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WAVE LOADS OF SLENDER MARINE CYLINDERS DEPENDING ON INTERACTION EFFECTS OF ADJACENT CYLINDERS

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ABSTRACT

Within a basic research programme at the Coastal Research Centre (FZK) in Hannover large-scale wave experiments were performed with single vertical and inclined Cylinders (Oumeraci, 2004). Additionally, cylinder groups were investigated with special reference to shelter and amplification effects depending on cylinder spacing. Nonbreaking regular and irregular waves as well as breaking freak waves were generated. The test set-up and some first results of the experiments looking to the maximum wave loads are reported in the paper.

INTRODUCTION

For the design of marine structures including cylindrical components the influence of neighbouring cylinders on the wave loading (interference, shelter and amplification effects) cannot yet be estimated with sufficient engineering accuracy. Apelt and Piorewicz (1986) reported results of small-scale tests with breaking waves acting on rows of cylinders. They found that breaking wave forces on cylinders in a row in many cases are larger than those on a single isolated cylinder. Smith and Haritos (1997) investigated group interference effects in small-scale experiments. For specific cylinder group configurations Morison-coefficients depending on KC-number were derived. One of the main problems up to date is the uncertainty associated with the transfer of small-scale model test results to prototype conditions.

In the Large Wave Channel (GWK) at the Forschungszentrum Küste (FZK), wave loads on Coastal and Offshore structures can be examined in a very large scale, thus minimizing scale effects. The main data of GWK are effective: length 309 m, width 5 m, depth 7 m, maximal water depth 5 m, maximal wave height 2.5 m, breaker height up to 3.2 m. Any kind of waves can be generated: Regular wave trains, solitary waves, wave packets (freak waves) and irregular waves (common and any other spectra measured in the field).

EXPERIMENTAL MODEL SET-UP

The measuring slender cylinder made of steel with a diameter 0.324 m was installed like a cantilever pile at the support structure. The bending moments of the measuring cylinder were measured by calibrated strain gauge applications. The wave kinematics were recorded synchronously using nine wave gauges and two current meters (Fig. 1). Fig. 2 shows a photo of the model set-up with the measuring cylinder and the support structure.

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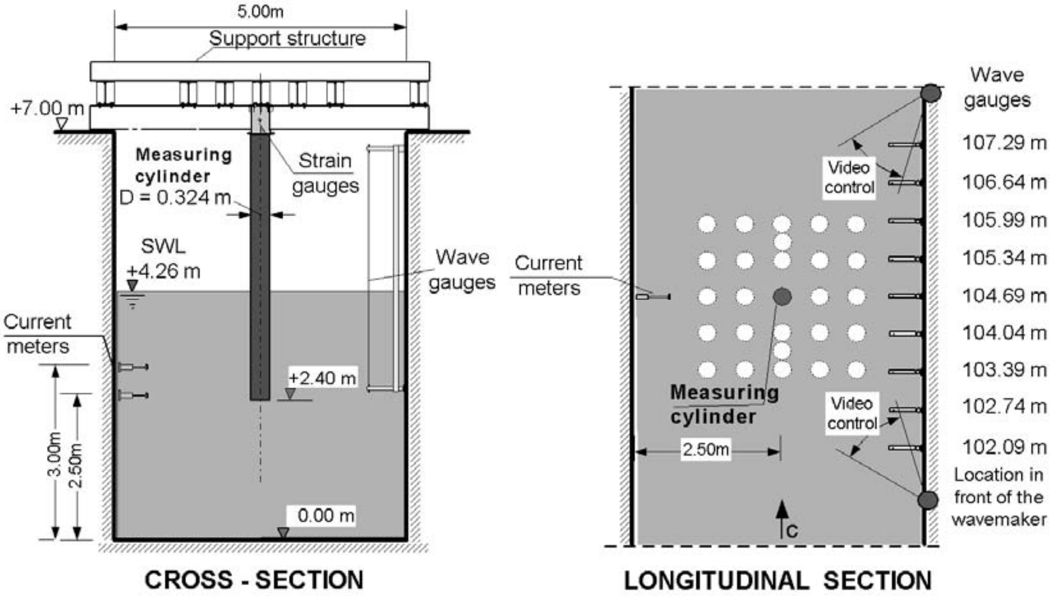

