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MEASUREMENT AND ANALYSIS OF DIRECTIONAL SEAS IN A BASIN

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SUMMARY
Before measurements with directional seas can start, boundary conditions as wave heights, periods, spectral shape and also spreading should be established. Various methods to obtain these boundary conditions are mentioned in the paper. Results with the corner reflection method are given and the method is evaluated. Measurements with a set of directional meters is described and the results are compared with the generated seas. Finally the effects of directional seas on a moored ship in a harbour is given.

INTRODUCTION
The number of directional wave basins is rapidly increasing all over the world. Wave basins with the traditional 2-D (uni-directional) wave generation methods will be replaced by the directional wave basins which can generate one additional parameter: the directional spread. Good progress in analysis and generation of directional seas was reported in 1987 at the IAHR seminar, Lausanne (see for example Sand and Mynett (1987), Nwogu et al. (1987), Suh and Dalrymple (1987)). The influence of directional spread in comparison with uni-directional waves might be significant for a lot of phenomena. The application of directional seas in the design of offshore structures is already very common. The influence on ship motions in open seas was reported by Mynett et al. (1988), the influence on stability of rubble mound breakwaters by Christensen et al. (1984).

New modelling techniques have been invented such as the corner reflection method, described by Funke and Miles (1987) and in another way by Dalrymple (1988). This technique gives an enlargement of the effective test area with a homogeneous sea state by means of the suppression of undesirable reflections from side walls and the use of partial side walls as reflector for other (oblique) wave components.

BOUNDARY CONDITIONS FOR GENERATION OF DIRECTIONAL SEAS
General. Uni-directional seas can be described by a set of parameters. The most common parameters are the significant wave height ($H_{1/3}$ or H_{mo}), the wave period (average wave period T_m or peak period T_p) and the description of the spectral shape and/or groupiness of the waves (ε, Q_p or κ (Battjes and Van Vledder (1984))). All parameters with there notations are given in IAHR/PIANC (1986). The description of directional seas requires the same parameters, supplemented by the directional spread which can be characterized by the directional spreading function $S(f,\theta)=S(f).D(f,\theta)$. The function $D(f,\theta)$ is often defined as a cosine-2s shape or as a Gaussian shape with the standard deviation σ as the spreading parameter (Sand and Mynett (1987)). The spreading described by σ will be used in this paper. A good overall view of possible measures for spreading is given by Dingemans (1987).

Measurements. For most investigations an estimation of the wave parameters has to be made. This can be done by measurements or by numerical simulation. The WAVEC buoy (Kuik et al. (1988)) gives amongst others information on the spectrum, the mean wave direction and the spreading (with three parameters). An example is shown in Fig. 1, taken from the WAVEC brochure. These buoys can be placed in deep and in more shallow water. WAVEC buoys are installed in deep water in the North Sea. One WAVEC bouy was installed in the Wadden Sea at a depth of 4 m with tides up to 3 m. These results are used to give the directional boundary conditions for wave run-up measerements which are performed at a dike one kilometer from the buoy.

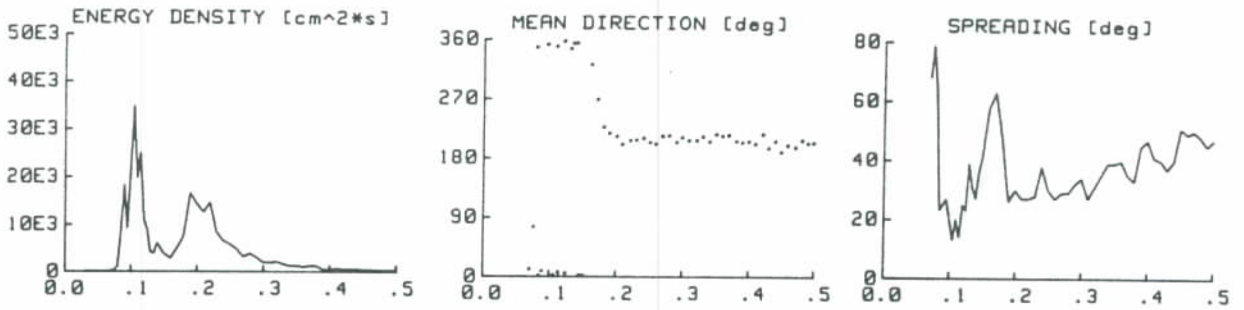

Fig. 1 Results of WAVEC buoy (from WAVEC brochure)

