

Scour protection for offshore wind energy monopile structures with geotextile sandcontainers

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SUMMARY

Monopile structures for offshore wind turbines founded in movable sand bed are affected by scour mainly due to waves. An innovative scour protection was proposed by using geotextile sand containers. A research programme on the stability of such alternative scour protection has been started recently. Large-scale model tests are being performed in the Large Wave Channel (GWK) of the Coastal Research Centre (FZK). Basic test series were performed with single geotextile sand containers and container groups with different container weights, varied in sizes and percentages of filling. First results are reported, which demonstrate the influences of the percentage of filling and the direction of wave approach direction. Further a first approximation on the dimensioning of sand containers is estimated as an empirical approach depending on the wave height and the percentage of filling.

KEYWORDS: Offshore wind energy turbines, monopile structures, scour protection, geotextile sand containers

1. 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 more and more 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. 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 (see eg. Pilarczyk, 2000) is poor and needs to be improved.

In order to investigate the stability of such alternative scour protection with geotextile sand containers a research programme has been started recently at the FZK. In the experimental part of this programme physical large-scale model tests are being performed in the Large Wave Channel (GWK) of the Coastal Research Centre (FZK) to minimise scale effects occurring both with simulation of wave induced hydrodynamic processes and especially with the scaling of natural fine sands, which are existing at the proposed offshore areas.

2. EXPERIMENTS

In the beginning of the sand container experiments some few pilot tests were performed with 4 different geotextile sand containers sizes to get a first approach for dimensioning the containers for the proposed main tests with a complete scour

protection array around a monopile in the GWK. 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 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 programmes the sand containers were varied in size and percentage of filling, which results in 12 different container weights (Table 1). 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 1. 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) in filled condition are given in Table 1.

