LABORATORY "FREAK WAVE" GENERATION FOR THE STUDY OF EXTREME WAVE LOADS ON PILES

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Abstract: Large-scale experiments of breaking wave attack on slender cylinders were performed in the LARGE WAVE CHANNEL at the Coastal Research Centre in Hannover, Germany. Using large-scale physical models the influence of scale effects on the real physical mechanisms can be widely minimized. Very steep waves (similar to "freak waves") were generated to investigate extreme breaking wave impacts.

INTRODUCTION

Slender cylindrical structures (piles) are needed for various coastal and ocean structures. Until now, for the attack of very steep breaking waves ("freak waves") design procedures for slender cylinders are not very reliable (Sarpkaya and Isaacson, 1981; Kjeldsen, 1981). Valuable contributions of breaker induced forces on piles were given by Wiegel (1982). Kjeldsen et al. (1986) performed laboratory tests with vertical piles attacked by plunging breakers. Field and large-scale laboratory tests with a 0.7 m diameter vertical pile were carried out by Sparboom (1987) in order to measure real wave-loads in shallow water under storm surge conditions (high Reynolds-numbers).

Some results of small-scale tests on breaking wave impact at slender cylinders were reported by Chan et al. (1995). The importance of scale effects in physical wave modeling was pointed out by Oumeraci (1984).

The occurrence of "freak waves" with high damage potential was described by Kjeldsen (1997). Most important for this paper was the laboratory generation of so-called "freak-waves" which start to break at a predetermined location at the test

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cylinder in the wave flume (Clauss and Bergmann, 1986; Clauss and Kühnlein, 1997).

Concerning extreme wave loadings of a structure or of a structural component it is of particular interest to analyse single wave effects in a wave flume. Single wave tests have the advantage that very high sampling rates for the data acquisition can be used. In the present study, pressure impact time histories were resolved in the range of milliseconds and below. Local loads or pressures were determined exactly and total forces as well as wave kinematics were measured simultaneously (Wienke et al., 2000).

TEST SET-UP

The experiments were carried out in the LARGE WAVE CHANNEL of the Forschungszentrum Küste (Coastal Research Centre) in Hannover, Germany. This channel has an effective length of 309 m, a width of 5 m and a depth of 7 m. For the tests, the still water level was around 4 m (Fig. 1).

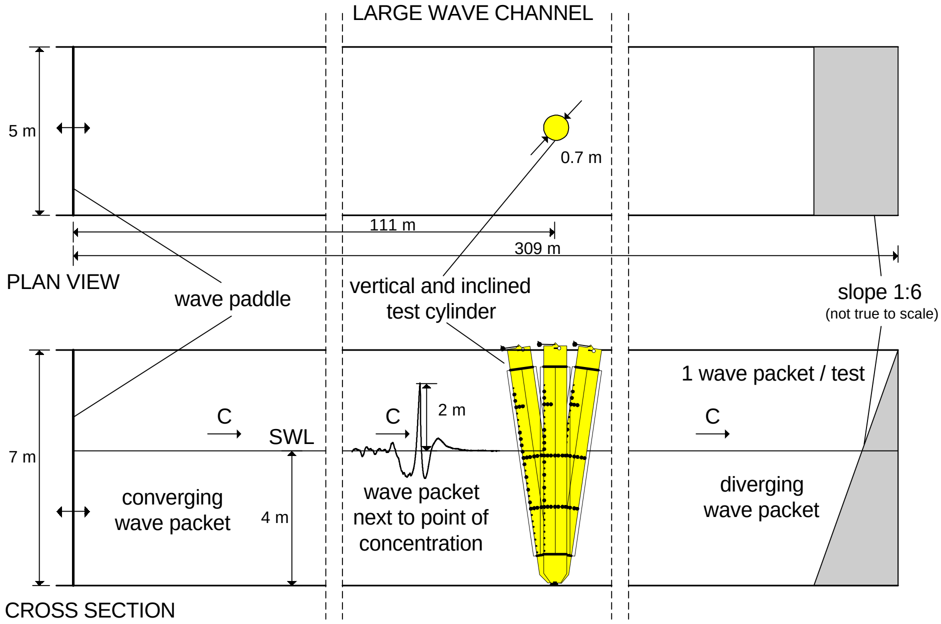


Fig. 1. Test set-up in the LARGE WAVE CHANNEL

A steel cylinder with a diameter of 0.7 m was installed on the horizontal channel bottom in a distance of 111 m from the wave paddle. The top of the test cylinder was fixed at a traverse structure at the top edge of the channel. At the bearings strain gauges were installed to measure the total force as the sum of the forces at both bearings. Furthermore, 55 pressure transducers were installed in the cylinder. Some were installed in the front line and some others around the circumference of the cylinder (Fig. 2).