Figure 1. Model set-up in the Large Wave Channel (GWK)

Neighbouring cylinders (diameter 0.324 m) were also installed like cantilever piles at the support structure. The spacing between the measuring cylinder and the neighbouring ones with the same diameter were varied up to three times the diameter (3 x D). 15 different configurations of inline, transverse and mixed inline/transverse rows of the piles were investigated with respect to practical applications (Fig. 3). The measuring cylinder is installed in the midline of the wave flume in a distance of 104,69 m from the wave paddle.

Figure 2. Model set-up with the measuring cylinder
(Configuration 1, single isolated cylinder)

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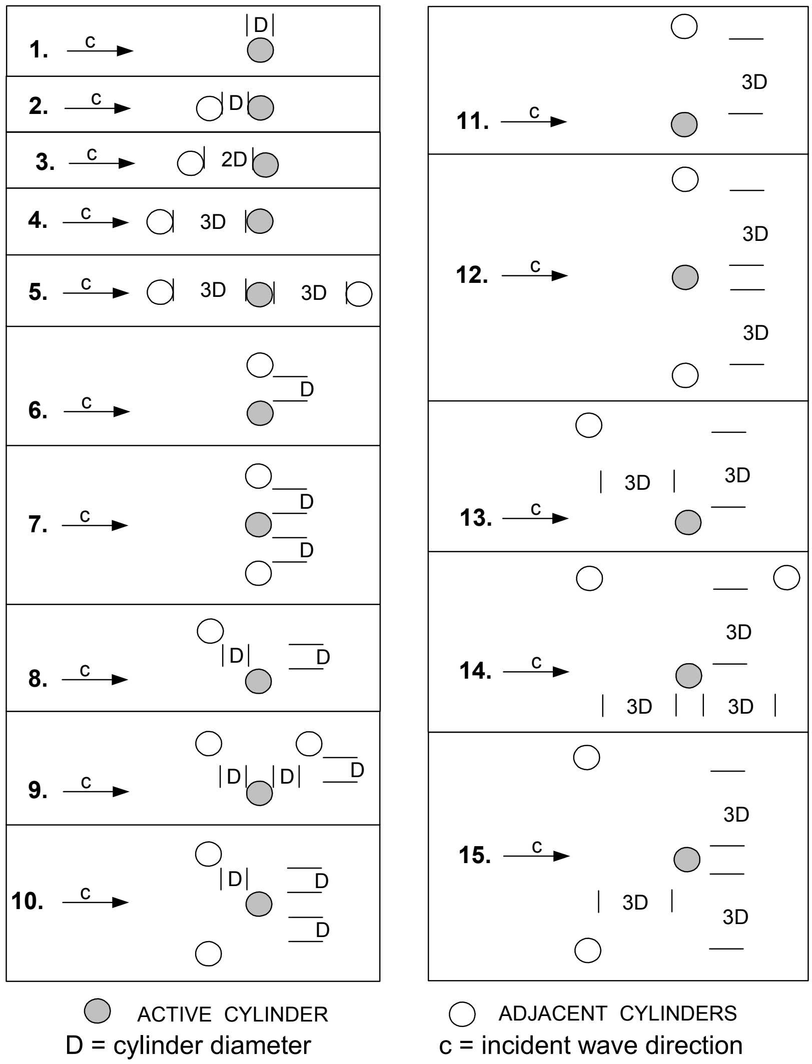

Figure 3. Investigated configurations of cylinder groups

WAVE PROGRAMME

Regular nonbreaking waves were generated with wave heights 0.80 to 1.40 m and wave periods 4 to 8 s (H/L = 0.0162 to 0.0659). Each wave test was performed with 20 waves. Furthermore, Jonswap wave spectra with at least 100 nonbreaking waves were simulated with significant wave heights 0.80 and 1.00 m and peak periods 4, 6 and 8 s (max H/L = 0.039 to 0.078).