Table 1 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

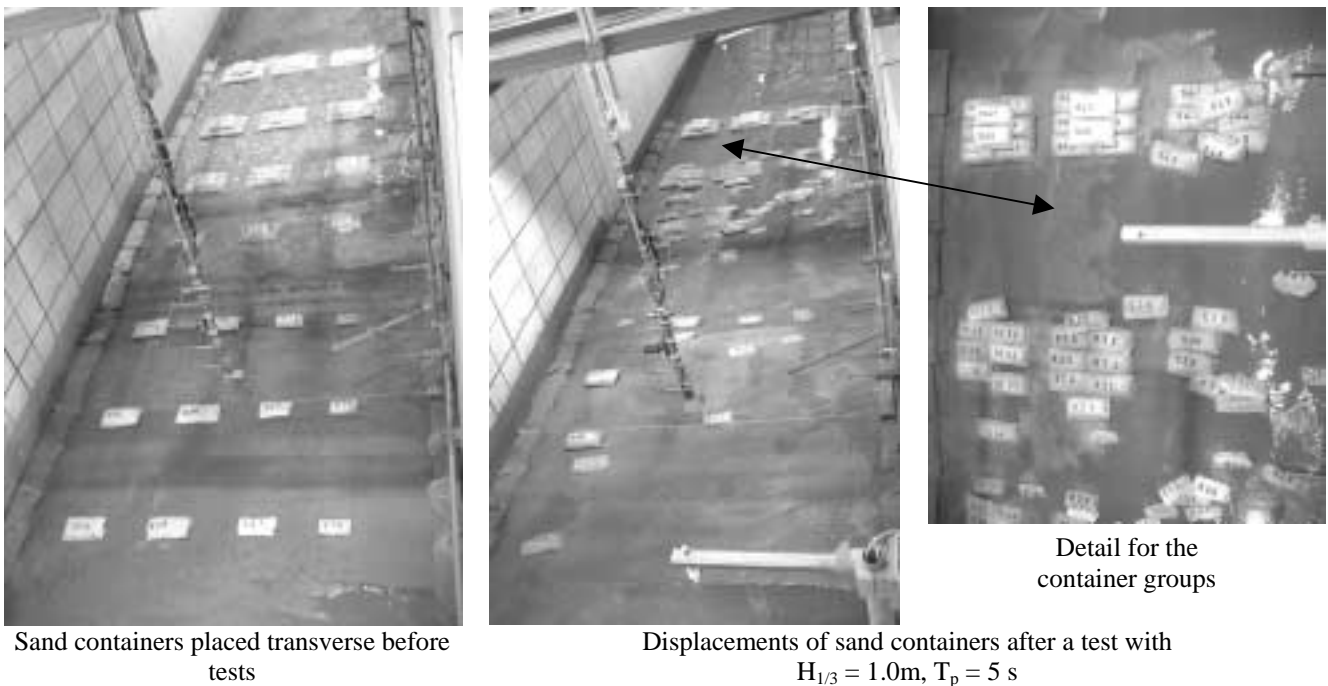


Fig. 1 : Model set-up of the sand containers placed on a horizontal sand bed covered with a geotextile filter layer

The different container sizes were placed both as single ones 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. 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 on a geotextile sublayer. The test configuration transverse to the wave attack is shown in Fig. 1 (left hand photo).

The water depth 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. 1) and to re-establish the test configuration.

3. RESULTS

In the following first results from the basic stability tests are reported. Some results are shown exemplarily in Figs. 2 to 5, 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 results for the single containers are given in Figs. 2 (inline wave approach) and 3 (transverse wave approach) and the ones for the container groups in Figs. 4 (inline) and 5 (transverse). The Y-axis is along the GWK in wave approach direction (inline), the X-axis is transverse to the wave approach direction over the total width (5 m) of the GWK. The open squares give the container positions before the test, the dashed ones the position after the test.

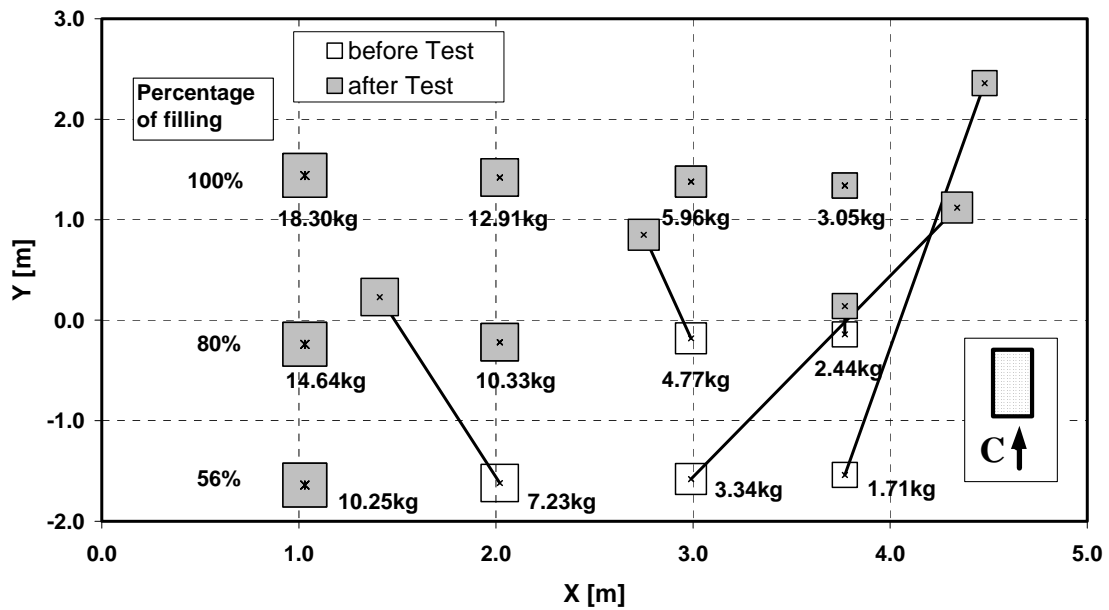


Fig. 2 Displacements measured after a test with wave attack inline to single containers

