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Innovative Scour Protection with Geotextile Sand Containers for Offshore Monopile Foundations of Wind Energy Turbines

Innovative Scour Protection with Geotextile Sand Containers for Offshore Monopile Foundations of Wind Energy Turbines

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I. INTRODUCTION

Creating renewable energy with wind turbines has increased rapidly in the previous years. This was mainly caused by environmental aspects with respect to carbon dioxide accumulation (greenhouse effect). But now also economical reasons become an important factor due to increasing prices and to shortage of fossil fuels as a consequence of increasing global energy consumption.

In some countries areas with effective wind conditions for wind turbines on land are restricted and increasingly occupied by wind turbines already. Thus, offshore areas become increasingly important for installing new wind parks. Otherwise technical and consequently economic boundary conditions for offshore wind parks are much more complex and difficult compared to the conditions of landside wind parks.

One of these complex and difficult offshore conditions relates to the foundation of the support structure, mostly designed as monopile structures. Such monopile support structures for offshore wind turbines in areas with movable sand beds may be affected by local scour processes due to wave and current action.

An innovative solution for monopile scour protection was proposed by using geotextile sand containers. Fig.1 shows a sketch of such a scour protection and the proposed model set-up for large-scale tests in the GWK . In comparison to a rubble mound design the sand containers are made from soft materials minimizing the danger of cable and monopile damage during the construction period. The knowledge about design criteria for such geotextile sand containers [1] is poor and needs to be improved.

In order to investigate the stability of such alternative scour protection around a monopole structure with geotextile sand containers, a research programme has been started recently at the FZK. In this programme physical large-scale model experiments in the Large Wave Channel (GWK) of the Coastal Research Centre (FZK) are being performed to minimise scale effects occurring both with simulation of wave induced hydrodynamic processes and especially with the scaling of natural fine sands, which both prevail at the proposed offshore areas. In the first part of the investigations pilot experiments on the stability of single geotextile sand containers and of container groups were performed. The results of these experiments are presented in the following and have been used for dimensioning the scour protection for the proposed main tests with a complete scour protection array around a monopile in the GWK.

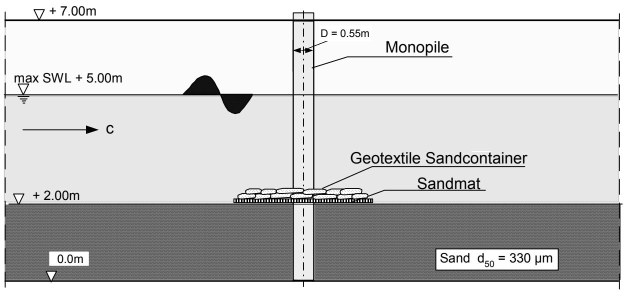


Figure 1.
Sketch of a scour protection with geotextile sand containers and proposed model set-up for large-scale tests in the GWK

II. EXPERIMENTS

In the beginning of the pilot experiments some few pilot tests were performed with 4 different geotextile sand containers sizes to get a first approach for dimensioning. All sand containers were placed on a horizontal sand bed. The sand bed was covered with a geotextile filter layer (sand mat) which is normally used as sublayer filter for scour protection. A longitudinal section of the GWK with the installed sand bed is given in Fig. 2. The sand containers were placed in an area on the horizontal sand bed around the proposed monopole.

A few additional tests were performed both with totally and with partly filled sand containers. The results showed a surprising strong influence of the percentage of filling, which means that the stability of sand containers not only is a function of the total weight. A trend was found that sand containers with lower total weights and high percentage of filling are more stable compared to those with higher weights and low percentage of filling.

Based on these first results, it was necessary to perform more comprehensive basic tests on the stability of sand containers before performing tests with a complete scour protection design around a monopile. For these basic test programme the sand containers were varied in size and percentage of filling, which results in 12 different container weights (Table I). Four different container sizes were used, the dimensions length (l) and width (w) in flat unfilled conditions are listed in the first row of Table I. Each of this four container sizes were charged with three percentages of filling: 56%, 80% and 100%, the relevant weights G and the dimensions length (l), width (w) and height (h) under filled conditions are given in Table I.

