applied research project at LWI model tests were recently conducted, particularly focussing on geocontainers used as dune protection. Both hydraulic stability and wave overtopping were investigated.

First, small-scale investigations were performed at LWI focussing on the wave overtopping of a dune barrier made of geocontainers. As a result recommendations for the crest height design are provided. Also preliminarily results regarding the hydraulic stability were obtained.

Based on these results large-scale investigations of the hydraulic stability of this type of structure were performed (Oumeraci et al., 2002a; Oumeraci et al., 2002b; Oumeraci et al., 2002c).

3 SMALL-SCALE MODEL TESTS

3.1 Objectives

Small-scale model tests (Oumeraci et al., 2002b) were conducted (i) to identify the most relevant parameter for stability, (ii) to more easily perform a wide variation of parameter and (iii) to optimise the programme of the planned large-scale model tests in the Large Wave Flume of Hannover (GWK).

3.2 Model construction

The small-scale tests were performed in the wave flume of LWI (Figure 1) using sand filled containers (80% filling) of 0,25 m x 0,1 m x 0,06 m (scale of 1:8). A preliminary design of these tests was made using the design of a sand container barrier which was under construction at Glowe (Island of Rugia). For practical purposes the crown width of the barrier was selected to be twice the container length, the slope was 1:1.

Figure 1: Small-scale model tests at LWI

In addition, the position of the sand containers was varied throughout the tests so that the horizontal projection length l of the containers changed. This was achieved by placing the containers longitudinally and transversally in the flume (Figure 2).

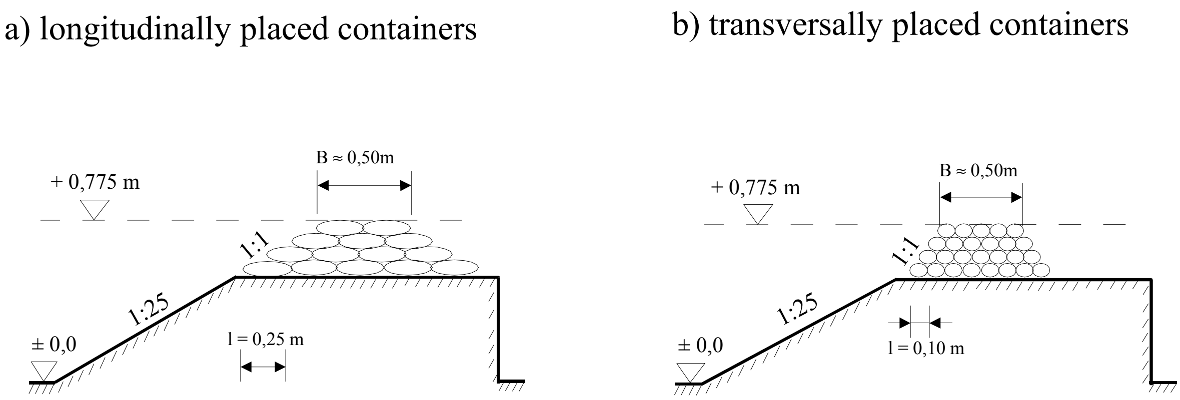

Figure 2: Model construction for hydraulic stability in a scale of 1:8 (LWI flume)

The sand container barrier was built on a 1:25 sloped foreshore with a water depth d = 0.775 m at the toe of the construction. The main purpose of these tests was to preliminarily investigate the wave overtopping and the stability of the sand containers. The height of the foreshore was 0.46 m. Nine wave gauges were used to measure the wave field in front of the structure where four of those wave gauges were positioned in a wave array at the beginning of the foreshore. Additional five wave gauges were used to measure the water surface elevation directly at the structure (Figure 3).