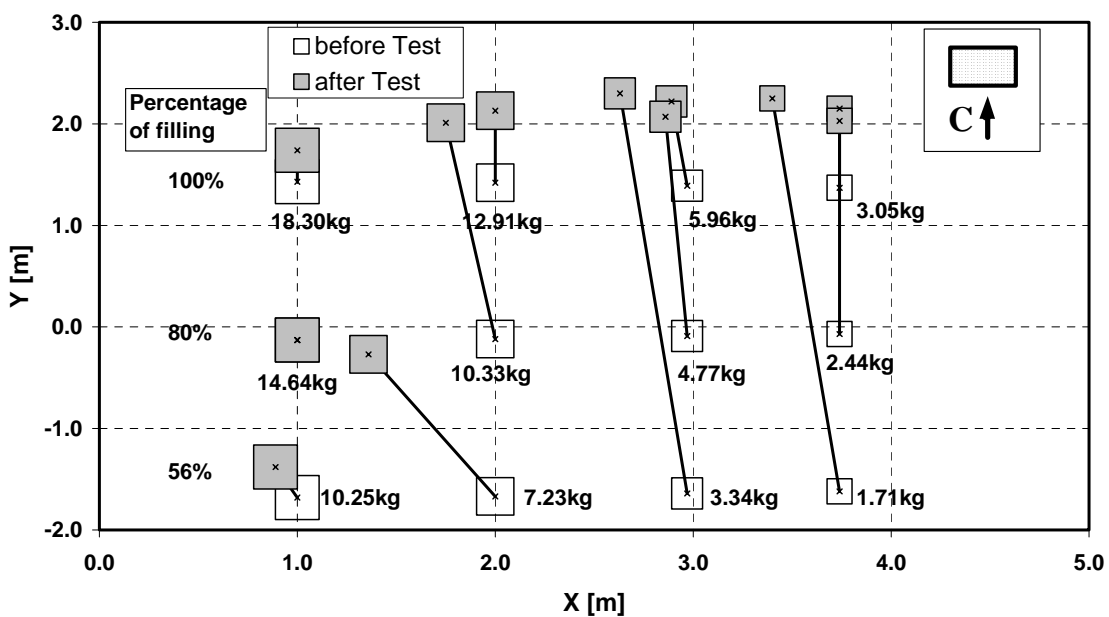


Fig. 3 Displacements measured after a test with wave attack transverse to single containers

The displacement data in Fig. 2 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. 3 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. 4 and 5, where displacement data are plotted measured of one container size ($l = 36$ cm, $w = 18.5$ cm, unfilled) with 3 different percentages of filling. The wave approach in Fig. 4 is inline, the one in Fig. 5 is transverse. As well as for the data of the single containers the influence of the percentage of filling comes out clearly.