Numerical simulation. Numerical wave fore or hind-cast models can give also an impression of the wave parameters. An example of the third generation wave models WAM (Hasselman et al. (1988)) is shown in Fig. 2. WAM is a discrete coupled spectral model for the prediction of windwaves on oceans and seas. The model keeps a balance of energy density for each spectral component. It includes the effects of propagation and refraction, wave growth by wind input, dissipation by white-capping and bottom friction and nonlinear interactions. The main feature of the WAM model is the computation of the nonlinear transfer such that no restrictions are necessary to the spectral shape. The model can be applied for not too shallow areas. The WAM model has been used (Fig. 2) to predict the full two-dimensional spectrum in a situation with a turning wind (direction changing from 30° to 90° and a constant wind speed of 20 m/s). The figure shows the frequency spectrum, mean direction θ_o and spreading σ per frequency for the situation that the peak of the spectrum is about 60 degrees.

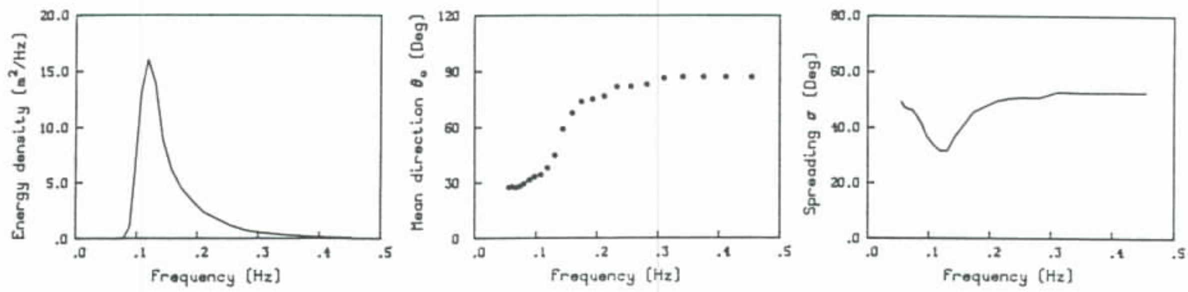

Fig. 2 Results of the third generation wave model WAM

HISWA is a wave propagation model, specially suited for coastal regions. It takes into account the effects of depth and current refraction and directional spreading. Energy dissipation due to bottom friction and wave breaking as well as energy growth due to wind are incorporated. The model is formulated in terms of wave action, which is convenient for the propagation of waves. One is referred to Dingemans et al. (1986) and Dingemans (1987).

Prototype measurements and numerical models can give the boundary conditions which are required to perform a model investigation in a directional basin.
The influence of bottom topography on directionality can be simulated in the basin and the influence of directional seas on a variety of structures can be investigated.

THE CORNER REFLECTION METHOD
In the conventional wave generation methods, waves will give undesirable reflections from sidewalls. Funke and Miles (1987) described the use of corner reflectors in a directional wave basin. They give a method for the suppression of undesirable reflections from a side wall for oblique plane waves and the use of partial side walls near the wave generator for the production of oblique waves, which appear to emanate from virtual segments beyond the side walls. The result is an enlargement of the effective test area for homogeneous sea state simulation. Dalrymple (1988) described a similar technique, but he used the mild slope equation for plane slopes to compute the required motion of the wave generator segments to achieve a homogeneous wave field at a certain line of the basin. Both methods are based on the linear wave theory. The corner reflection method described by Funke and Miles was installed at Delft Hydraulics' basin.

Test runs were performed with monochromatic and random long crested seas at various angles and with directional seas at various angles, both with and without the corner reflection method. Although not all data have been analyzed, a few conclusions can already be drawn.

