CHAPTER 101

FORCES ON A PONTOON IN THREE DIMENSIONAL WAVES

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1. INTRODUCTION

Wave forces on a long pontoon (floating breakwater, floating bridges etc.) depend to a large extent on the three dimensional wave pattern. There is no deterministic method for calculating wave forces for such structures in a three dimensional sea and laboratory equipment for testing long structures in irregular three dimensional waves does hardly exist

Forces, bending moments etc on floating structures may in principle be calculated on basis of a transfer function $K(f,\theta)$ and the two dimensional wave power spectrum $E(f,\theta)$ giving the one dimensional force power spectrum $\phi(f)$ according to

$$\phi(f) = \int_{\theta} K^2(f,\theta) E(f,\theta) d\theta \qquad (1)$$

where

f = frequency

θ = angle between mean wave direction and direction of the individual wave component

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This concept, which is being used to a certain extent in ships hydrodynamics, is based on a linear relationship between wave height and forces, bending moments etc.

The force distribution is calculated from the relationship derived by Longuet-Higgins (2) and is frequently used in wave statistics. This relationship is the following

$$F = k \sqrt{\int_f \phi(f)\,df} \tag{2}$$

where

F = force

k = coefficient, depending on which statistical force is wanted.

The force F is the zero-upcrossing force as defined in Fig. 7. (see chapter 3 1). For the significant force $F_{1/3}$, k = 2,83, (2), (3).

The whole concept is shown in Fig. 1.

The transfer function $K(f, \Theta)$ can be found analytically or by model tests.

The purpose of the investigation described in this paper was to obtain some experimental data on the validity of the concept applied to a pontoon of rectangular cross-section. As the transfer function for such a pontoon, partly reflecting and partly transmitting the waves, is not so easily obtained by calculations, the force transfer function was found experimentally in regular waves. The wave forces in three dimensional waves were obtained in a wind wave flume. The scalar wave power spectrum has been measured, but unfortunately we have not had the opportunity to measure the directional power spectrum of the waves. We have therefore in the calculations had to make assumtion of the directional spread of the spectrum.

2. MODEL TEST ARRANGEMENT

The tested pontoon had a rectangular cross-section with width, draft an length of 0,44 m, 0,12 m and 3,00 meters respectively.

The two dimensional transfer function was obtained in tests using regular waves in a test arrangement as shown in Fig. 2 Fig. 3 shows details of the pontoon and its instrumentation. The total lateral forces were measured by use of strain gauges placed at both ends of the pontoon Except for the small motions necessary to obtain a response of the strain gauges the pontoon was fixed.

The tests in three dimensional waves were carried out in a wind/wave channel This channel is 78 meters long, and 3,8 meters wide. The water depth at the pontoon was 0,37 meters, while the depth in most parts of the channel was approximately 1,0 m. The test setup in the wave channel is shown in Fig. 4.

The waves were generated by wind with a velocity of approximately 10 m/sec. The ratio between wind velocity and wave celerity in such wind wave flumes is generally high, and the waves tend to have a steepness which is higher than normally found in fjords and in the ocean In order to reduce the wave steepness a wave filter was placed some distance in fromt of the pontoon as shown in Fig. 4.

3 TEST RESULTS

3.1. Transfer function

The transfer function was obtained by running tests with different wave periods, wave heights and wave directions.

The wave pattern in the test basin was as indicated in Fig 2. All measurements were made before the secondary reflected waves from the walls of the test basin reached the pontoon.

Fig 5 shows samples of the test results The diagrams show wave force vs wave height The angle between the direction of the wave propagation and the direction of force is indicated.

The relation between wave force and wave height is fairly linear and "best-fit" lines showing the linear relation is drawn by eye. This relation is given by

$$F^{*} = K^{*}(\theta, f)H \qquad (3)$$

where

F^{*} = force

H = wave height

$K^{*}(\theta,f)$ = coefficient depending on wave frequency and wave direction

It is seen that the forces towards the "lee" direction of the waves are slightly larger than towards the "windward" side. This is also revealed in the force recordings, a sample of which is shown in Fig. 6.