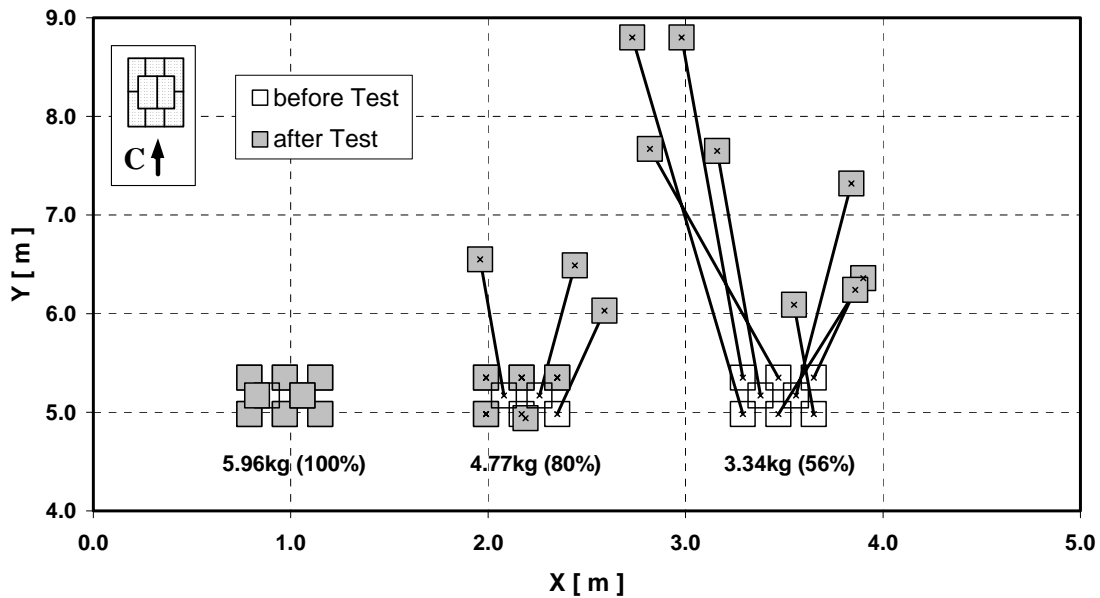


Fig. 4 Displacements measured after a test with wave attack inline to container groups

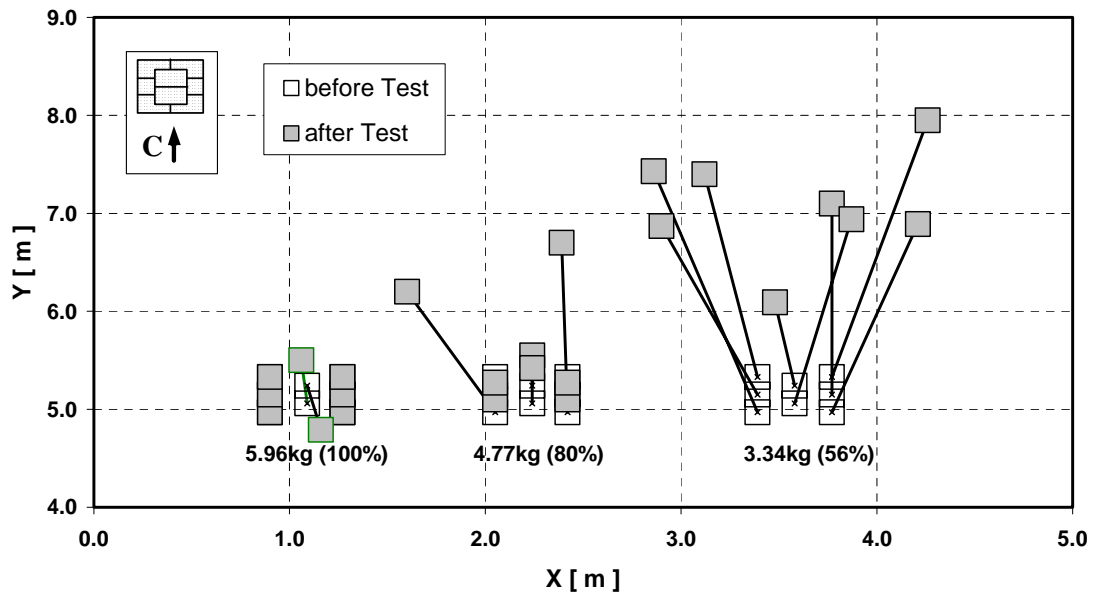


Fig. 5 Displacements measured after a test with wave attack transverse to container groups

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.

The inline displacements measured in the test series with the single containers placed inline to the wave approach, as shown in Fig. 2, are plotted in Fig. 6 versus the wave heights $H_{1/3}$. The data confirm that the percentage of filling also has an important influence on the stability of the sand containers.