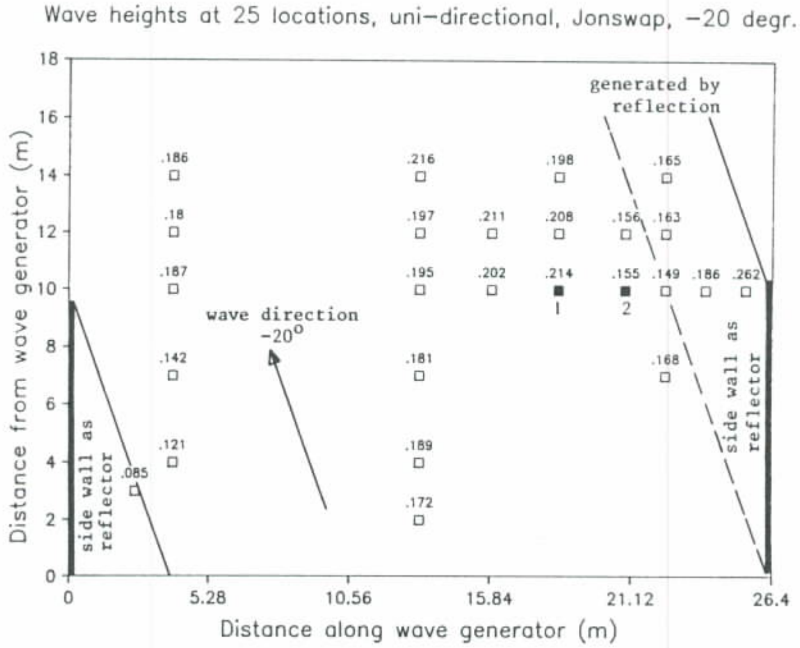

Fig. 3 Measured wave heights with the corner reflector method

Fig. 3. shows the set-up of the measurements and the results of one test with an oblique long crested random wave field (θ=-20 degr., H_s=0.20 m, T_p=2.0 s.). Wave heights were measured at 25 locations. The wave heights at locations 1 and 2 show the inhomogenity of the wave field which is probably caused by diffraction or not complete reflection. The wave field of oblique long crested waves between the edges of the side walls is not completely homogeneous. The connection of the wave front directly generated by the wave generator and by the reflection of the side wall shows an inhomogenity. On one side of the connection the wave height is too low and at the other side the wave height is too high.

Wave angles smaller than 10-20 degrees do not or only partly reflect from the side wall. The wave travels along the side wall without reflection and the wave height at the edge of the side wall can be more than 90 % higher than the average of the wave field (stem reflection). It is not recommended to use the corner reflection method if the wave angle is less than 15-20 degress (θ=0° is perpendicular to the line of the wave generator).

In almost each test spurious waves were generated between the side walls with the direction parallel to the line of the wave generator (θ=90 degr.). These spurious waves generally showed a wave height in the order of 5-10 % of the generated wave field, but sometimes resonance occurred resulting in waves 3-5 times higher than the generated wave field. After installing a wave damper at one side of the wave basin (opposite to side wall used for reflection) spurious waves between the side walls were eliminated. This method is not applicable for the generation of directional seas were both side walls are required for reflection. In that case some spurious waves, between the walls, must be accepted.

Waves with a steepness near the breaking limit were breaking in the area where both the directly generated and the reflected waves were present (crossing waves). This breaking caused a loss of energy resulting in an inhomogeneous wave field. The corner reflection method, therefore, cannot be used for steep waves.
The corner reflection method has its largest advantage if waves have to be generated under a large angle. Fig. 4 shows the test set-up for an investigation on run-up and overtopping on a 1:4 sloping structure. The 15 m long test structure has an angle of 15 degrees with the line of the wave generator. Waves with θ=-65° were generated which gave almost striking waves on the structure (80 degrees from perpendicular wave attack). The wave field was almost completely generated by reflection.