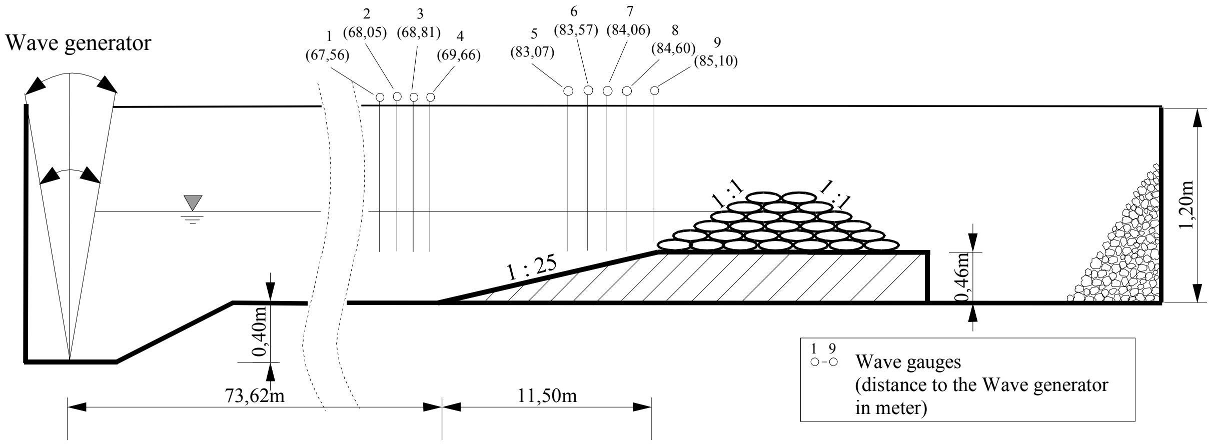

Figure 3: Position of wave gauges in the wave flume of LWI

3.3 Results of small-scale model tests

The significant wave height H_s, the peak wave period T_p and the slope of the structure α proved to be the most relevant parameters for the stability of the sand containers. The containers started to move when a critical wave height with the associated wave period was exceeded (Figure 4).

All investigations related to different slope angles of the structure have shown that mildly sloped constructions showed an unfavourable stability behaviour which can be explained by the insufficient overlapping of the containers. The analysis has shown that a large overlapping leads to higher contact forces between the sand containers and thus to an improved stability behaviour.

In the analysis of the stability the drop out of a single container from the “armour” layer was defined to be the threshold for loss of stability. This analysis was performed by visual inspection. To determine the stability number N_s the approach by Wouters (1998) was used:

Figure 4: Removed sand containers during small-scale model tests at LWI

$$N_s = \frac{H_s}{(\rho_E / \rho_w - 1) \cdot D_{50}} = \frac{C_w}{\sqrt{\xi_0}} \tag{1}$$

where:

N_s = stability number [-]
H_s = incident significant wave height [m]
ρ_w = density of water [kg/m^3]
ρ_E = density of sand container elements [kg/m^3] defined as:

$$\rho_E = (1-n) \cdot \rho_s + \rho_w \cdot n$$

n = porosity of filling material [-]
C_w = empirical parameter derived from the stability number N_S [-]
D_{50} = thickness of armour layer [m]
ξ_0 = $\frac{\tan\alpha}{\sqrt{H_s / L_0}}$ = Iribarren number [-]

α = slope angle of structure slope [°]

L_0 = $\frac{g \cdot T_p^2}{2\pi}$ = deep water wave length using T_p [m]

Plotting the stability number N_s as a function of the Iribarren number ξ_0 provided a good correlation of the data obtained from the performed tests (Figure 5). Based on the relation given by Wouters (1998) the empirical parameter C_w was determined to C_w = 2,0.

Despite some considerable scatter of the data points it could be shown that a relation based on Wouters (1998) can properly predict the stability threshold of sand containers under wave load. In comparison to Wouters (1998) 10% higher unit weights of the sand containers were obtained. Furthermore, it was found that not only the weight of the sand container, but also the longitudinal dimension of the containers in wave direction and the corresponding overlap with the neighbouring container represent the most relevant parameters.