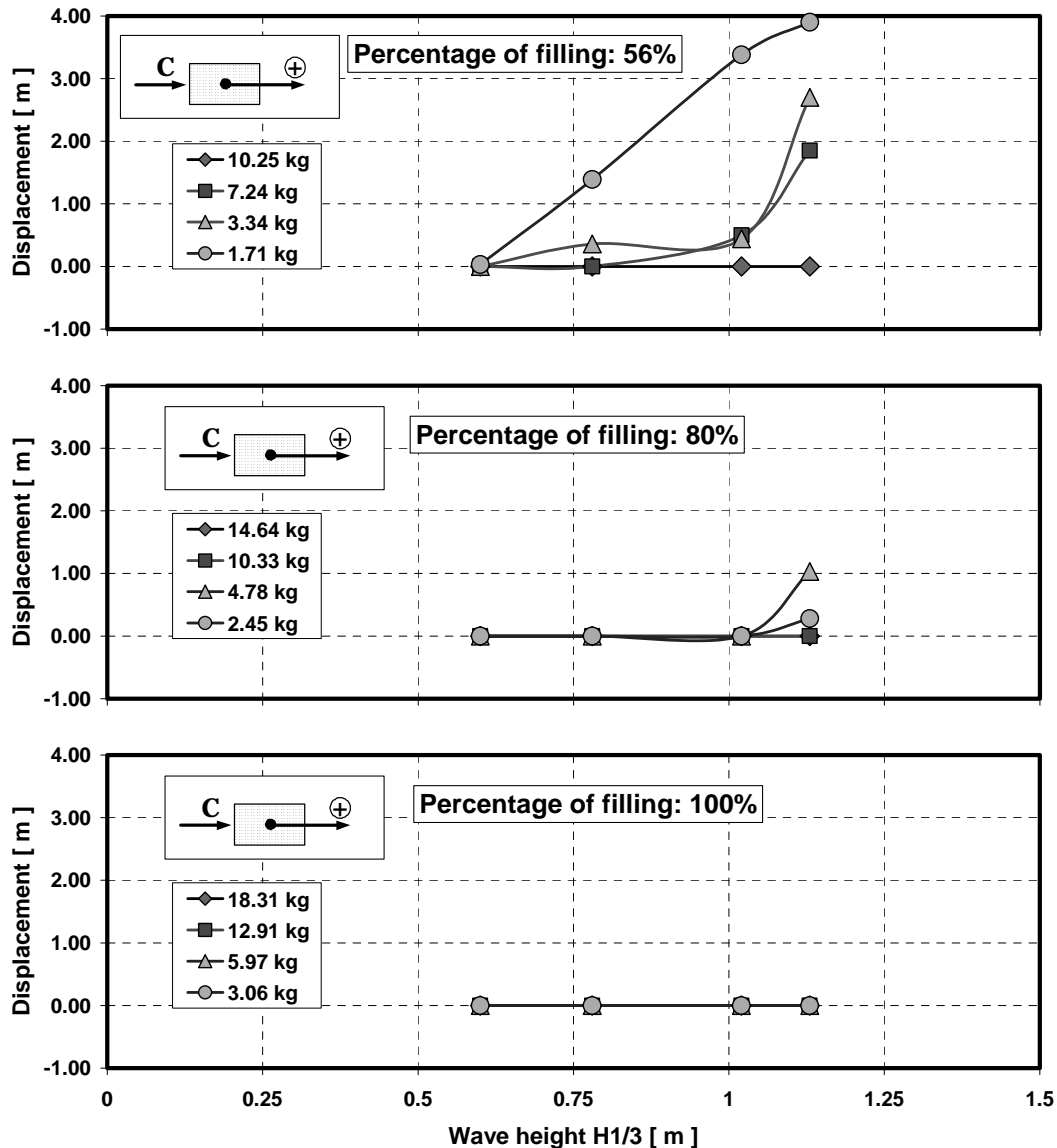


Fig. 6 Displacements versus wave heights (single containers with inline wave attack)

The data in Fig. 7 give the same trend for the container groups with inline wave approach. The solid line in Fig. 7 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 often only the upper layer containers were displaced (see Fig. 1).