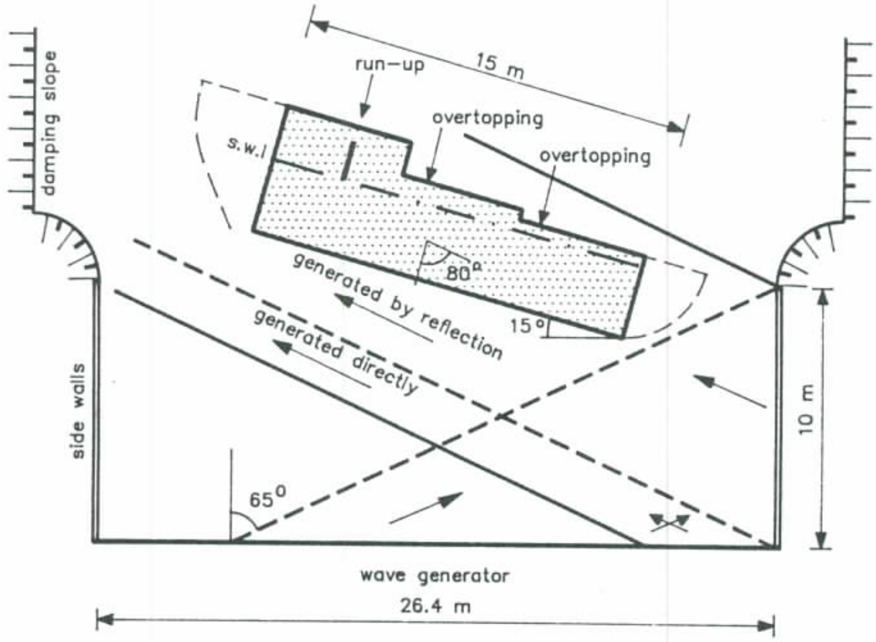

Fig. 4 Generation of waves under 65°, giving almost striking waves at the 1:4 sloping structure for measurements of run-up and overtopping

SINGLE POINT MEASUREMENTS
Directional seas in a basin can be measured by an array of wave gauges or by single point measurements. Sand and Mynett (1987) described the analysis of single point measurements in laboratory situations with one wave gauge and two velocity meters in the horizontal plane. The analysis resulted amongst others in the mean direction of the wave field and the spreading parameter σ. This is the technique used at DELFT HYDRAULICS. In one particular investigation three tests were per-

formed, one with long crested waves (σ=0 degr.), one with a directional sea with minor spreading (σ=25 degr.) and finally one with major spreading (σ=42 degr.). Fig. 5 gives for all three tests the energy density, the mean direction and the spreading as a function of the frequency. The results are presented, using a linear scale factor of 90.

The long crested sea shows a constant direction and a low value for the spreading (σ=13 degr.). This value will always deviate from zero due to the expression of the distribution function in terms of Fourier series expansion. A less sensitive measure for seas with small or no spreading may be one of the measures described by Dingemans (1987). Research on this topic is going on. Generally the spreading for long crested seas in laboratories is measured between 10 and 30 degr. (see Sand and Mynett (1987)). Fig. 5 shows a larger spreading according to an increased generated spreading, the lowest plots from left to right.

Fig. 6 gives more detailed results of one of the tests. The results of three directional meters are presented which were placed a few meters apart in the model. The different meters gave similar results, showing a homogeneous wave field.