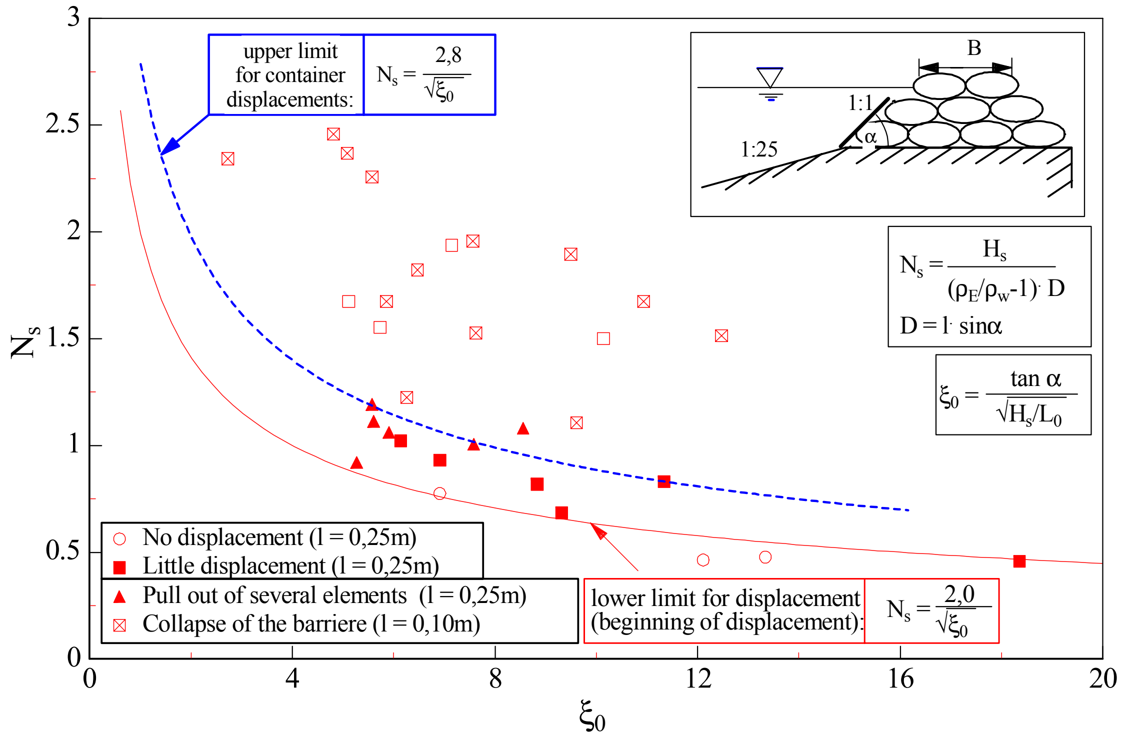

Figure 5: Stability number N_s vs. Iribarren Paramter ξ_0 (small-scale model tests)

4 LARGE-SCALE MODEL TESTS

4.1 Objectives

Based on the results of the small-scale investigations large-scale tests were performed in the Large Wave Flume of Hannover (GWK). The main purpose of these tests was the detailed investigation of the stability of sand containers under wave load. Within three test phases a 1:1 sloped dune barrier composed of sand container of different sizes (150 l and 25 l, respectively) with and without fixation belts were investigated.

4.2 Model construction

The construction of the model was mainly designed on the basis of existing prototype constructions such as in Glowe, German Baltic Sea. First, a foreshore was constructed with a slope of 1:25 and a length of 50 m so that the foreshore was 2 m high at the toe of the dune barrier (Figure 6).

For modelling the dune barrier sand containers made out of polypropylene filter fleece (type Secutex) were used. Two different geocontainer sizes were applied. In test phase I, 150 l containers were tested. The dune barrier was made of 10 to 12 different layers of sand containers which were stepwise increased throughout the tests. The filling material was sand with a density of 1,8 t/m^3. All containers were filled up to 80%.

Wave measurements were undertaken by means of 22 wave gauges from which eight were grouped together to two gauge arrays (four each) for reflection analysis. Gauge 1 was located at a distance of 80 m and gauge 2 at a distance of 176 m from the wave paddle. Further wave gauges were equally distributed over the foreshore up to the toe of the dune barrier. The locations of the remaining wave gauges is shown in Figure 7.

Figure 6: Large-scale model with 150 l sand containers in the Large Wave Flume of Hannover (GWK)

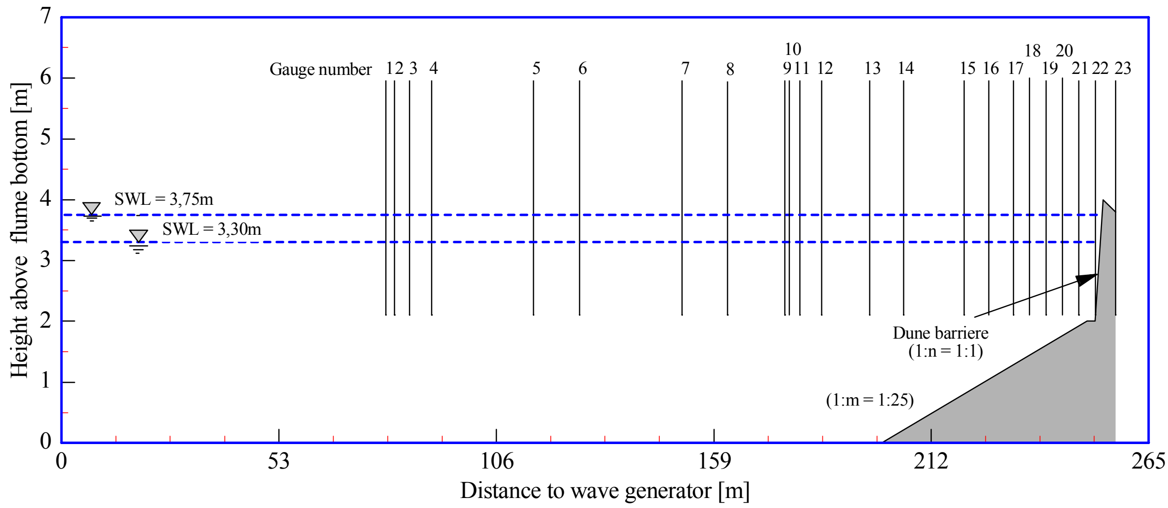

Figure 7: Locations of the wave gauges in the Large Wave Flume (GWK)

Further investigations were carried out using smaller sand containers of about 25 l (test phase II). These elements were used as reference tests for 25 l sand containers with fixation belts (test phase III).