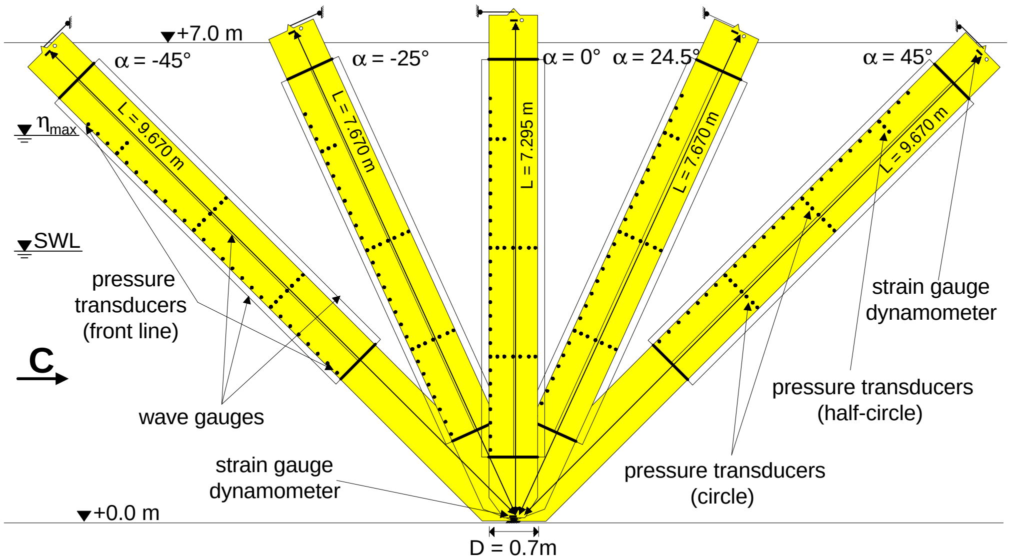


Fig. 2. Test cylinder with installed measuring instruments

WAVE GENERATION AND WAVE LOAD CLASSIFICATION

There are two different opportunities for the generation of single waves in the LARGE WAVE CHANNEL. On the one hand solitary waves can be generated by the piston-type wave maker. Using a typical still water level of 4.75 m the maximum elevation of a solitary wave is around 0.8 m (Fig. 3). On the other hand wave packets can be simulated. Focussing the point of concentration of a wave packet at the structure the elevation of the water surface corresponds to a single wave. In this way maximum wave elevations of about 2 m above SWL can be generated at the structure (Fig. 4).