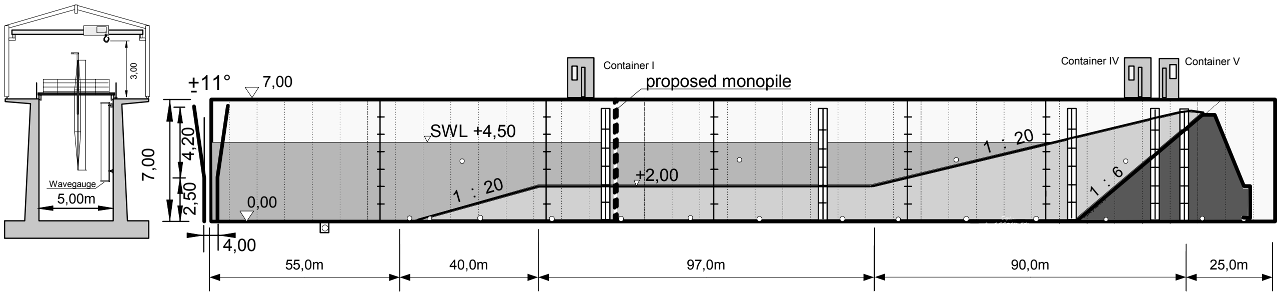
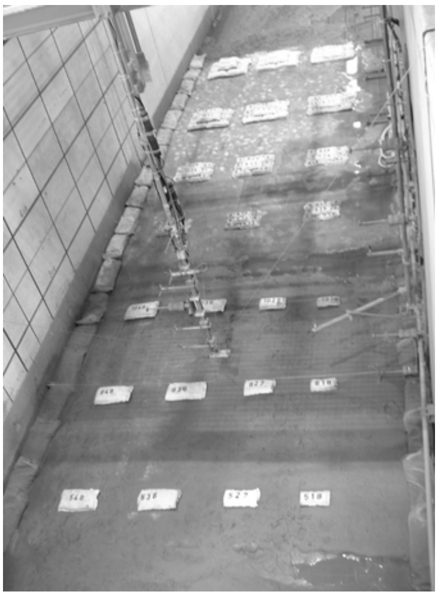


Figure 2. Longitudinal section of Large Wave Channel (GWK) with installed sand bed and proposed monopile

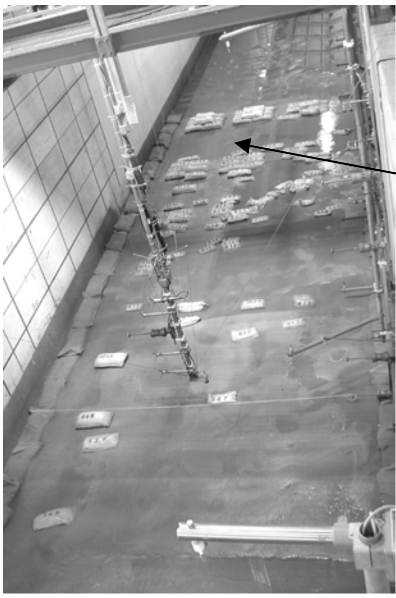
TABLE I

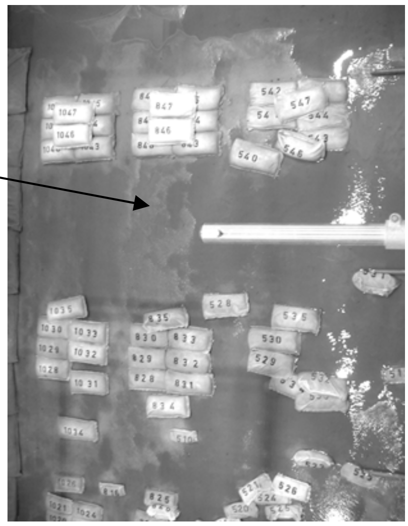
DIMENSIONS OF THE GEOTEXTILE SAND CONTAINERS

Geotextile Container Size (unfilled) l x w [cm]	Percentage of Filling [%]											
	56				80				100			
	Weight G [kg]	Dimension [cm]			Weight G [kg]	Dimension [cm]			Weight G [kg]	Dimension [cm]		
		l	w	h		l	w	h		l	w	h
29.5 x 14.5	1.71	28.2	14.4	3.3	2.45	27.2	13.6	5.0	3.06	27.3	13.3	6.6
36.0 x 18.5	3.34	35.6	17.7	3.9	4.78	34.2	17.2	6.0	5.97	35.4	16.9	7.5
47.0 x 23.0	7.24	45.2	22.8	5.2	10.33	44.0	22.1	7.8	12.91	43.9	22.3	10.2
48.0 x 26.0	10.25	51.3	24.8	6.9	14.64	51.3	25.3	9.0	18.31	48.7	25.2	11.8



Sand containers placed transverse before tests





Detail for the container groups

Displacements of sand containers after a test with $H_{1/3}$ = 1.0 m, T_p = 5 s

Figure 3. Model set-up of the geotextile sand containers placed on a horizontal sand bed covered with a geotextile filter layer

The different container sizes were placed on the geotextile sublayer both as single containers and as a group of 8 containers in two layers, which results in totally 108 containers for each test. The lower layer of each group consists of 6 containers (3 times 2) and the upper layer of 2 containers, lying in the midst of the lower layer (see definition sketch in Figs. 7 and 8). The container group array should give first results on the interacting effect in a container array. Furthermore, the containers were placed inline and transverse to the wave approach direction. The test configuration transverse to the wave attack is shown in Fig. 3 (left hand photo).