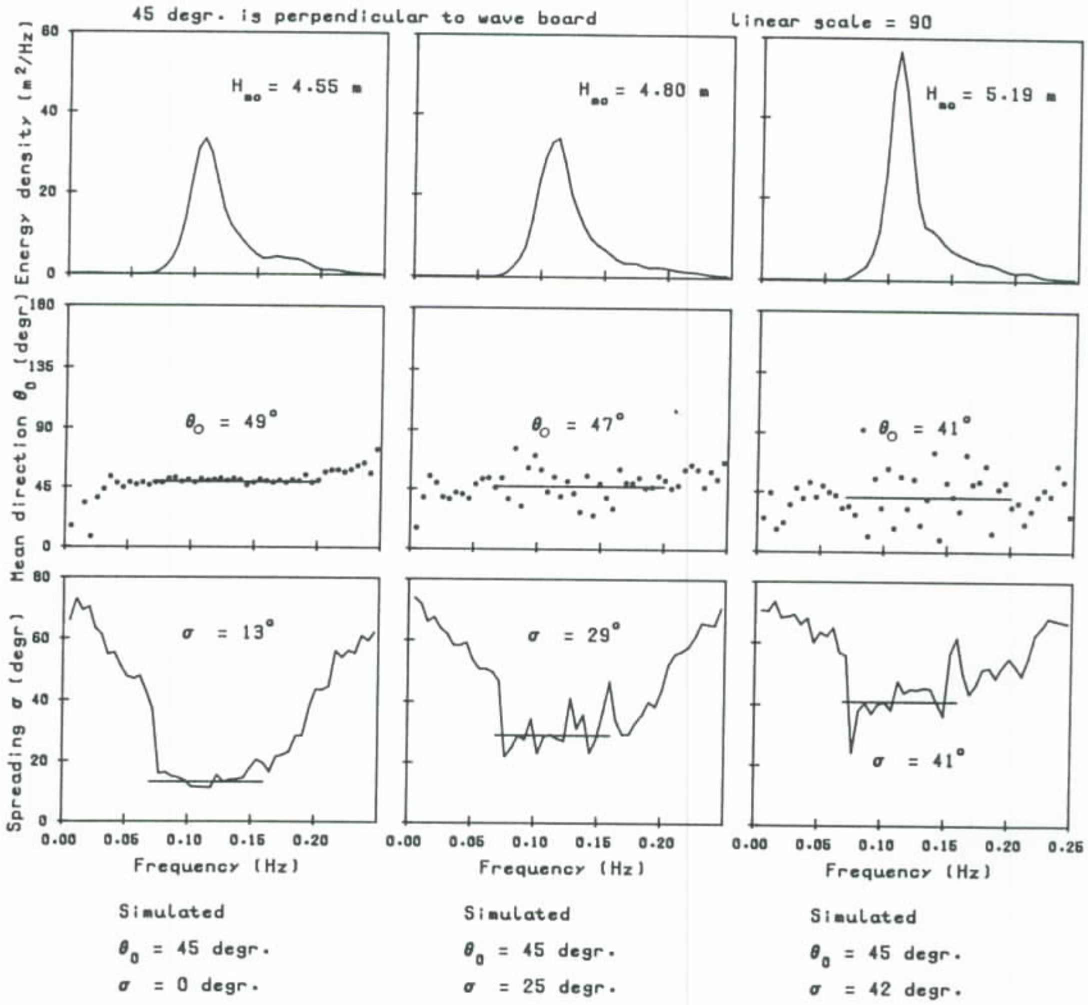

Fig. 5 Analysis of long-crested and directional seas measured by a single point meter