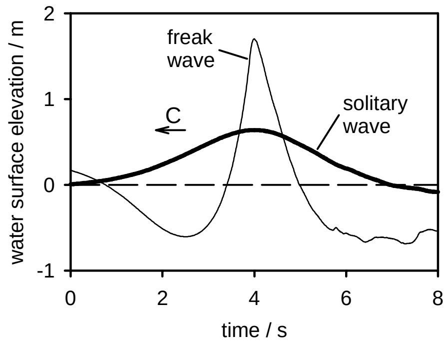


Fig. 3. Single waves in the LARGE WAVE CHANNEL

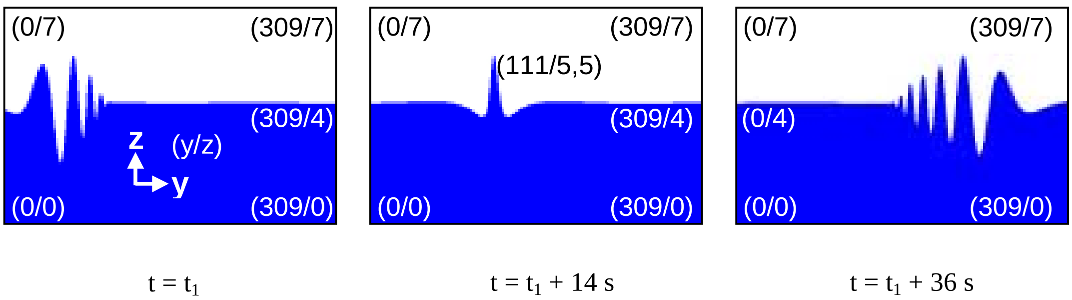


Fig. 4. Gaussian wave packet in the LARGE WAVE CHANNEL

The wave packet is significantly steeper than the solitary wave (Fig. 3). If the maximum elevation of the wave packet is enlarged moreover the wave packet starts to break (Fig. 5). Focussing the breaking location in front of the structure very extreme loads act on the structure and can be examined.

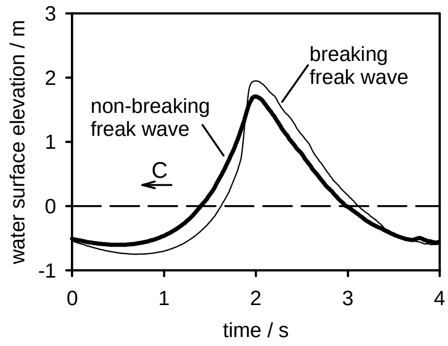


Fig. 5. Wave packets in the LARGE WAVE CHANNEL

All generated wave packets were quite similar at the location of breaking and only plunging breaker occurred. The time history of the wave elevation was detected with a wave gauge next to the location of breaking. Neglecting the small variation during one wave period the shape of the water surface is obtained by multiplying the time history with the wave celerity. In this way values for the parameters which characterise the breaking waves are determined (Fig. 6).

Parameter	Definition	Values given by Kjeldsen, (1990)*	Measured values
wave height	H		2.2 m - 2.8 m
maximum water surface elevation	η'		1.7 m - 2.0 m
wave period	T		4.11 s - 4.28 s
wave celerity	C		5.8 m/s - 6.2 m/s
steepness	$s = \frac{2 \cdot \pi \cdot H}{g \cdot T^2}$		0.08 - 0.10
crest front steepness (in space)	$\varepsilon_{X,B} = \frac{\eta'}{L'}$	0.32 – 0.78	0.55 - 0.80
crest front steepness (temporal)	$\varepsilon_t = \frac{2 \cdot \pi \cdot \eta'}{g \cdot T' \cdot T}$		0.50 - 0.75
vertical asymmetry factor	$\lambda = \frac{L''}{L'}$	0.90 - 2.18	1.9 – 2.7
horizontal asymmetry factor	$\mu = \frac{\eta'}{H}$	0.84 – 0.95	0.71 – 0.77

* field measurements

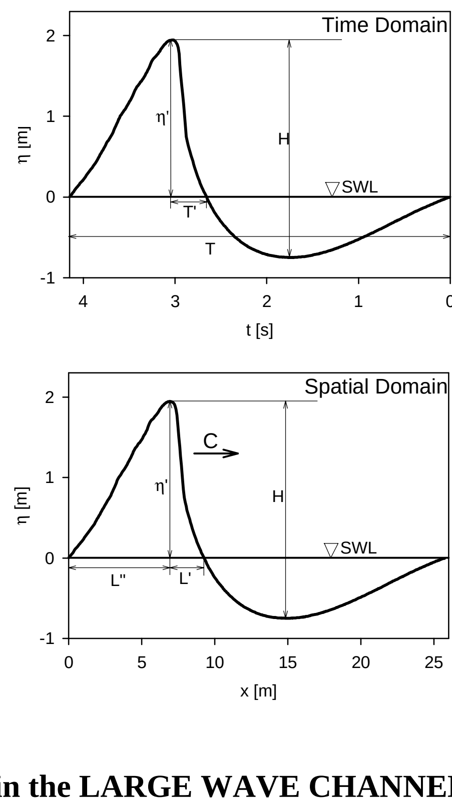


Fig. 6. Breaking wave parameters measured in the LARGE WAVE CHANNEL: Definition and comparison with field data

Acting on the cylinder these breaking waves of similar shape showed obvious differences concerning the loading records. Therefore, the distance between breaking location and cylinder was varied systematically. Five loading cases were defined (Fig. 7). With increasing number of the loading case the breaking location was shifted closer to the cylinder.