The influence of wave approach direction comes out exemplarily from comparing the results in the upper part of Fig. 8 with the data in the middle part of Fig. 6 (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. 10.

As the waves generated in the GWK are long crested (two-dimensional), wave induced currents in transverse direction are only very small and negligible normally. Nevertheless, transverse displacements of the sand containers were recorded as shown exemplarily in the lower plot of Fig. 8. It was found that the transverse displacements generally increase with increasing inline displacements.

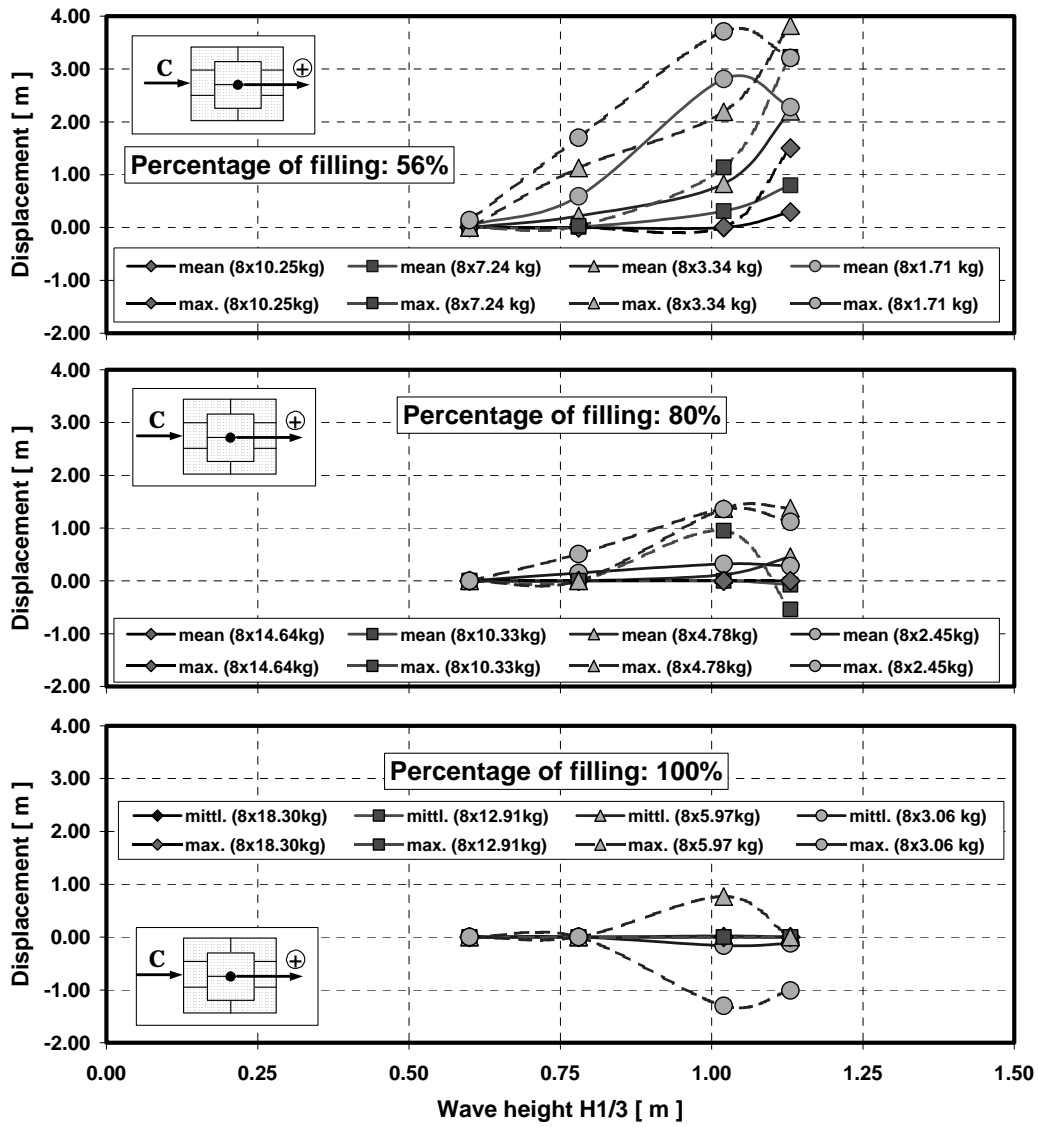


Fig. 7 Displacements versus wave heights (container groups and inline wave attack)