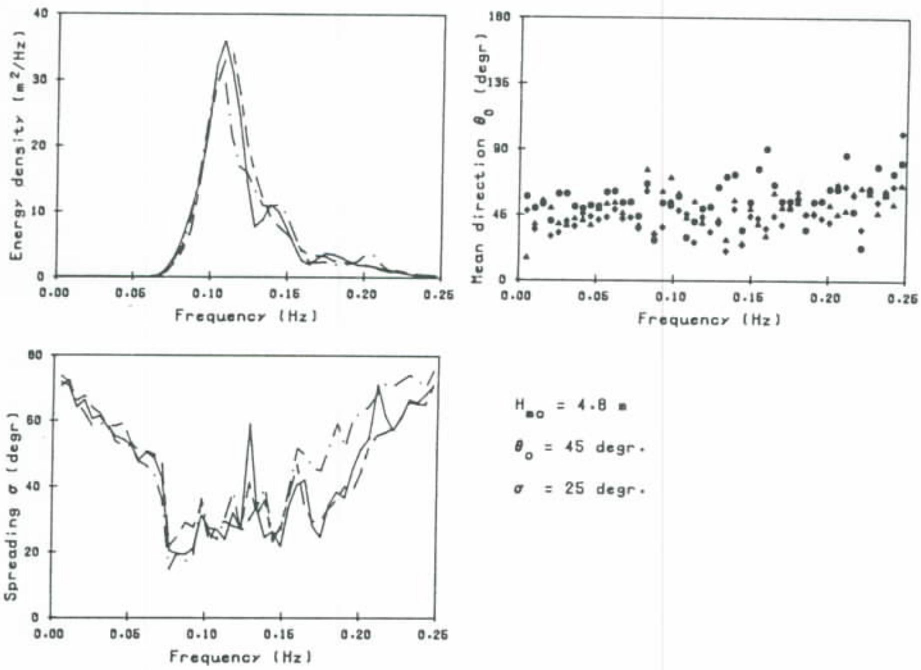

Fig. 6 Comparison of three directional meters, placed a few meters apart

Fig. 7 gives preliminary results of the boundary conditions of the investigation on run-up and overtopping, see also Fig. 4. The results of the investigation will be reported elsewhere. Fig. 7 shows the relation between measured and theoretically generated mean direction, both for long crested and directional seas. The overall trend is good. The directional seas show a smaller measured mean direction than theoretically generated, partly due to missing components when the generated angle becomes too large.

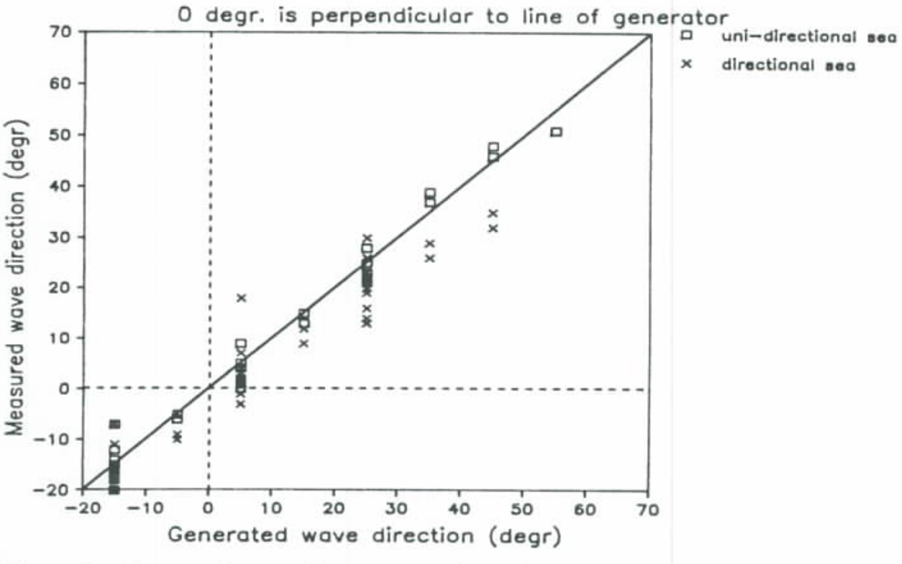

Fig. 7 Comparison of generated and measured mean direction

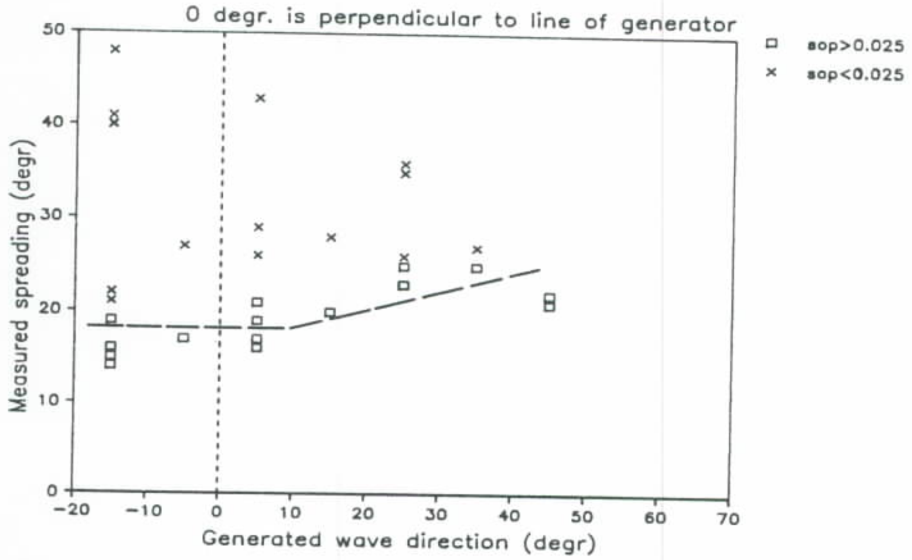

Fig. 8 Measured spreading for uni-directional seas as a function of generated wave direction and wave steepness