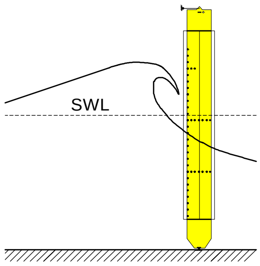
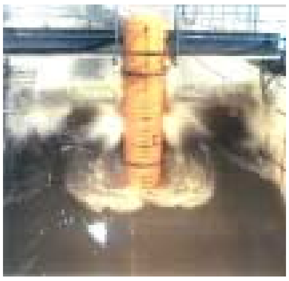
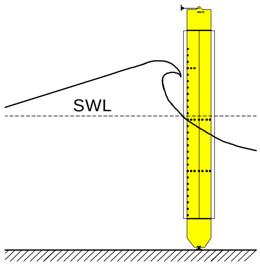
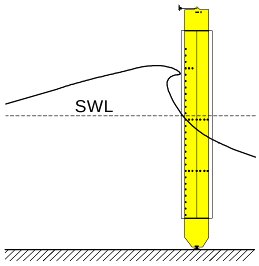
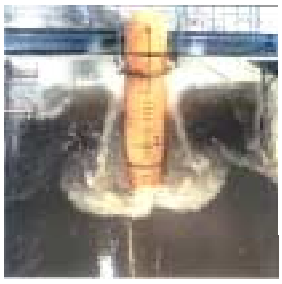
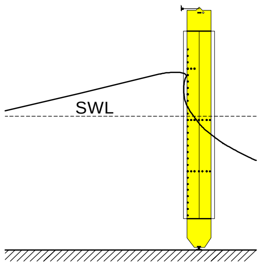
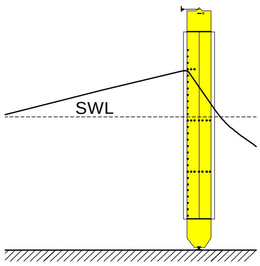
1	• wave breaking far in front of the cylinder • overcurling breaker tongue hits cylinder below wave crest level • broken wave		
2	• wave breaking in front of the cylinder • breaker tongue hits cylinder just below wave crest level • splash going up and down • breaking wave		
3	• wave breaking immediately in front of the cylinder • breaker tongue hits cylinder at wave crest level • radial splash • breaking wave		
4	• wave breaking at the cylinder • damped impact due to cylinder wave run up • splash going up • partial breaking wave		
5	• no wave breaking in front of the cylinder • quasi-static force		

Fig. 7. Classification of different loading cases

Waves of loading case 1 break far in front of the cylinder and the breaker tongue hits the cylinder in an angle of around 45° related to the horizontal plane. Loading case 2 means that the waves break evidently in front of the cylinder and the hitting breaker tongue is inclined regarding the horizontal plane by an angle of around 25°. Waves of loading case 3 break immediately in front of the cylinder and the breaker tongue is still moving along the horizontal plane when the cylinder is attacked. Loading case 4 describes waves breaking at the cylinder. Waves of loading case 5 do not break in front of the cylinder but at the rear. This definition of the five loading cases is applied for each of the five investigated yaw angles (Fig.8).

-45° inclination against wave direction	**-25°** inclination against wave direction	**0°** vertical cylinder	**+24.5°** inclination towards wave direction	**+45°** inclination towards wave direction