4.3 Results of large-scale model tests

In comparison to the small-scale tests the large-scale elements were observed to be less stable. This can be explained by the less favourable ratio of the filling material as compared to the size of the containers. Qualitatively the same behaviour of the sand containers as in the small-scale model tests could be observed. The sand containers at the crest of the structure started to move earlier than the elements on the slope due to the different load conditions. For the geometry investigated, design formulae could be developed which can distinguish between crest and slope elements. The main loading of the crest elements is the run-up and overtopping here whereas slope elements are principally loaded by the pore water pressure inside the structure (Uplift). The results of the three test phases can be summarised as follows:

4.3.1 Test phase I with 150 l sand containers

The analysis of the data from test phase I using 150 l geocontainers (dimensions of 1.50 m x 0.75 m unfilled) showed a large scatter of the stability number N_s from which a clear threshold between movement and no movement can hardly be identified (Figure 8).

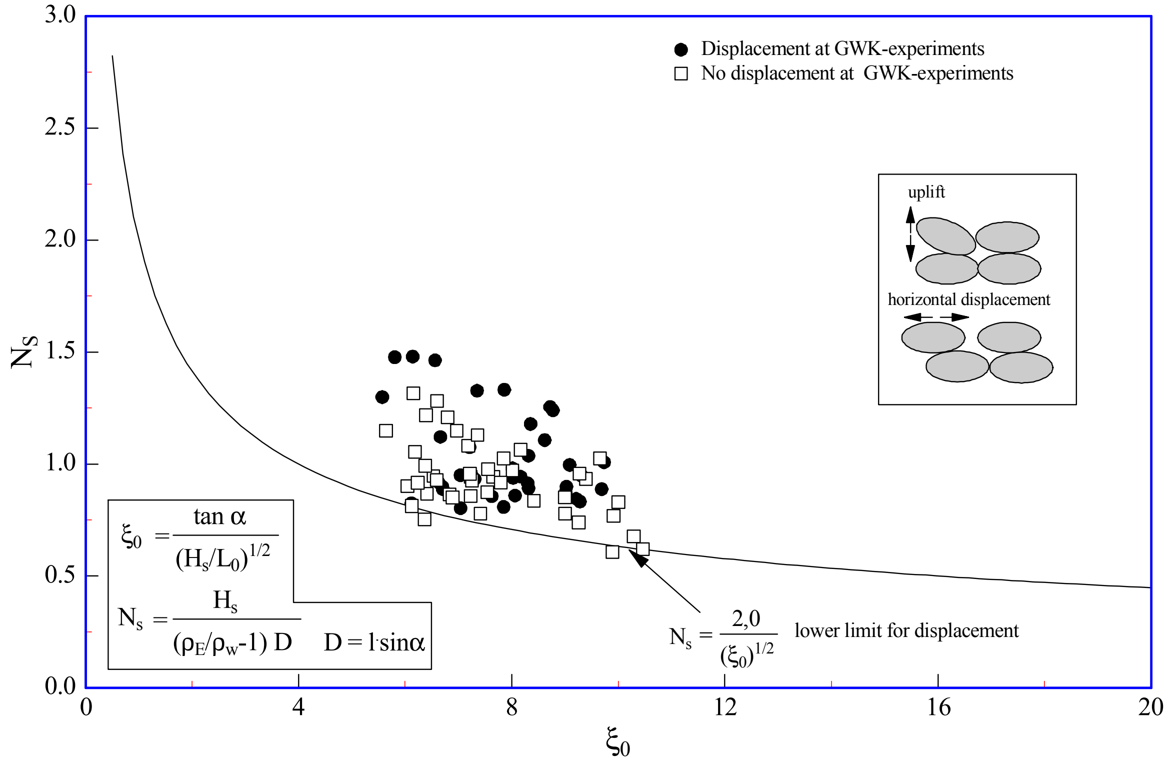

Figure 8: Stability number N_s vs. Iribarren number ξ_0 for test phase I in the Large Wave Flume

Relating the initiation of movement to the number of container layers it was however possible to obtain a distinction with respect to the stability behaviour of crest and slope elements (Figure 9). It could be shown that the threshold of sand container movements is higher with increasing number of layers.

This can be explained by a higher freeboard with increasing number of layers while a larger freeboard results in lower overtopping flow velocities and consequently in a lower loading of the crest elements. Furthermore, an increasing number of layers means a better stability of all elements around the still water level. This is due to the larger weight of the top layers which yields higher stability for the same wave loading. It was also found that crest elements start to move earlier than slope elements since the latter are more densely packed and interlocked (Figure 11).