Fig. 8 gives the measured spreading for long crested seas as a function of the theoretically generated mean direction for the same investigation as mentioned above. A division was made for long waves ($s_{op} = 2\pi H_s/gT_p^2 < 0.025$) and more steep waves ($s_{op} > 0.025$). The (very) long waves show a large increase in measured spreading, where the steeper waves give spreading values between 15 and 25 degr. This large difference might be due to much higher reflections from the structure for the long waves. The measured spreading for the steeper waves increases slightly with increasing mean direction.

Various degrees of spreading were generated during the investigation on run-up and overtopping. Fig. 9 gives the relationship between the measured and generated spreading and shows again the difference between long and more steep waves. The figure shows too the deviation from the theoretical value for the long crested and almost long crested seas ($\sigma < 20$ degr.).

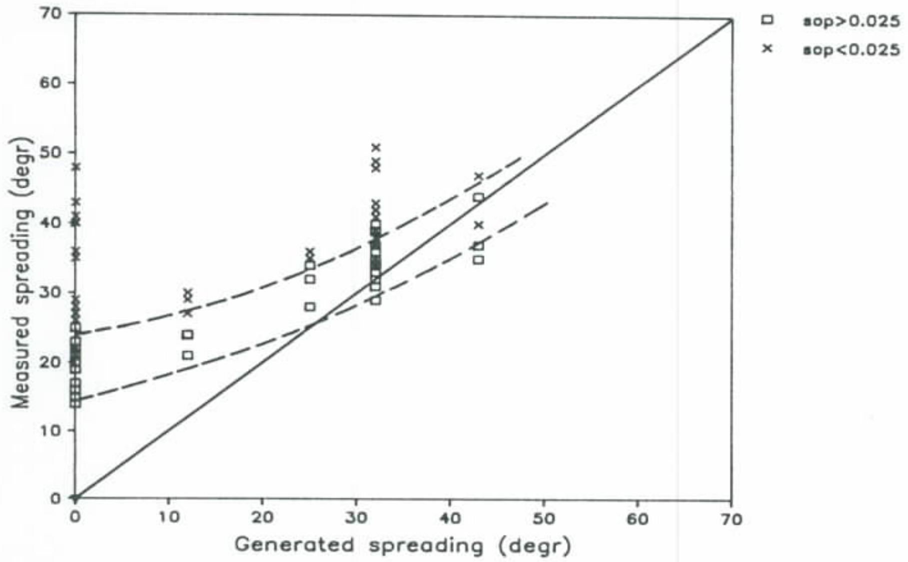

Fig. 9 Comparison of measured and generated spreading

APPLICATION OF DIRECTIONAL SEAS ON A MOORED SHIP IN A HARBOUR

For harbour design it is important to ascertain the safety of mooring and cargo handling of moored ships in a harbour. The ship responds to the waves penetrating into the harbour. For that reason the impact of directional spreading on wave penetration and ship response was studied.

Surge, that is the motion in the ship's longitudinal direction, is frequently the most critical ship motion. Since the natural frequency for surge is smaller than 0.05 Hz, the ship mainly responds to the low frequency part of the wave energy spectra. Therefore, a correct reproduction of the second order group-induced bound long waves is imperative for physical model tests for wave penetration and ship response (Sand, (1982a)).

Bound long waves are caused by short waves. As a result of the presence of wave groups, a second order long wave will be introduced. These waves, also called set-down, travel with the group velocity of the short waves. Sand (1982b) showed that the amplitude of the directional bound waves seem to be significant smaller than those of uni-directional waves and that the wave lengths of the long waves can be simply altered by changing the directional spreading of the short waves.

A harbour layout and a moored general cargo ship was modelled on a linear scale of 90. Tests were performed for two local wave directions (105 and 125 degrees) each with three degrees of different directional spreading measures (long crested, σ=25 degr. and σ=42 degr., see Fig. 5).