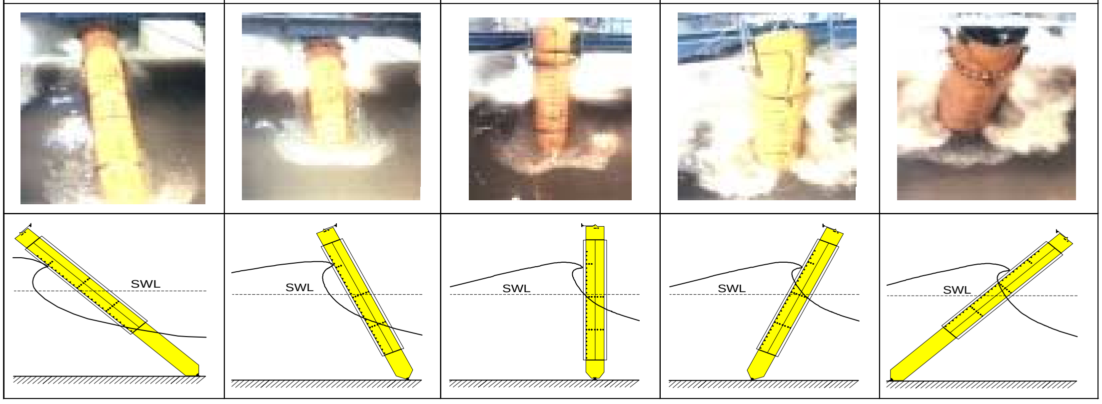


Fig. 8. Loading case 3 for the different investigated yaw angles

IMPACT LOADING

The total force acting on the cylinder has been determined by adding the loads measured at the two bearings at the top and at the bottom. The maximum force caused by a typical solitary wave is below 1 kN. Attacked by a wave packet the total force acting on the cylinder is around 7 kN. Since the wave packet is steeper than the solitary wave the increase of force takes place faster. Very much larger values of the total force are measured for wave packets breaking in front of the cylinder (Fig. 9).

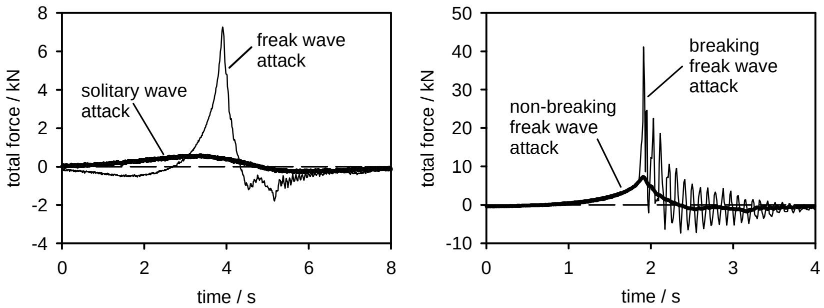


Fig. 9. Measured forces acting on the cylinder for different wave attack

The large forces due to breaking waves are restricted to a small extension at the cylinder and these forces act only during an extremely short time. Therefore this force due to breaking waves is called slamming force. It can be detected by pressure measurement at the cylinder. Comparing the pressure time history with the time history of the water surface elevation the different values of the wave period and the slamming duration are illustrated (Fig. 10). The small extension of the slamming force is confirmed by the pressure distribution along the height of the cylinder.