Breaking freak waves were generated by Gaussian wave packets (Clauss and Kühnlein, 1997; Sparboom et al., 2001; Schmidt-Koppenhagen et al., 2004). The breaking location can be predetermined with accuracy in the simulation procedure for the wave maker control. Different concentration points of the wave packets in front of the cylinder groups and behind the cylinder groups generate different cylinder wave loadings. For these investigations, five different concentration points close to the cylinder groups were selected to get the highest wave loads or bending moments (Tab. 1). Each of the wave packets were generated with a wave height (Hgen) of 1.50 m and a wave period (Tgen) of 6.0 s. These wave parameters only describe the generation process with the wave maker and not the breaking freak wave at the cylinders. It should be noted that the concentration point of a wave packet is not necessarily equal to the breaking point.

Fig. 4 shows a wave test with nonbreaking waves (configuration 7 in Fig. 3) whereas in Fig. 5 a breaking freak wave hits the cylinder group (configuration 12 in Fig. 3).

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d = 4.26 m	Location of Concentration Points, Distance from the Wave Paddle [m]				
Wave Height H_{gen} = 1.50 m	103	105	107	109	111
Wave Period T_{gen} = 6.0 s	×	×	×	×	×

Table 1. Gaussian wave packets for the generation of breaking freak waves

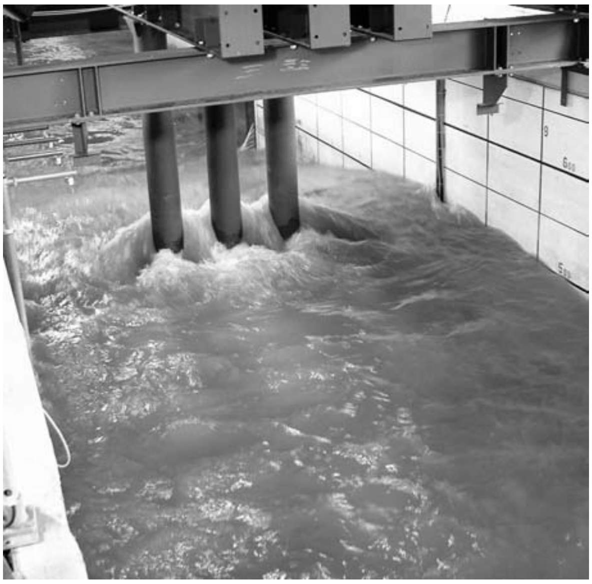

Figure 4. Nonbreaking waves (configuration 7)

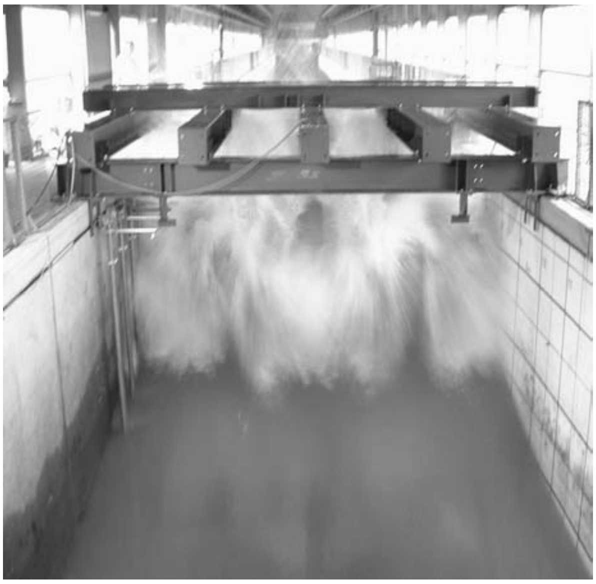

Figure 5. Breaking freak wave (configuration 12)

Synchronous time records of the wave height, the horizontal component of the orbital velocity and the inline bending moment are given exemplarily in Figs. 6 - 8. The wave kinematics were recorded with a wave gauge and a current meter at 104.69 m in front of the wave maker (equal to the location of the measuring cylinder). The current meter was installed 1.26 m below SWL (see Fig. 1).