Two stability formulae were developed to distinguish between the stability of crest and slope elements. For the slope elements the following formula was obtained:

$$N_s = \frac{H_s}{(\rho_E / \rho_W - 1) \cdot D} = \frac{2.75}{\sqrt{\xi_0}} \qquad (2)$$

where:

D = characteristic diameter of sand container defined as $D = l \cdot \sin\alpha$
l = length of sand container (container dimensions in wave direction) [m]

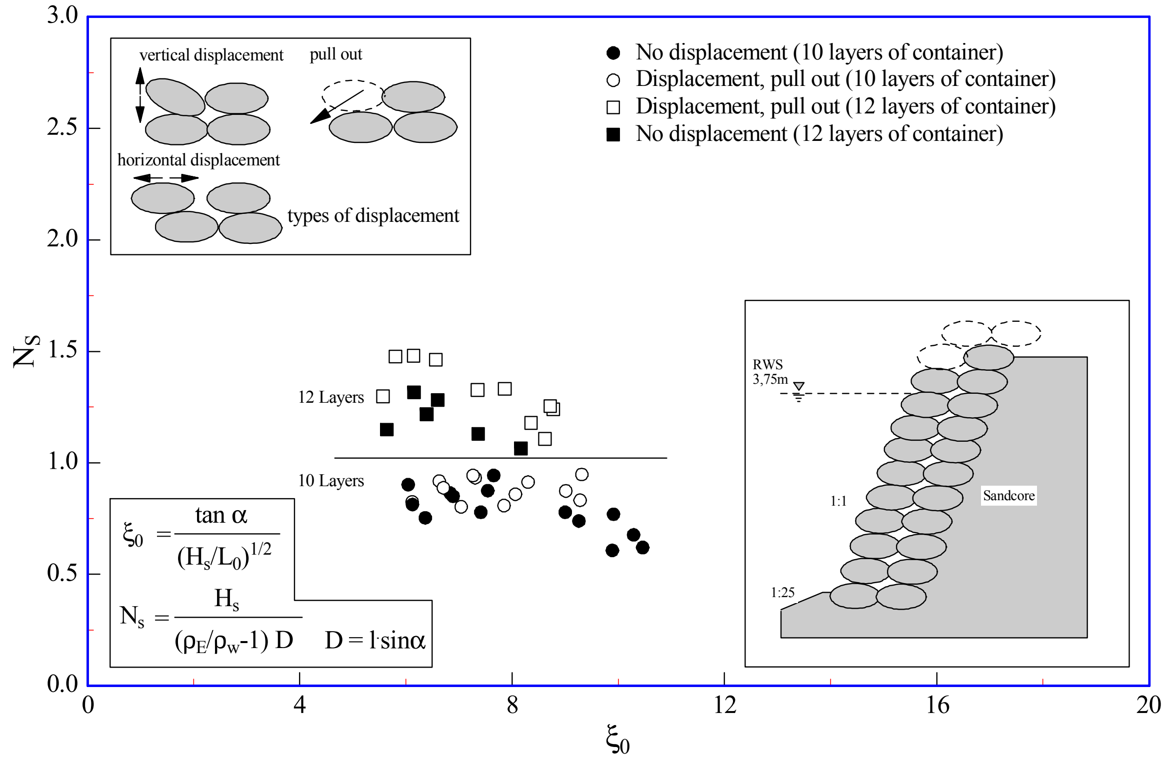

Figure 9: Influence of freeboard on displacement of containers

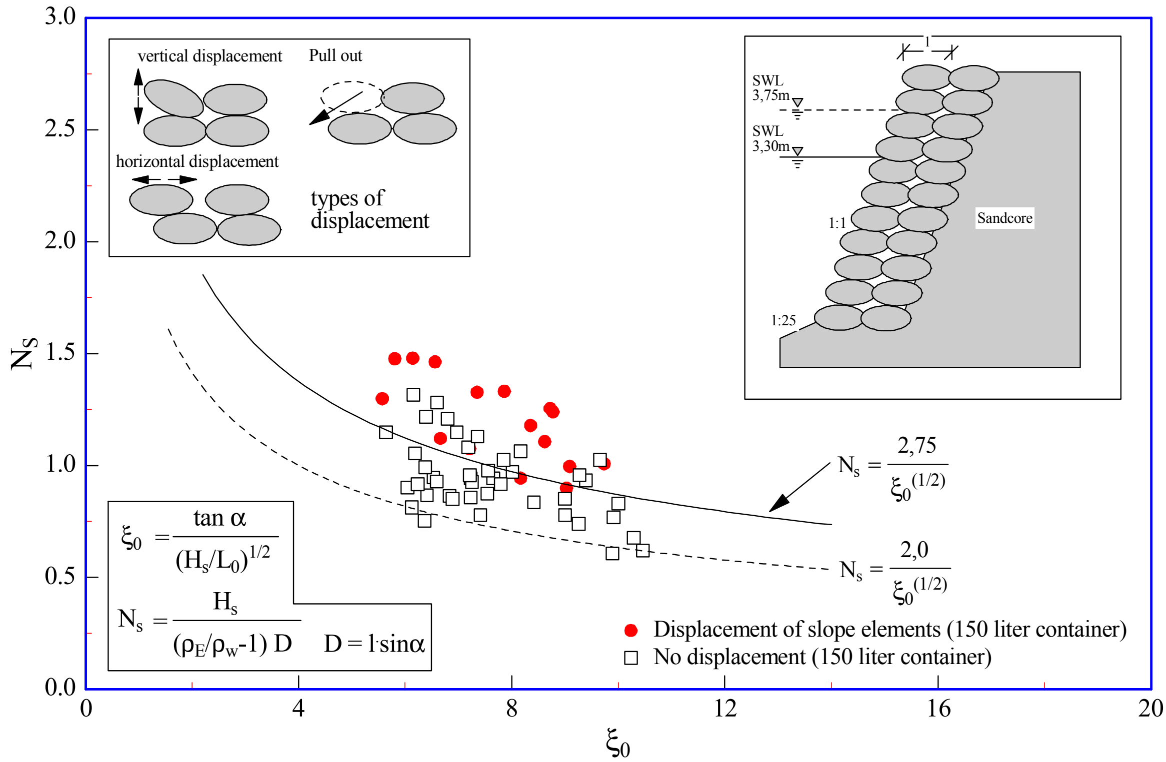

Figure 10: Stability of containers on the structure slope (test phase I)

Figure 10 clearly shows that all containers on the slope are much more stable than predicted by the stability formula given by Eq.(1) with the empirical parameter $C_W = 2.0$. Instead C_W increases to