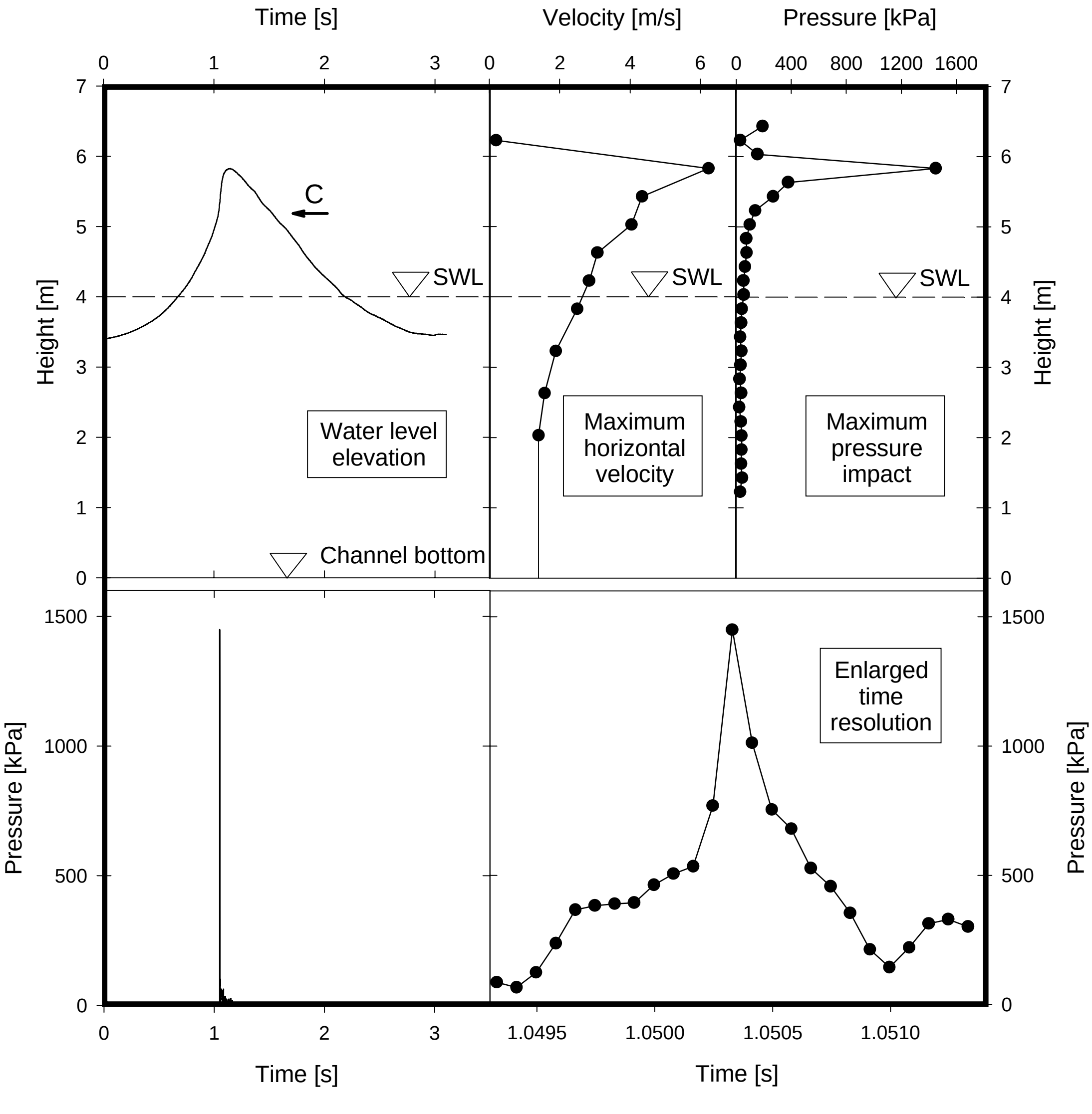


Fig. 10. Measured slamming pressures

The total force measured at the bearings of the test cylinder was separated into a quasistatic part varying in time with the water surface elevation and a dynamic part due to the slamming force. The experimentally obtained values for the dynamic force are plotted in Fig. 11. For each angle of inclination the mean, the maximum and the minimum values are plotted. The highest maximum value of the dynamic force is obtained for the yaw angle of -25° (inclination against wave direction).