The water depth above the sand bed was kept constant with 2.5 m. Irregular wave trains (Jonswap-spectra) of 120 waves with wave heights between $H_{1/3}$ = 0.6 m to 1.13 m and a peak period of T_p = 5 s were generated. After each test the GWK was drained in order to measure the displacements of each container (middle and right photos in Fig. 3) and to re-establish the test configuration.

III. RESULTS

In the following first results from the basic stability tests are reported. Some results are shown exemplarily in Figs. 5 to 8, where the displacements measured after a test with $H_{1/3}$ = 1.13 m are plotted in the plan views of the test area in the GWK. The Y-axis is along the GWK in wave approach direction (inline) with zero point at the proposed monopole position, the X-axis is transverse to the wave approach direction over the total width (5 m) of the GWK with zero point at the left wall of the channel.

The open squares give the container positions before the test, the dashed ones the position after the test. The displacements are recorded after each test accordingly to the definitions in Fig. 4. Each displaced sand container was replaced in its original position before the next test. The results for the single containers are given in Fig. 5 (inline wave approach) and Fig. 6 (transverse wave approach) and the ones for the container groups in Fig. 7 (inline) and Fig. 8 (transverse).

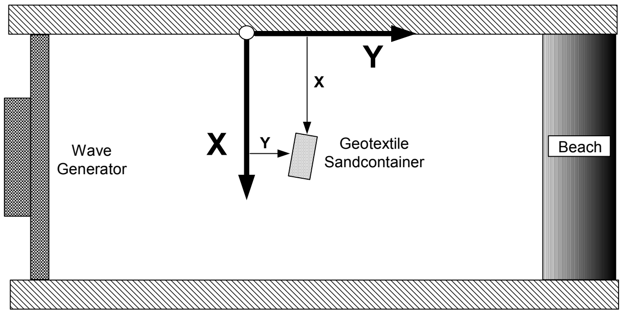


Figure 4. Definition of measured displacements

The displacement data in Fig. 5 for the single containers with inline wave approach demonstrate clearly the influence of the percentage of filling: There is a distinct trend of increasing stability with increasing percentage of filling. For example the 3.05 kg sand container with a filling of 100% is stable, whereas the 7.23 kg container with a filling of 56% is unstable. The data in Fig. 6 for the single containers with transverse wave approach show a similar but not so pronounced trend.

Results from the tests with the container groups are shown exemplarily in Fig. 7 and 8, where measured displacement data are plotted for one container size (l = 36 cm, w = 18.5 cm, unfilled) with 3 different percentages of filling. The wave approach in Fig. 7 is inline, the one in Fig. 8 is transverse. As well as for the data of the single containers the influence of the percentage of filling comes out clearly.

The reason for this effect may be explained by the following hypothesis: Partly filled containers may change their shape due to interior movement of the sand particles which may be caused from the wave-induced currents. With changing shape consequently the shape resistance increases. Thus, the stability decreases due to increasing acting force from the wave-induced currents and this results in a beginning of movement. The movement then may be amplified by further increasing shape resistance.

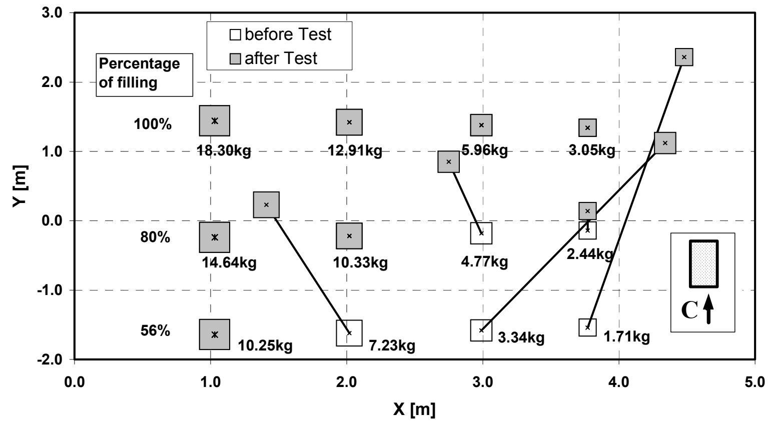


Figure 5. Displacements measured after a test with wave attack inline to single containers