C_w = 2.75 for slope elements. However, in the small-scale model tests no distinction was made between the movements of the elements on the slope and at the crest of the structure.

Figure 11: Sand container removed from structure slope

As already mentioned the crest elements (Figure 13) start to move earlier than the elements on the slope (Figure 12). It was observed that the stability behaviour of the crest elements was clearly dependent on the relative freeboard R_c/H_s.

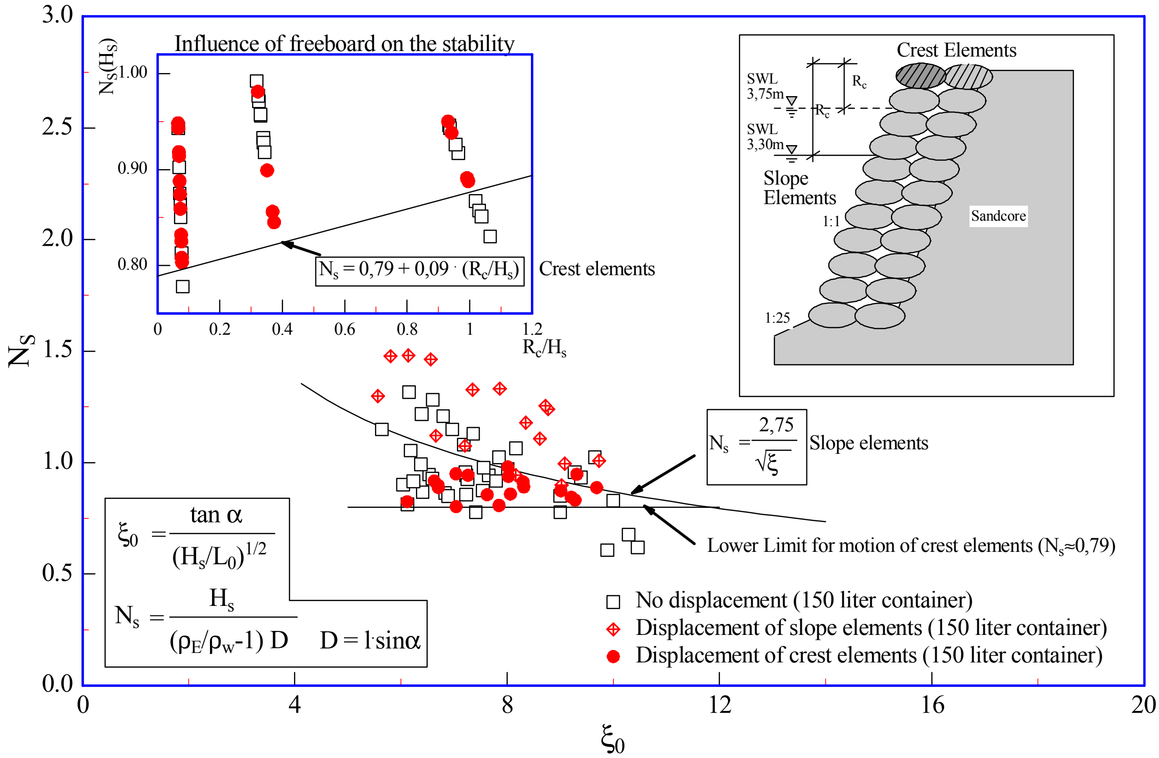

Figure 12: Stability of sand containers at the crest of the structure

From these observations a linear relation of the stability number N_s from the relative freeboard R_c/H_s was obtained:

$$N_s = \frac{H_s}{(\rho_E / \rho_W - 1) \cdot D} < 0{,}79 + 0{,}09 \cdot \frac{R_c}{Hs} \quad (3)$$

where:
R_c = freeboard [m]

Figure 13: Sand container removed from crest of structure (GWK tests)