FIRST RESULTS

The maximum measured values of the wave-induced inline bending moments are of special interest for design purposes. It should be noted, that for each of 15 cylinder configurations 23 wave tests were repeated with a very high accuracy at a constant water depth of 4.26 m. This is an important prerequisite comparing the wave loads recorded at the measuring cylinder. Configuration 1 was used to measure the wave load (bending moment) of the isolated measuring cylinder. This is the reference wave load to which the measured wave loads of the other configurations 2 - 15 are related in this study.

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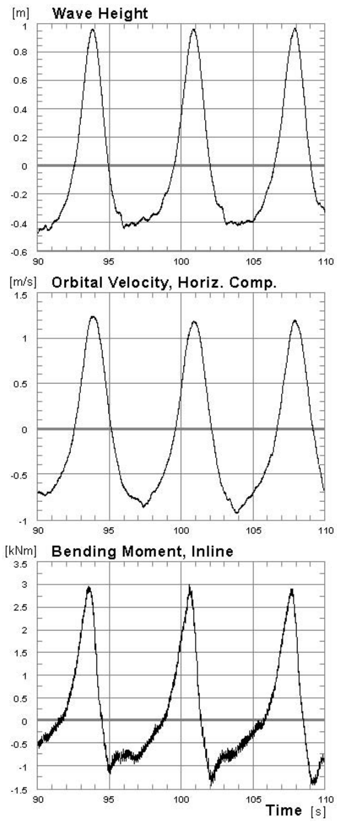

Figure 6. Nonbreaking regular waves
(H = 1.4 m; T = 7.0 s)

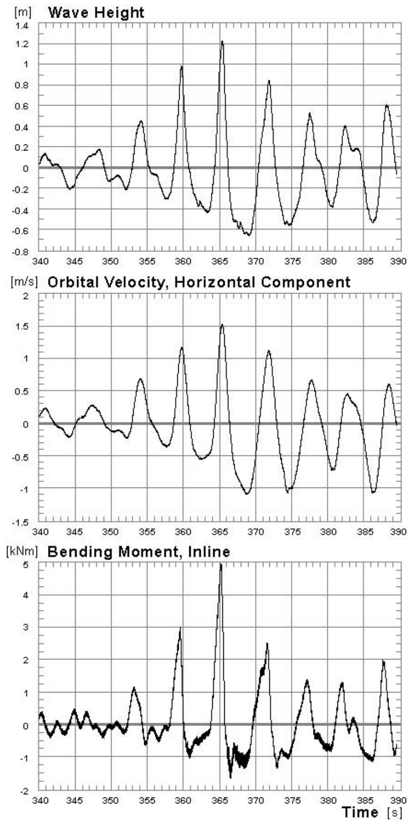

Figure 7. Nonbreaking irregular waves (Jonswap spectrum)
(H_s = 1.0 m; T_p = 6.0 s)

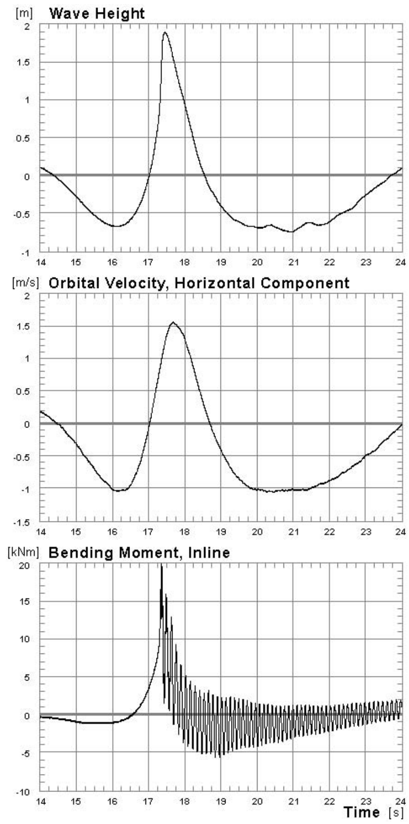

Figure 8. Breaking freak wave
(H_{gen} = 1.5 m; T_{gen} = 6.0 s)

Wave loads due to regular nonbreaking waves

For different wave periods and all 15 configurations, the maximum inline bending moments are given as a function of the wave height in Fig. 9. Comparing the bending moments, a 60 % increase of the wave load is found for configuration 7 with spacing of 1 x D between three cylinders in a transverse row. For the spacing of 3 x D in configuration 12 a 35 % increase is found whereas in configuration 11 (spacing 3 x D between two cylinders in a transverse row) a 25 % increase is observed. This seems to be in contrast to the common rule of thumb that there is no interaction between two slender cylinders with a spacing larger than 3 x D.