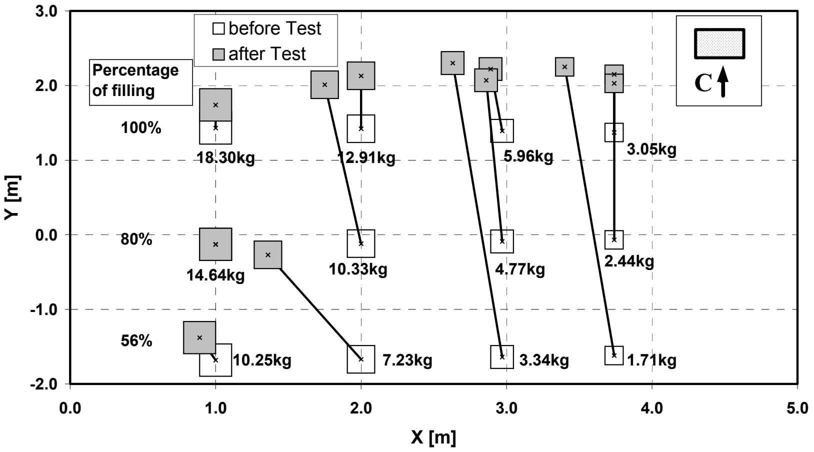


Figure 6. Displacements measured after a test with wave attack transverse to single containers

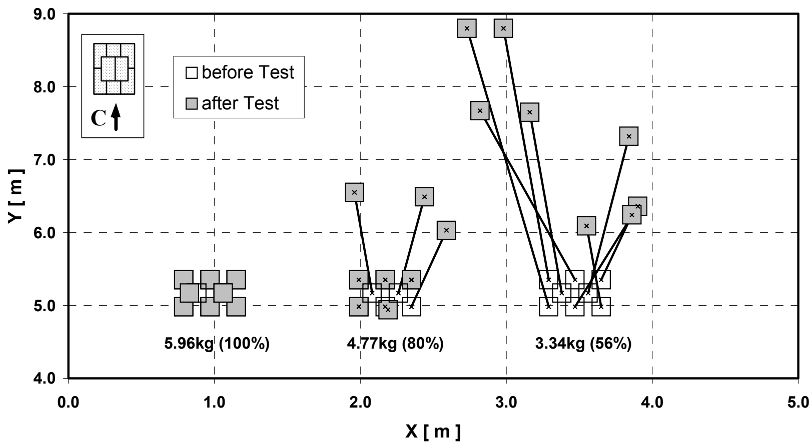


Figure 7. Displacements measured after a test with wave attack inline to container groups

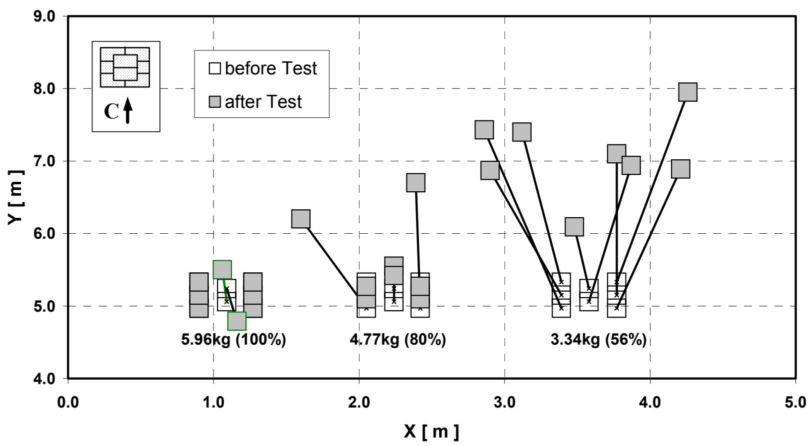


Figure 8. Displacements measured after a test with wave attack transverse to container groups

The inline displacements measured in the test series with the single containers placed inline to the wave approach, as shown in Fig. 5, are plotted in Fig. 9 versus the wave heights $H_{1/3}$. The data confirm that the percentage of filling has also an important influence on the stability of the sand containers.