The reason for the difference between the forces in the two directions is believed to be higher order effects

However, it is not possible within the simple linear concept we are dealing with to include these higher order effects We have therefore combined the two directions by defining another coefficient $K(\theta, f)$ as

$$K(\theta, f) = K^{*}(\theta, f)_{lee} + K^{*}(\theta, f)_{windward} \quad (4)$$

The following relationship is then obtained

$$F = K(\theta, f)\ H \quad (5)$$

where F is the double amplitude force

F is comparable to H as indicated in Fig 7

The $K(\theta, f)$ values are shown in the diagram of Fig 8

Based on the diagram of Fig 8 we have made a contour "map" of the transfer function as shown in Fig 9

3 2 Directional spectrum

As mentioned in the introduction we have not had the opportunity to measure the directional spectrum of the waves in the wind wave flume. however, the scalar spectrum has been obtained. The waves were measured at the pontoon site in the flume when the pontoon was taken away Fig 10 shows a sample of a paper record of the waves.

The waves were recorded on a magnetic tape This record was then digitized with a time interval between samples of 0,128 sec and the power spectrum was calculated from a sample of 200 consecutive waves The "raw" spectrum was smoothed by the method of hanning (3) The calculated spectrum is shown in Fig 11

It has been usual in theory on wave directional spectra to assume a spectrum directionality function

$$\left[a(f,\theta)\right]^2 = \left[a(f)\right]^2 \, y(\theta, \eta_s) \tag{6}$$

where

$$y(\theta, \eta_s) = \frac{(\cos\theta)^{\eta_s}}{K(\eta_s)} \tag{7}$$

and

$$K(\eta_s) = \int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}} (\cos\theta)^{\eta_s} d\theta \tag{8}$$

Fig. 12 shows y vs θ for different values of η_s

We have estimated the directional power spectrum based on a $\cos^4\theta$ -law The estimate of the directional spectrum is shown as a contour map in Fig 13 The implication of using a $\cos^4\theta$ -law instead of, say, a $\cos^2\theta$ - law will be discussed later.

3 3 Calculated force spectra and force distributions

Based on the transfer function and the estimated directional wave power spectrum, the force power spectrum was calculated according to equation (1) The numerical calculation was carried out by applying $\Delta f = 0{,}1$ sec and $\Delta\theta = \pi/96$. The result of the calculation is shown in Fig 14

The force distribution was calculated according to equation (2) and is shown in Fig. 15.

3 4. Measured forces and force distribution

The forces were recorded on both a paper and a magnetic tape A sample of a force record is shown in Fig 16

The measured force power spectrum is shown in Fig 14 together with the calculated spectrum

The measured force distribution is shown in Fig 15 The measured force as well as the calculated force is the zero-upcrossing force as defined in Fig 7 d

4 COMMENTS

There is apparently a good agreement between the measured force distribution and the calculated force distribution as shown in Fig 15 however, the calculated force spectrum and the calculated force distribution is based on assumptions on the spectrum directionality function The form of the transfer-function is such that a $\cos^2\theta$ - directionality law will give lower calculated forces than a $\cos^4\theta$ - law

It is therefore deemed necessary that the directional wave spectrum should be measured

5 CONCLUSIONS

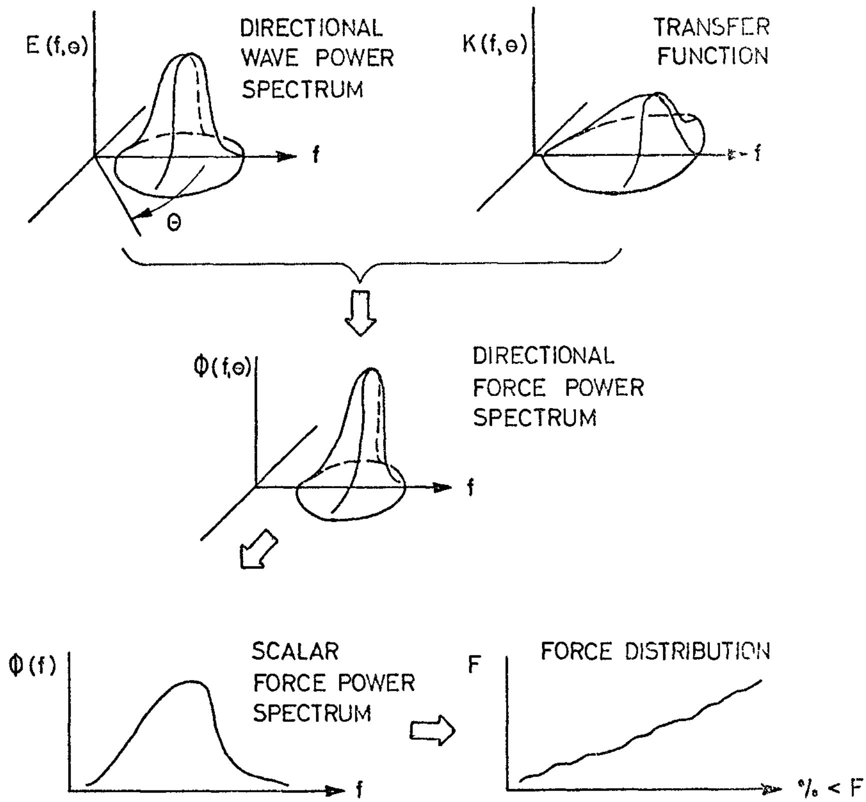
The work described in this paper gives an indication that the concept of equation (1) is a useful tool for engineering purposes when dealing with forces on long floating pontoons like floating bridges, floating breakwaters etc