It is obvious that no configuration shows a decrease of the wave load compared to the isolated cylinder. Especially, the configurations 2 - 5 show no wave load decrease as could be expected due to shelter effects. On the contrary, an amplification effect up to a 20 % increase for configuration 3, 4 and 5 is found.

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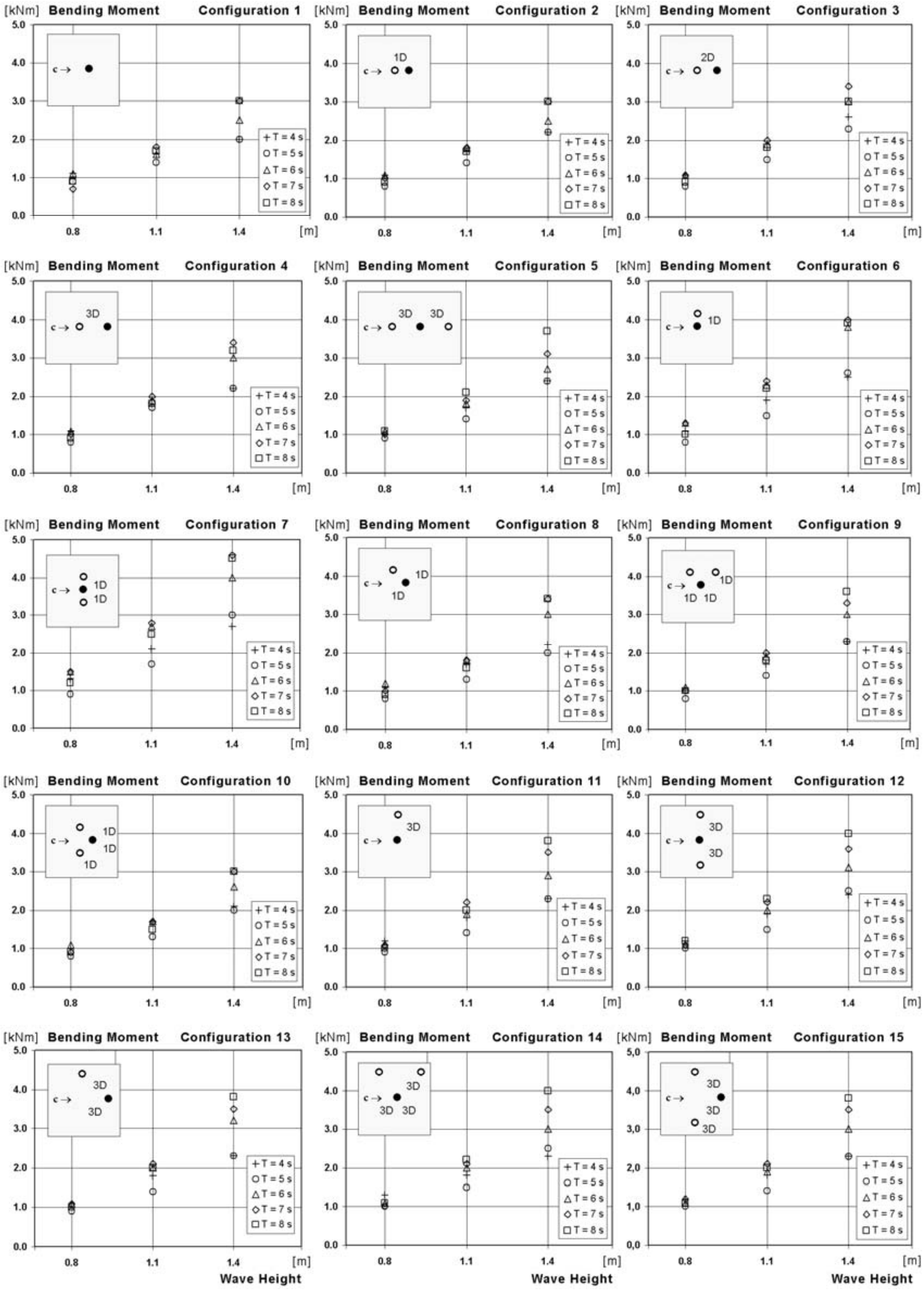