4.3.2 Test phase II with 25 l sand containers

All tests with 25 l containers were used as reference tests for the investigations how fixation belts between sand containers influenced the stability. In general, a similar behaviour of the small sand containers as compared to the 150 l sand containers was observed, i.e. the crest elements started to move earlier than the slope elements. However, no effect of the wave period on the stability could be observed. The stability number N_s for the slope elements was determined to:

$$N_s = \frac{H_s}{(\rho_E / \rho_W - 1) \cdot D} < 1{,}1 \quad (4)$$

A more detailed analysis of the movement of the crest elements has shown that a similar relationship between stability number N_s and relative freeboard R_c/H_s exists (Figure 14):

$$N_s = \frac{H_s}{(\rho_E / \rho_W - 1) \cdot D} < 0{,}885 + 0{,}05 \cdot \frac{R_c}{H_s} \quad (5)$$

Comparing these results with the results found with 150 l sand containers the smaller containers are relatively more stable. Thus, a relation between stability and model scale can be derived. In fact the dimensions of the sand containers were calculated according to the length scale of the models but the same filling material (sand) for both container sizes was used.

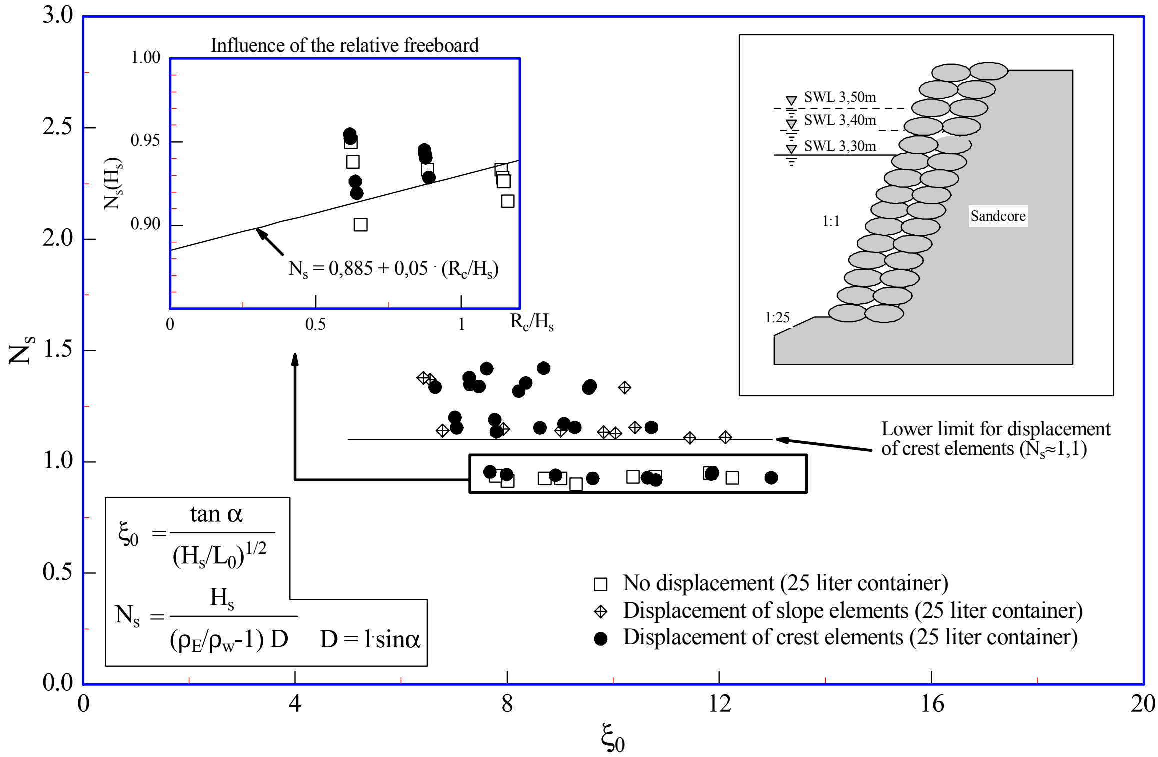

Figure 14: Stability of sand containers (test phase II)

4.3.3 Test phase III with fixation belts (25 l containers)

In test phase III, each layer of sand containers was connected to the neighbouring layer by means of a self-adhesive belt which was fixed approximately at the front one third of the higher layer. In total two different types of belt were used, but no significant difference in the adhesive characteristics was observed throughout the tests.

Generally, it could be shown that the fixation belts increase the stability of the sand containers considerably (Figure 15).

The effect of belts could easily be identified during the tests. It could be observed that the filling material is removed from the front part of the containers to the back part. Consequently, the front parts of the containers were folded backwards up to the position of the belts but were kept in position.

The effect of belts should however not be overestimated since the percentage of fastened container length was rather high due to the width of the fixation belts used. Furthermore, there is a strong need to carefully fix the belts. When re-using the belts the fastening characteristics significantly decrease. Generally, new belts should be used. In addition, the sand container damaged by the fixation should be replaced.