The data in Fig. 10 give the same trend for the container groups with inline wave approach. The solid line in Fig. 10 stands for the mean inline displacement of all 8 containers in each group and the dotted lines for the maximum inline displacement in each group. Mostly strong differences occur between mean and maximum displacements. This results from the fact that the containers support one another especially in the lower layer. Thus, only the upper layer containers were displaced often (see Fig. 3).

The influence of wave approach direction comes out exemplarily from comparing the results in the upper part of Fig. 11 with the data in the middle part of Fig. 9 (both for single containers with 80% of filling). Inline displacements for single containers attacked with inline wave approach starts with much smaller wave heights $H_{1/3}$ compared to transverse wave approach. It must be mentioned that for container groups the differences between inline and transverse wave approach are much less, which is shown in Fig. 13.

As the waves generated in the GWK are long crested (two-dimensional), wave induced currents in transverse direction are generally very small and negligible.

Nevertheless, transverse displacements of the sand containers were recorded as shown exemplarily in the lower plot of Fig. 11. It was found that the transverse displacements generally increase with increasing inline displacements

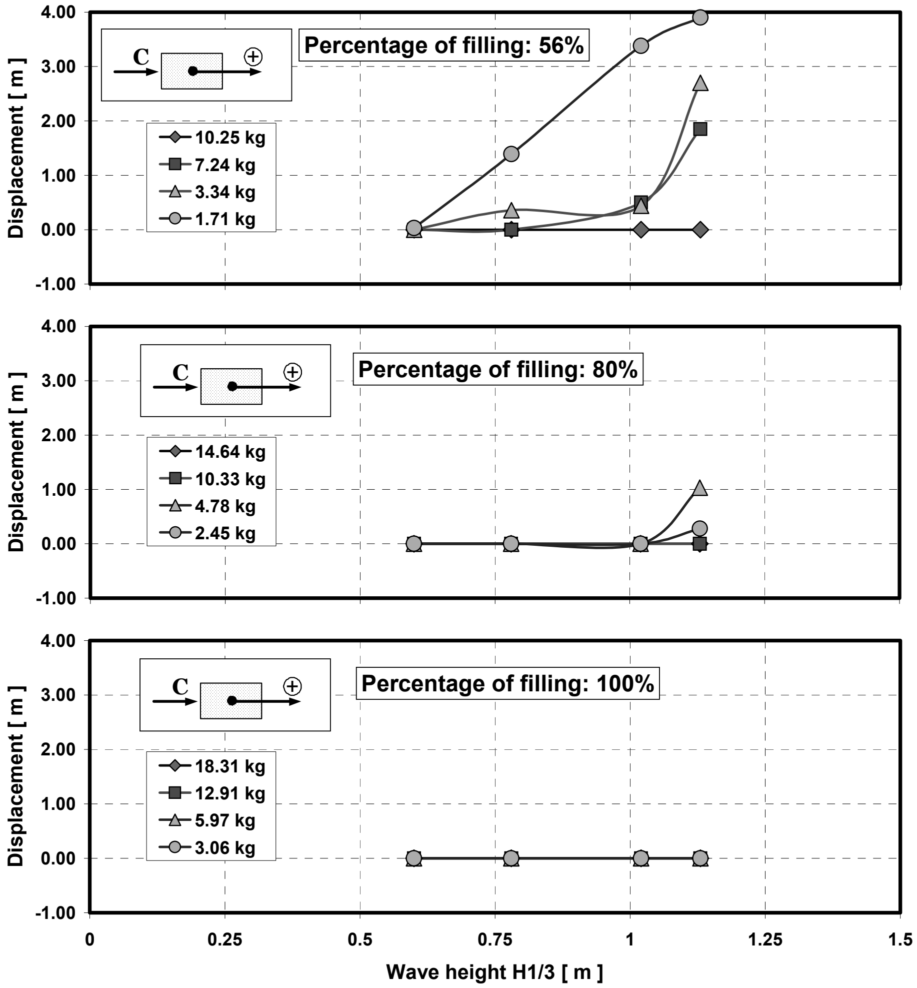


Figure 9. Displacements versus wave heights (single containers with inline wave attack)