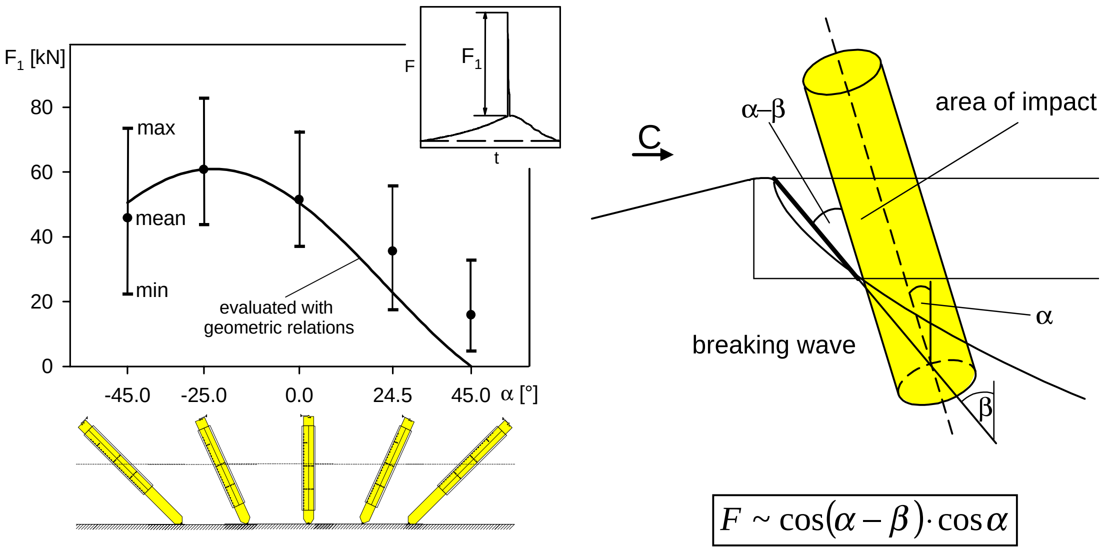
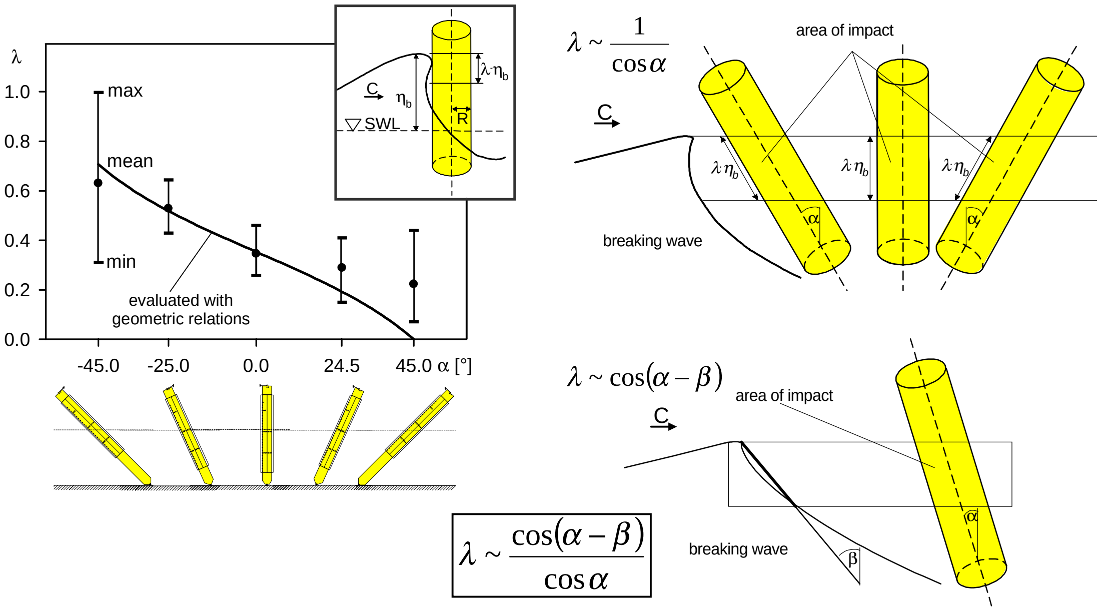


Fig. 11. Dynamic force versus yaw angle

The dynamic force is related to an area of impact at the cylinder. It is assumed, that the slamming force is only acting in this area and that the force is equal at the different levels of the area of impact. In this way a height of the impact area at the cylinder can be deduced. Dividing this length by the maximum elevation of the breaking wave, the curling factor λ is obtained. In Fig. 12 this curling factor is plotted, namely the mean, the maximum and the minimum values for each angle of inclination are shown. For the vertical cylinder a maximum value of 0.5 is obtained. This is in agreement to values given in literature (e.g. Wiegel, 1982). If the cylinder is inclined against wave direction, the height of the impact area increases. However, the height of the area of impact decreases, if the cylinder is inclined towards the wave direction (Wienke et al., 2001).

CONCLUDING REMARKS

It is shown that wave packets are a suitable tool for the simulation of steep breaking waves in a wave flume. The location of wave breaking can accurately be varied by the predetermination of the concentration point of the wave packet. So waves breaking in front of a test structure can be generated. The shift of the test structure can be equalized by the variation of the point of concentration of the wave packet. In this way slamming forces on a test cylinder with different yaw angles were investigated. For each yaw angle maximum values of the slamming force were obtained by varying the point of concentration over a range of nearly 10 m. The results show that the maximum force is acting on a cylinder which is slightly inclined against wave direction.



$$\lambda \sim \frac{1}{\cos\alpha}$$

$$\lambda \sim \cos(\alpha - \beta)$$

$$\lambda \sim \frac{\cos(\alpha - \beta)}{\cos\alpha}$$

Fig. 12. Curling factor versus yaw angle

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