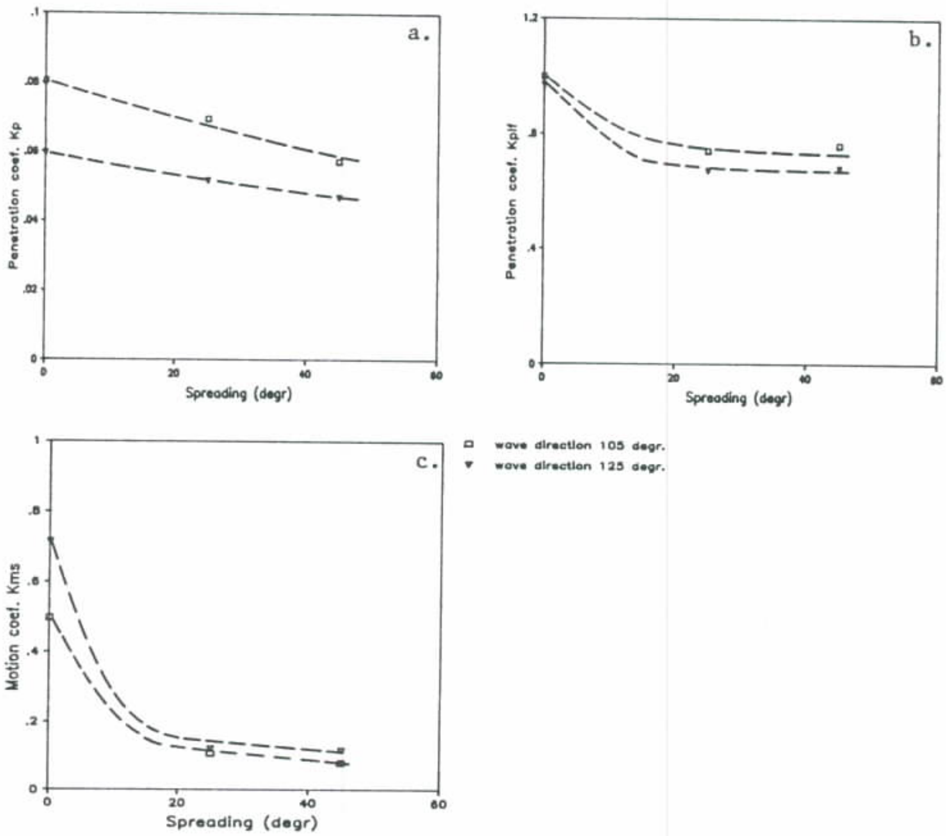

Fig. 10 Influence of directional seas on a moored ship in a harbour

The incident wave height, H_{moi}, and the energy content of the low frequency part of the energy spectra, $m_{0,lf,i}$, were measured on deep water. The wave height near the ship, $H_{mo,ship}$, and the low frequent part of the energy spectra near the ship, $m_{0,lf,ship}$, were measured simultaneously. The wave conditions near the ship can be given as a wave penetration coefficient (Fig. 10a):

$$K_p = H_{mo,ship}/H_{moi},$$

and a wave penetration coefficient for the long waves (Fig. 10b):

$$K_{p,lf} = \sqrt{(m_{0,lf,ship}/m_{0,lf,i})}$$

The wave penetration coefficients reduced somewhat by the effect of directional spreading (Fig. 10a). An increase of directional spreading results in a significant decrease of low frequent wave energy, $K_{p,lf}$ (Fig. 10b). The surge motion is the most critical ship motion. The surge motion is related to the incident wave height and is given in Fig. 10c. The surge motion coefficient is defined as:

$K_{m,s}$ = significant surge motion / H_{moi}

Directional spreading turns out to be very important for the surge motion. The surge motion coefficient reduced with more than 75% due to the effect of directional spreading.

The results of these model tests show that directional spreading is very important for the design of a harbour. A wave field in nature will always contain short crested directional waves. The bound long waves are therefor overestimated if model tests are performed with long crested uni-directional waves. Since the surge motion of a ship mainly responds to this low frequency part of the wave energy, the most critical ship motion is also overestimated.

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