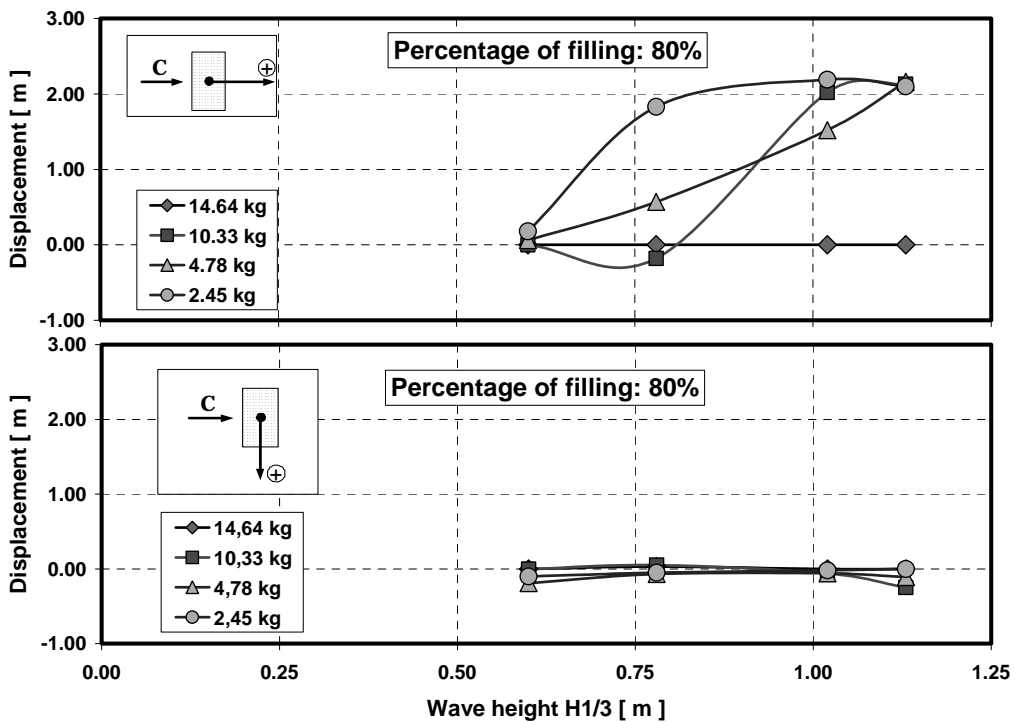


Fig. 8 Inline and transverse displacements versus wave heights (single containers, transverse wave attack)

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 conditions: Stable or unstable.

Some test results in the sense of stable or unstable are given exemplarily in Fig. 9, 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 result in a first empirical approximation

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

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 $T_p = 5 \text{ s}$ referred to the experimental conditions.

The empirical coefficients A estimated from all tests are given in Fig. 10 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.