Figure 9. Maximum inline bending moments induced by nonbreaking regular waves for 15 investigated cylinder configurations

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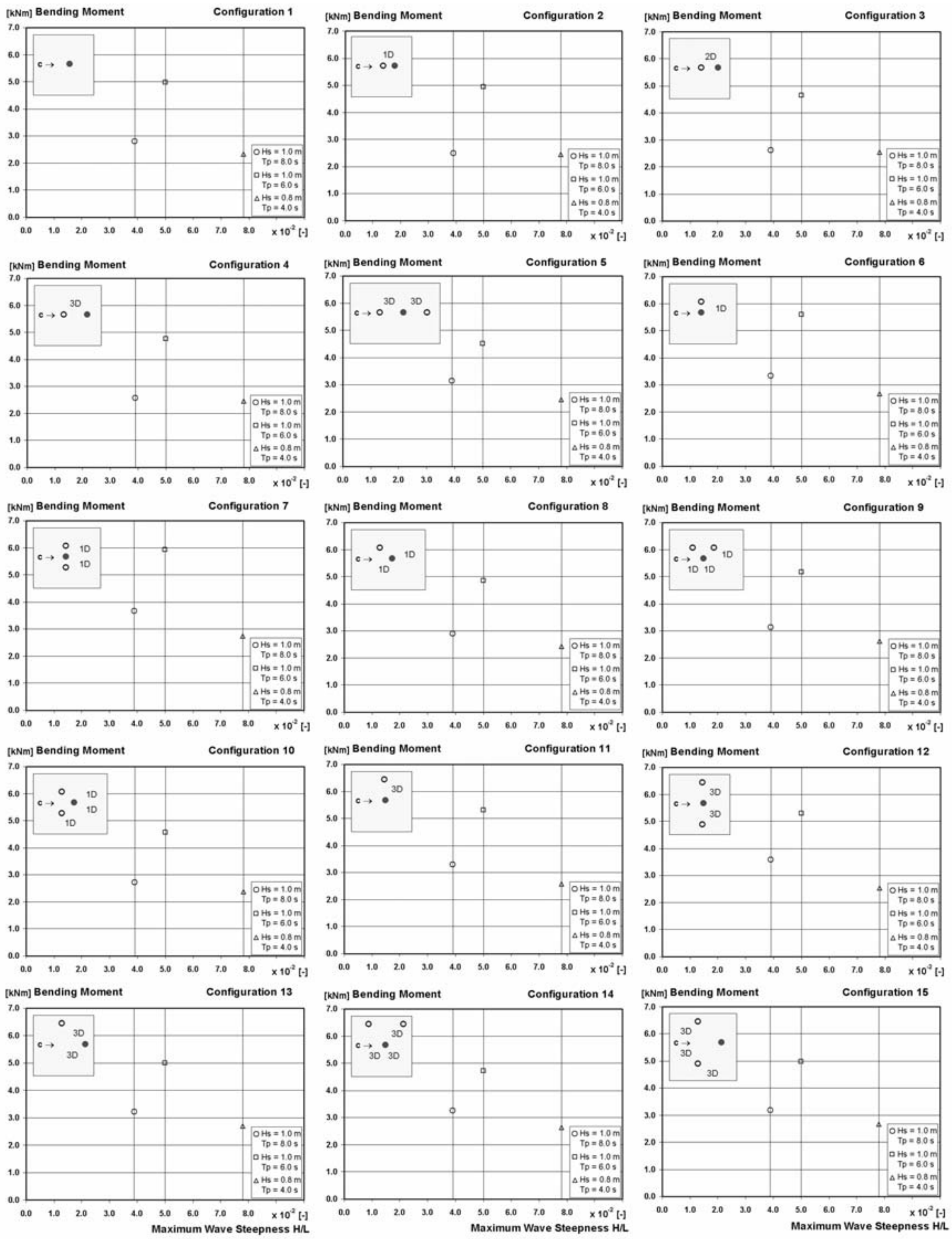