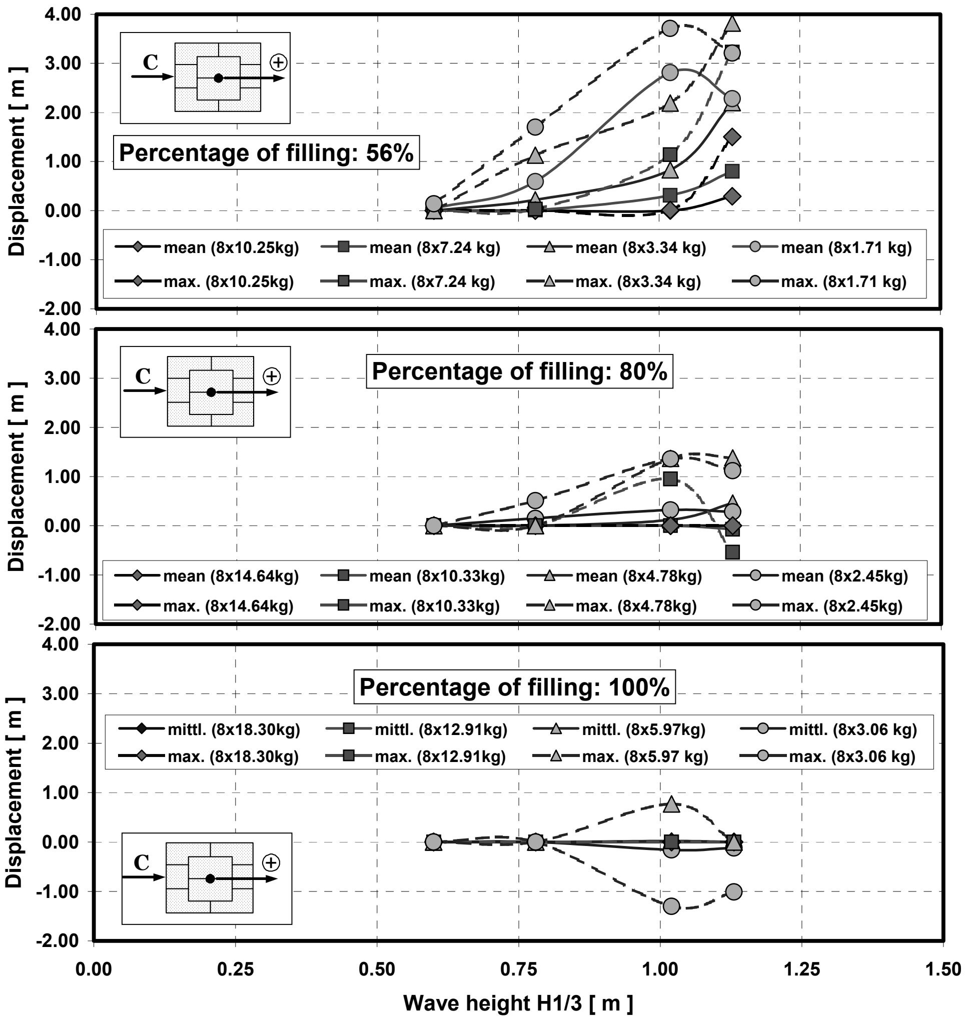


Figure 10. Displacements versus wave heights (container groups with inline wave attack)

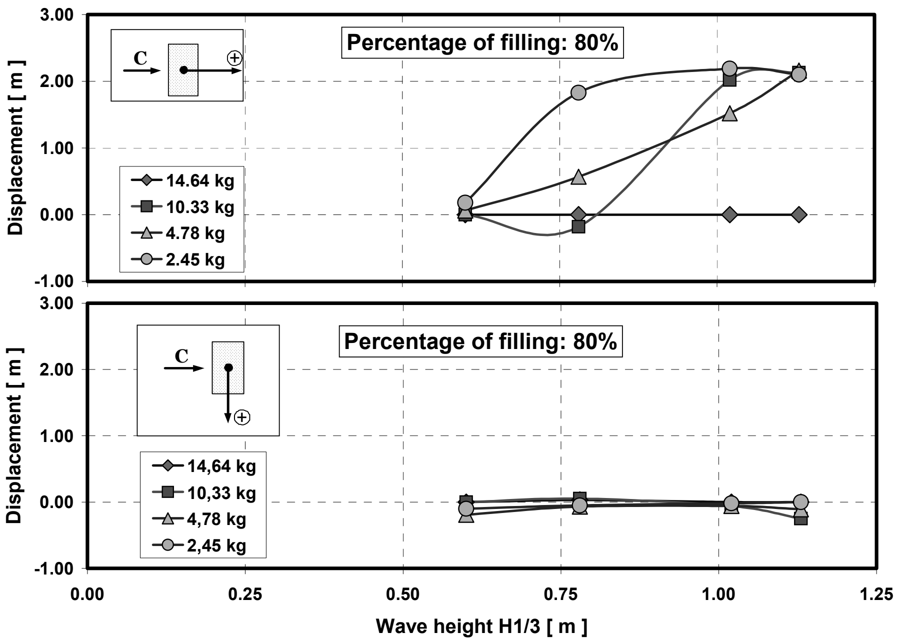


Figure 11. Inline and transverse displacements versus wave heights (single containers with transverse wave attack)