LITERATURE

1. TRAITTEBERG, A The effect of wave crests on wave forces Proc of Eleventh Coastal Engineering Conference, London, England 1968

2. LONGUET-HIGGINS, M On the statistical distribution of the heights of sea waves Journal of Mar Research. Vol 11, 1952, no 3, pp, 246-266

3 KORVIN KROUKOVSKY, B V. Theory of seakeeping SNAME, New York, 1961



E (f,θ)
DIRECTIONAL
WAVE POWER
SPECTRUM
f
θ
K (f,θ)
TRANSFER
FUNCTION
f
Φ (f,θ)
DIRECTIONAL
FORCE POWER
SPECTRUM
f
Φ (f)
SCALAR
FORCE POWER
SPECTRUM
f
F
FORCE DISTRIBUTION
% < F

FIG 1

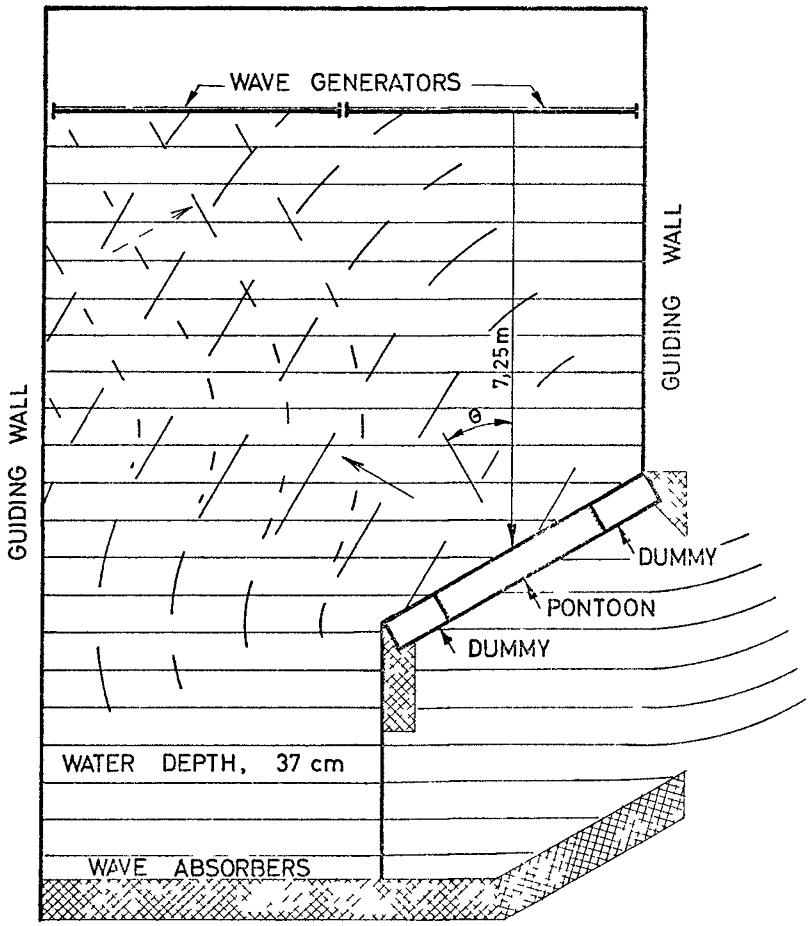


FIG 2 TEST ARRANGEMENT

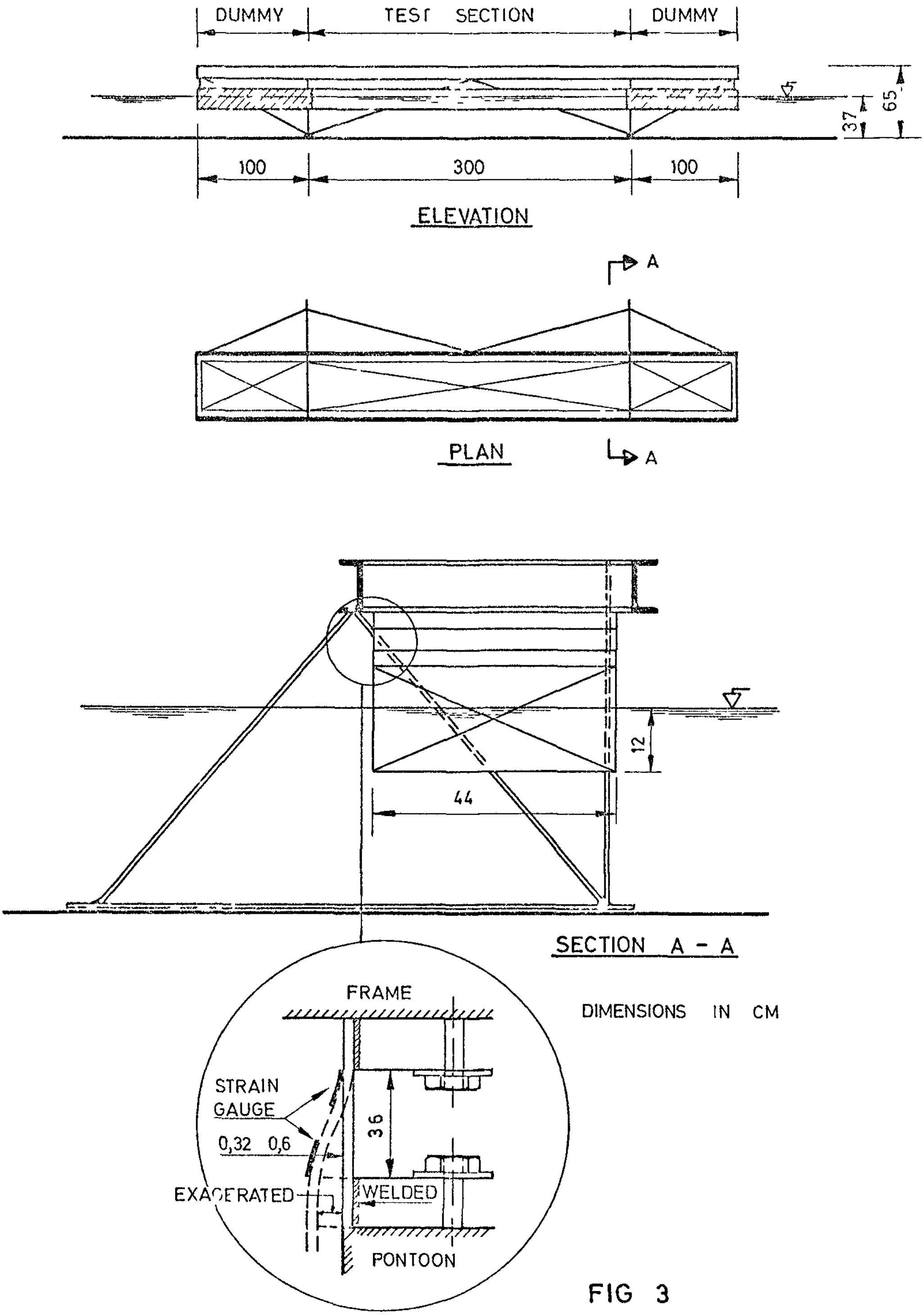
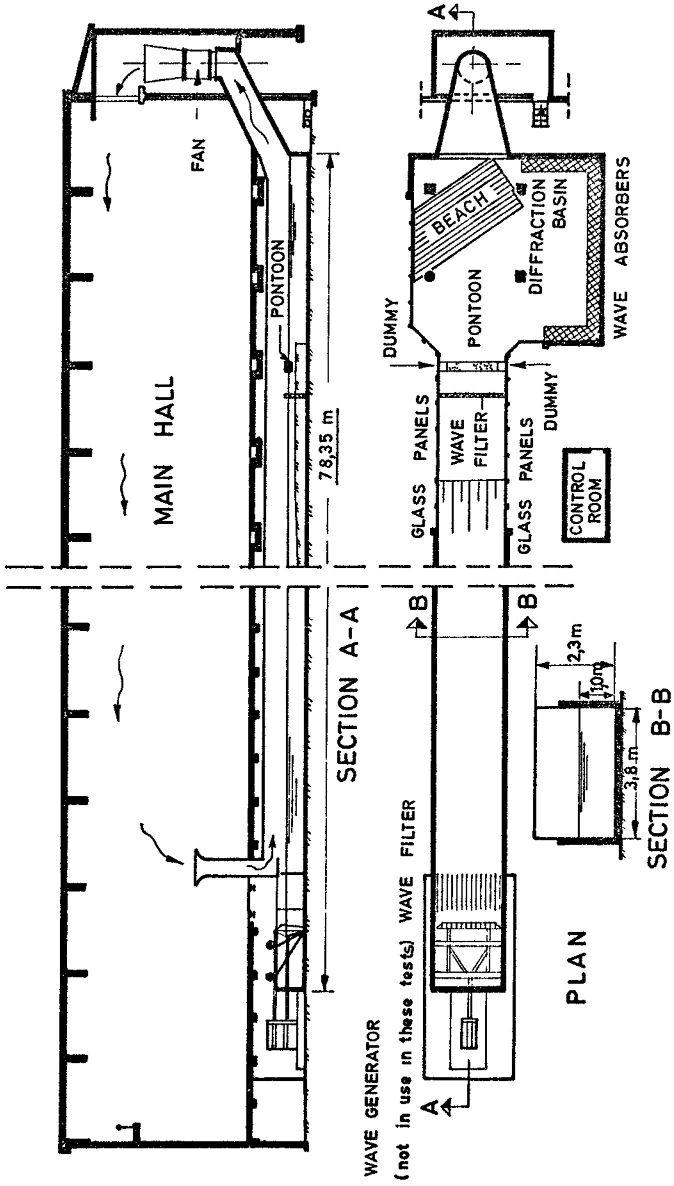