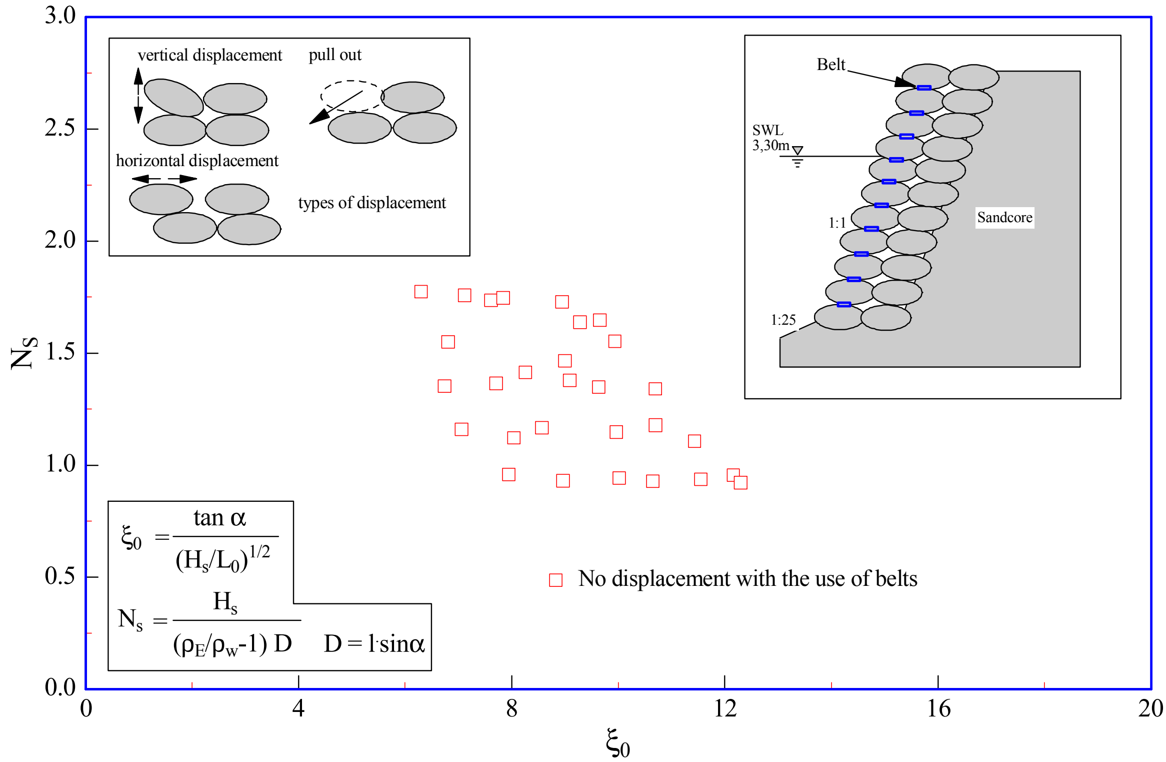

Figure 15: Stability numbers N_s of "fixated" sand containers (25 l)

5 CONCLUDING REMARKS

The analysis of the large-scale tests in the large wave flume of Hannover (GWK) has allowed to identify the most heavily loaded parts of the sand container barrier. These parts need to explicitly be considered when designing a barrier built of geotextile sand containers. The stability of the sand containers which are located shortly below the still water level and at the crest are most critical. It could be shown that the crest elements is generally dependent on the relative freeboard whereas the stability of the slope elements is mainly governed by the wave height, the wave period and the slope of the structure. The latter has a major influence since it directly affects the degree of overlapping of the slope elements. Subsequently the length of the sand containers should be large enough to ensure a proper overlapping. Therefore, once the characteristic diameter $D = l \cdot \sin\alpha$ (l =container length) has been determined in the preliminary design, it is recommended to proceed with the fill of a prototype sand container in order to obtain the final "design container length". In fact, a significant difference to the theoretical value might result due to the elasticity of the geotextile material.

The large-scale model tests with 150 l and 25 l containers have shown that the smaller scale leads to higher stability. This scale effect which was first observed by Venis (1967) has been confirmed by the tests in the Large Wave Flume (GWK), but also by the comparison with the small-scale model tests in the LWI flume.

The "fixation" of the sand container by self-adhesive belts resulted in a stability increase. Due to the type of belt fixation used in the tests which is associated with a large "fixation area", caution is recommended when trying to transfer these results to other conditions in prototype.

The belt fixation of elements has led to an increase of stability but it has to be considered that the type of fastening used within the tests (large contact area) has a major influence on the results.

6 ACKNOWLEDGEMENTS

The funding by and the cooperation with the "Staatliches Amt für Umwelt und Natur Rostock (STAUN Rostock)", and NAUE FASERTECHNIK are gratefully acknowledged. The large-scale model tests were conducted at the Large Wave Flume of the German Coastal Research Centre (FZK). The support of the permanent staff of the FZK during the experiments is also gratefully acknowledged.

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