It must be considered, that the displacements were measured after the tests. Thus, these displacement data may represent only the impact of the last waves in the total wave train and may be overlapped by movements in any direction before. Consequently, there might have been larger displacements due to higher impacts from waves during the test. Hence there is no direct correlation between displacements and wave heights, nevertheless a distinct trend is identifiable. But at least the displacement data can describe two ultimate conditions: Stable (displacement = 0) or unstable (displacement > 0).

Some test results in the sense of stable or unstable are given exemplarily in Fig. 12, where the data of container groups with inline wave attack are plotted in a matrix of container weights G versus measured wave heights $H_{1/3}$. The straight lines represent a first approximation of the borderline between stable and unstable conditions. The solid line stands for a filling of 80%, the dotted ones for a filling of 56% and of 100%, respectively.

These borderlines of all test data result in a first dimensional empirical approximation:

$$G\ [kg] > A\ [-] + 25\ H_{1/3}\ [m]$$

with the coefficient A depending on the percentage of filling. It must be noted that this first step approach is only valid for a period T_p = 5 s referred to the experimental conditions. To create a dimensionless approach the research work will be continued by further analysis of the experimental data considering the wave-induced current data measured on the sand bed.

The empirical coefficients A estimated from all tests are given in Fig. 13 versus the percentage of filling. It is obvious that the dependence on wave approach direction is less for container groups compared to single containers as well as the dependence on the percentage of filling. Otherwise, the definition of the criteria stable – unstable is not comparable directly as even one displaced container in one group of totally 8 leads to the mode “unstable”.

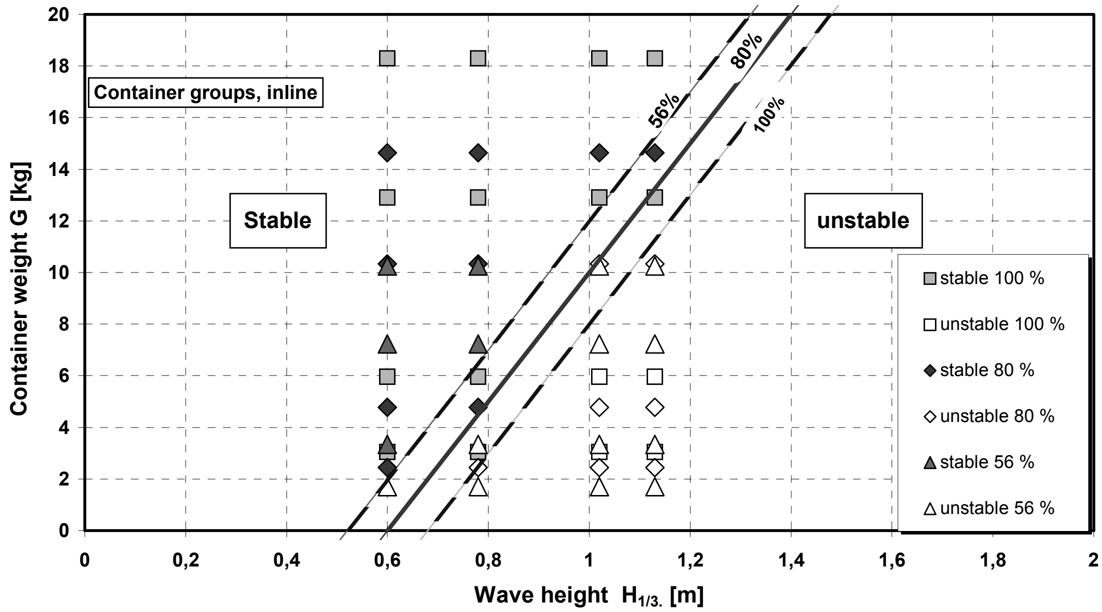


Figure 12. Stability conditions recorded from tests with container groups, inline wave attack