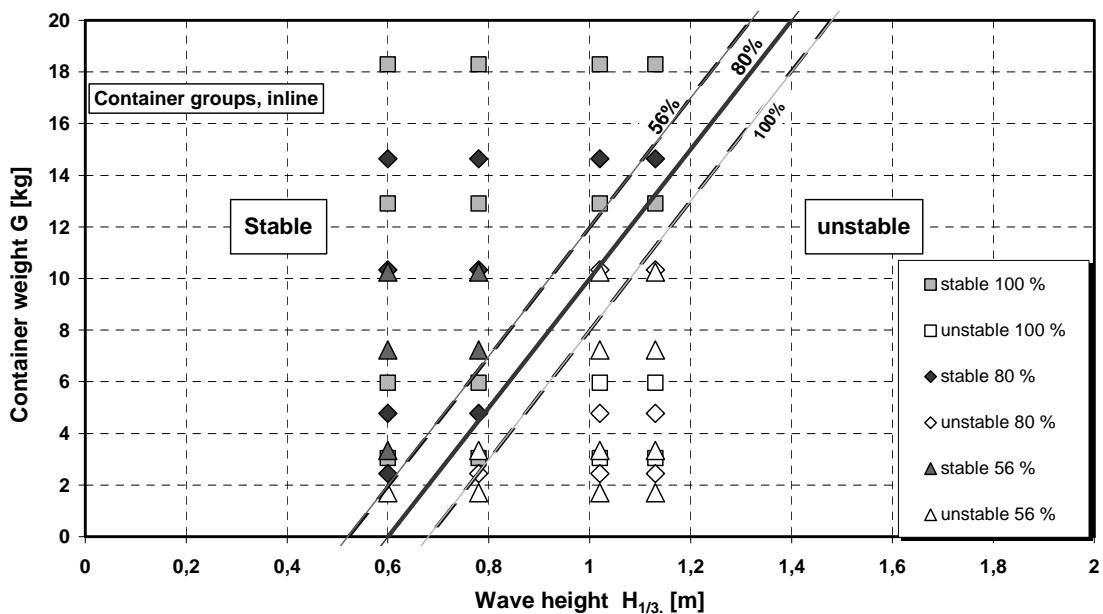


Fig. 9 Stability conditions recorded from tests with container groups and inline wave attack

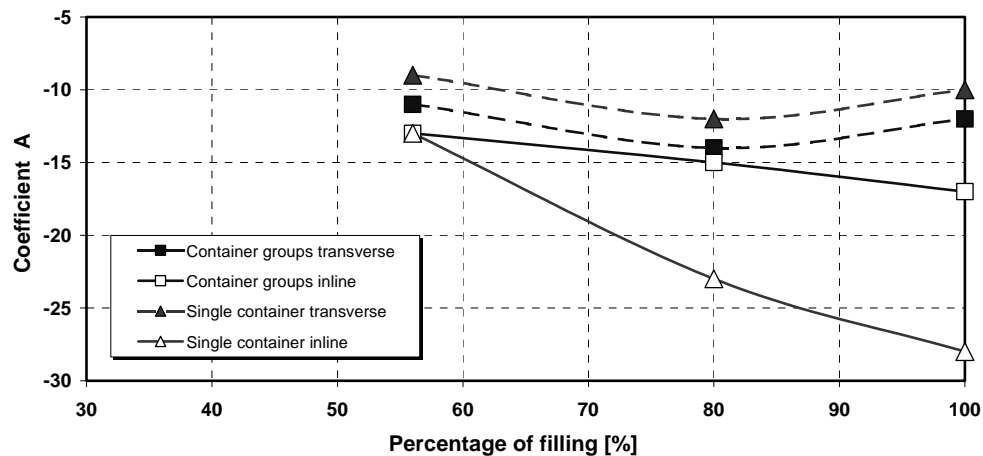


Fig. 10 Coefficients A versus percentage of filling for single containers and container groups and for inline and transverse wave attack

4. 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 is estimated in an empirical approach depending on the wave height and the percentage of filling.

The investigation will be continued both by 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 multi-layers of geotextile sand containers placed around a monopile structure (diameter of 5.5 m and water depth of 25 m in prototype) which is scaled down to 1:10 in the GWK.

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6. REFERENCES

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