DUMMY
TEST SECTION
DUMMY
65
37
100
300
100
ELEVATION
A
PLAN
A
12
44
SECTION A - A
FRAME
DIMENSIONS IN CM
STRAIN
GAUGE
0,32 0,6
36
EXACERATED
WELDED
PONTOON

FIG 3

FIG. 4 WAVE CHANNEL



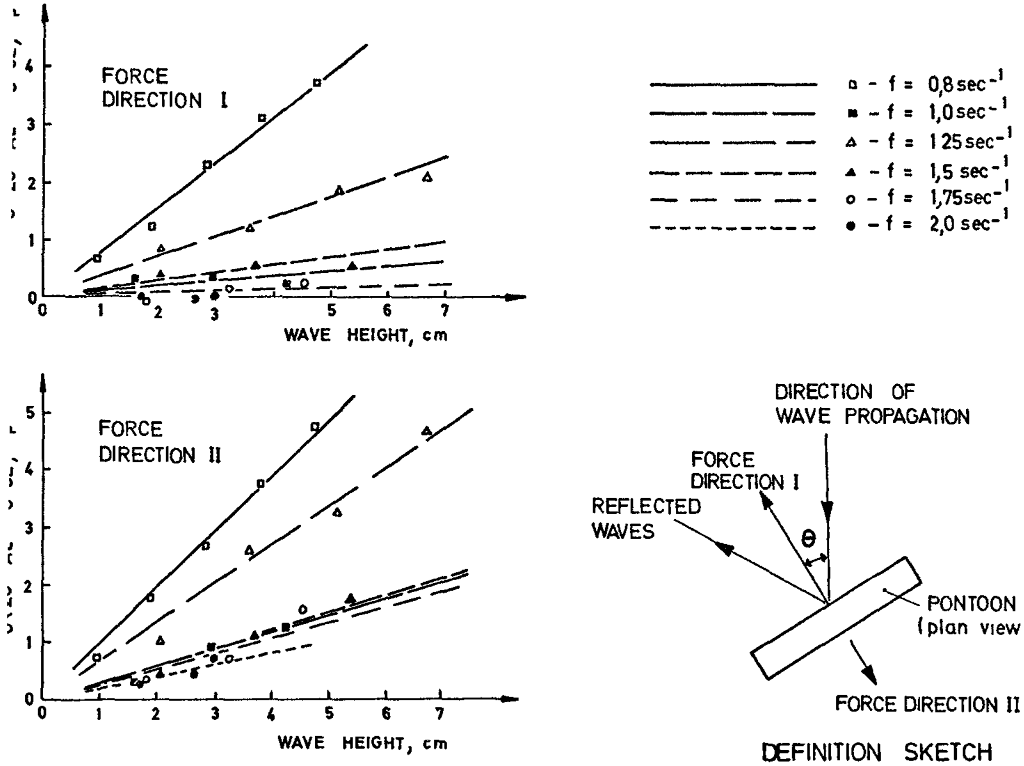