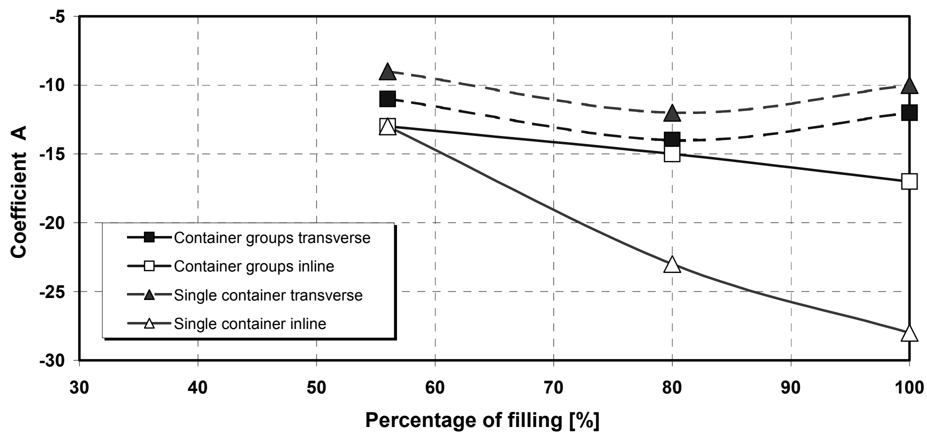


Figure 13. Coefficients A versus percentage of filling for single containers and container groups and for inline and transverse wave attack

IV. Concluding Remarks And Outlook

Investigations on the stability of an innovative scour protection design for monopile support structures using geotextile sand containers have been started in the Large Wave Channel (GWK) of the Coastal Research Centre (FZK). Basic test series were performed with single containers and container groups with different container weights, varied in sizes and percentages of filling. The first results lead to the following general statements:

- The stability of sand containers is not only a function of the total weight.
- Other influences are the percentage of filling and the direction of wave approach, which are smaller for container groups compared to single containers due to interaction effects in a group.
- The stability increases with increasing percentage of filling.

A first approximation from the measured data is estimated in an empirical approach on the stability depending on the wave height and the percentage of filling.

The investigation will be continued both by executing further analysis of the recent basic tests considering the wave-induced currents measured on the sand bed and by performing tests with a complete scour protection design around a monopile. The scour protection design consists of two layers of geotextile sand containers placed around a monopile structure (diameter of 5.5 m and water depth of 21 m in prototype) which is scaled down to 1:10 in the GWK (Fig. 14). Fig. 15 shows the 1:10 model of the monopile installed in the GWK under wave attack.

Figure 14. 1:10 model of the scour protection with sand containers in the GWK.

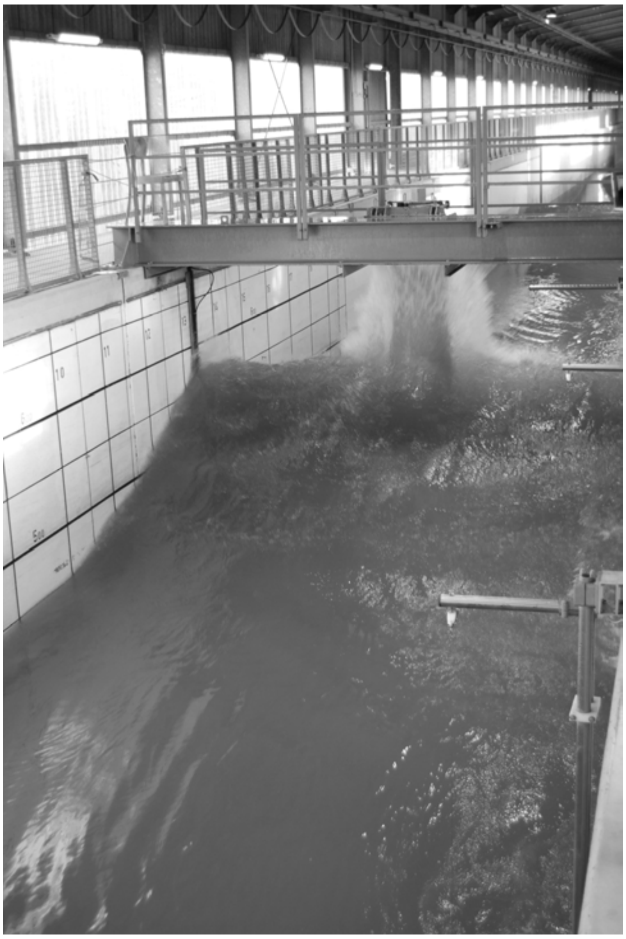


Figure 15. 1:10 model of the monopile under wave attack in the GWK.

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Reference

[1] K.W. Pilarczyk, *Geosynthetics and Geosystems in Hydraulic and Coastal Engineering*, A.A. Balkema, Rotterdam, 2000.