Figure 10. Maximum inline bending moments induced by nonbreaking waves of Jonswap wave spectra for 15 investigated cylinder configurations

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Wave loads due to Jonswap spectra with nonbreaking waves

In Fig. 10 there are plotted the maximum inline bending moments for three different Jonswap spectra. Instead of the wave height in Fig. 9 the measured values are plotted against the maximum wave steepness. Again, the highest amplification is found for configuration 7 with 1 x D spacing of three cylinders in a transverse row. But the increase is only 20 to 30 % compared to regular waves. The 3 x D spacing in a transverse row of configurations 11 and 12 shows also a smaller amplification compared to regular waves. For some configurations a slight decrease of the wave load is observed compared to the isolated single cylinder. Such decrease was not found in the case of regular nonbreaking waves (see Fig. 9).

Validation of a numerical model

The measured data of configuration 1 were used for validation and verification of a new developed numerical model calculating wave kinematics and wave forces (without breaking waves). The numerical model is based on a local Fourier approximation which is used to describe wave kinematics with irregular characteristic (Mittendorf and Zielke, 2004). Bending moments are calculated by Morison's approach superposing inertia and drag terms. First results of the validation are shown in Fig. 11. The wave kinematics are quite well calculated, the model calculation of the bending moment differs from the measured signal. The reason could be the uncertain selection of the force coefficients in Morison's formula. The validation of this special numerical model (developed for the design of offshore monopiles supporting windturbines) by large-scale laboratory force measurements was helpful and will be an important tool in the near future, also for more complicated offshore structures (e.g. inclined and horizontal cylindrical components).

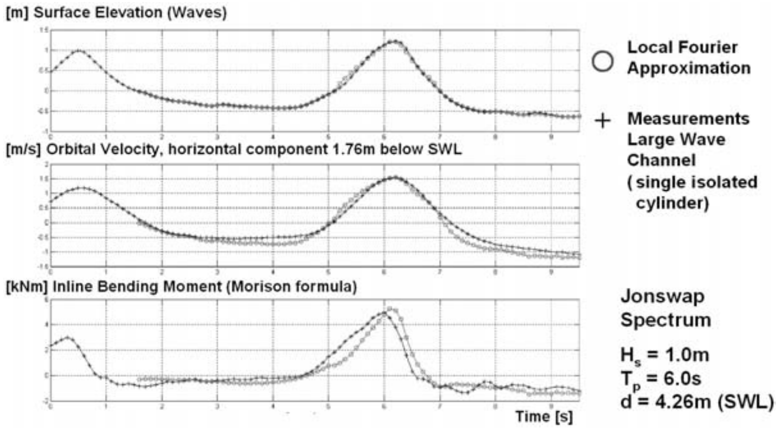

Figure 11. Validation of a numerical model for cylinder wave load calculations

Wave loads due to breaking freak waves

For this part of the investigations the measured bending moments Mki are compared for five different concentration points (x-axis) of equal wave packets (Fig. 12). Just after the concentration point of the wave packet the wave breaking process starts. The very steep wave comes up to a breaker height Hb = 2.60 m in each of the 75 tests with wave packets (see also Fig. 8). Looking to the upper graph in Fig. 12, for the configurations 2 to 5 with cylinders in an inline row a 40 % decrease of the loading in configuration 1 with the isolated single cylinder is shown. Wave loading due to wave breaking in front of the cylinder groups seems to be influenced by a relatively strong shelter effect.

For configurations 6 and 7 (1 x D spacing in a transverse row) the wave load increases up to 30 % whereas in the case of a 3 x D gap in configuration 12 the wave load increase is only 10 % (middle graph of Fig. 12). In the mixed configurations 8, 9 and 10 the decrease is much smaller than in configurations 2 - 5. The mixed configurations 13, 14 and 15 show no significant difference of the wave load against the isolated measuring cylinder (lower graph of Fig. 12).

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CONCLUDING REMARKS AND OUTLOOK

Since there is yet no reliable formulae available to calculate shelter, interference and amplification effects of closely spaced slender cylinders under wave attack, the results of the large-scale experiments reported in this paper - together with the results of further analysis which is in progress - could be used as a guidance for the design of marine structures with groups of slender cylinders analog to the investigated configurations.

The data base can also be used for verification and validation of numerical models. The extensive and systematic experimental programme consists of 345 wave tests with regularly and irregularly generated nonbreaking waves as well as breaking freak waves. The first results on the maximum wave loads reported herein will be extended to a detailed time- and space-dependant analysis of the synchronously measured wave loads and wave kinematics.

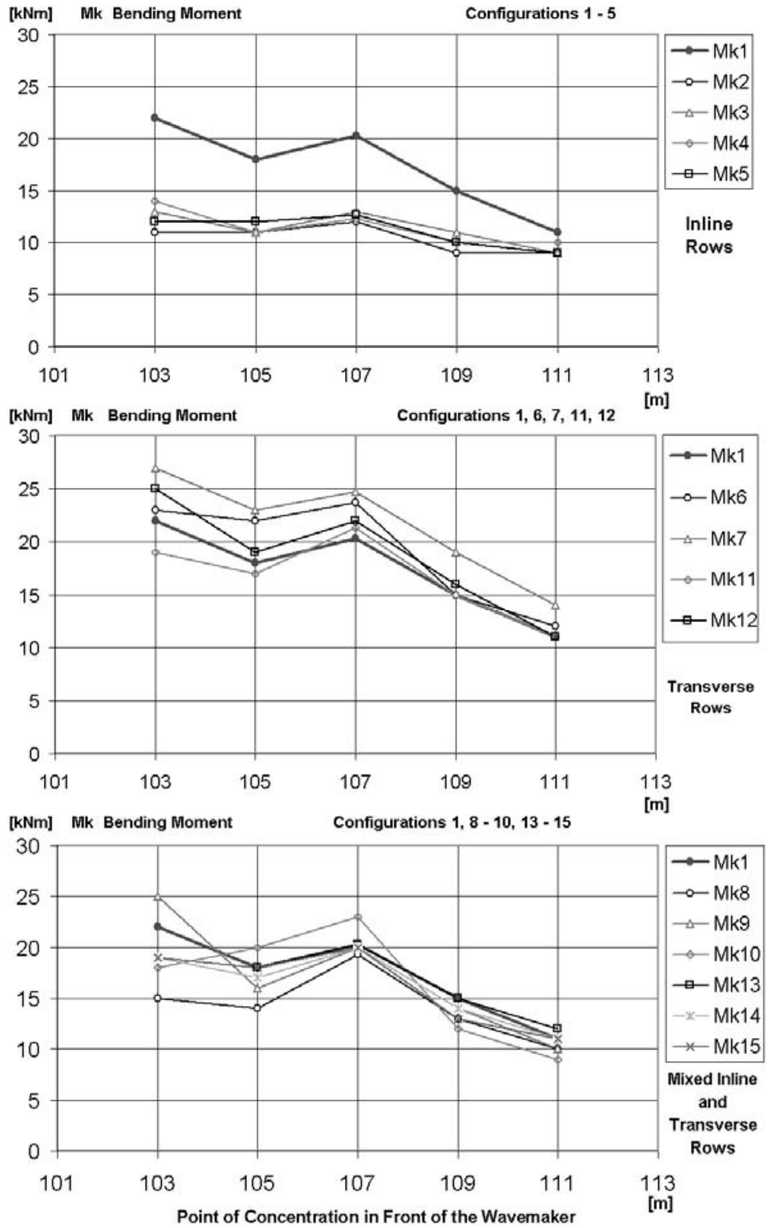

Figure 12. Maximum inline bending moments induced by breaking freak waves with H_b = 2.60 m for the investigated 15 cylinder configurations

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