FIG 5 FORCE VS WAVEHEIGHT FOR θ = 30°

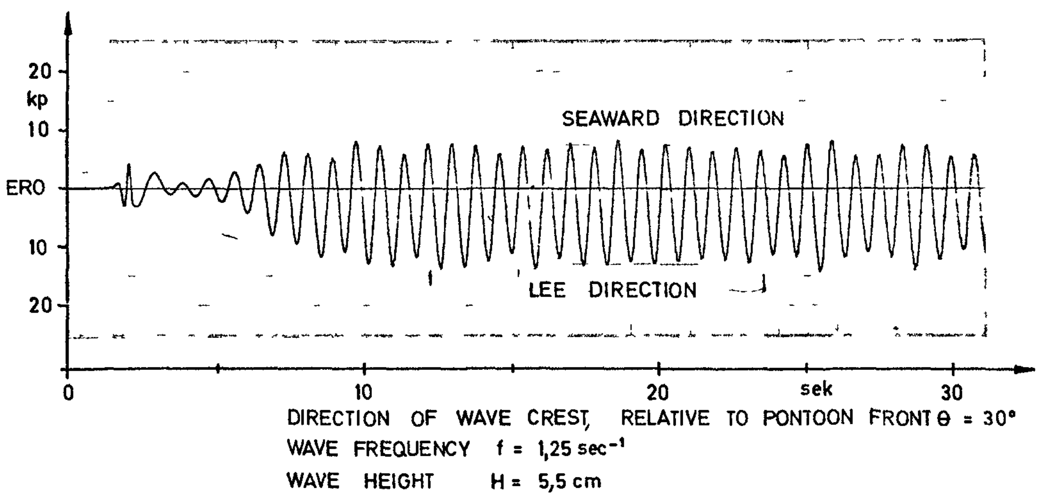


FIG 6 SAMPLE OF FORCE RECORD (regular waves)

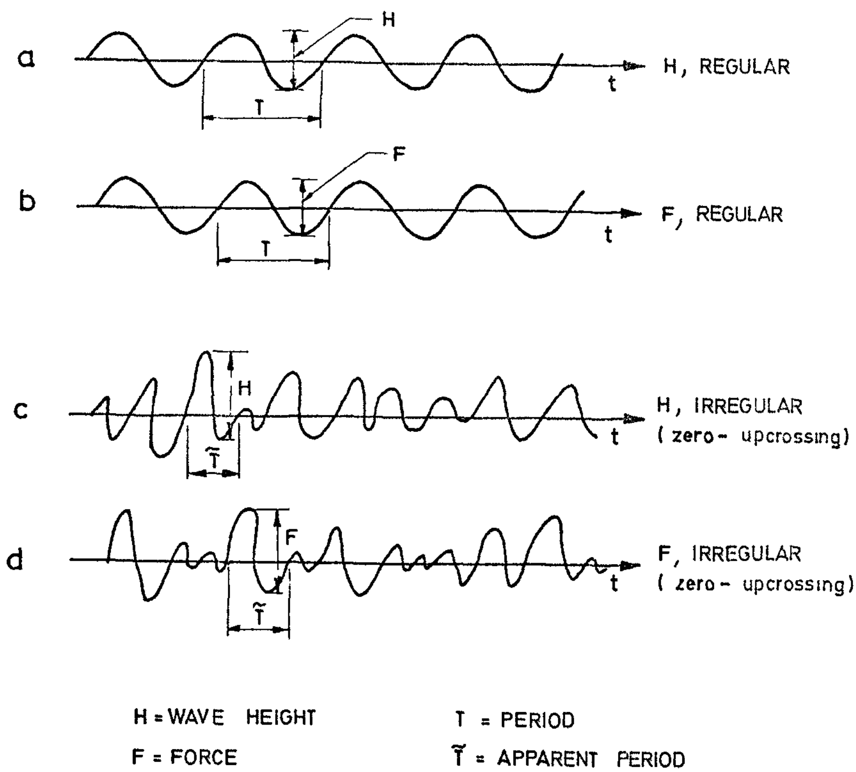


FIG 7 DEFINITION SKETCHES

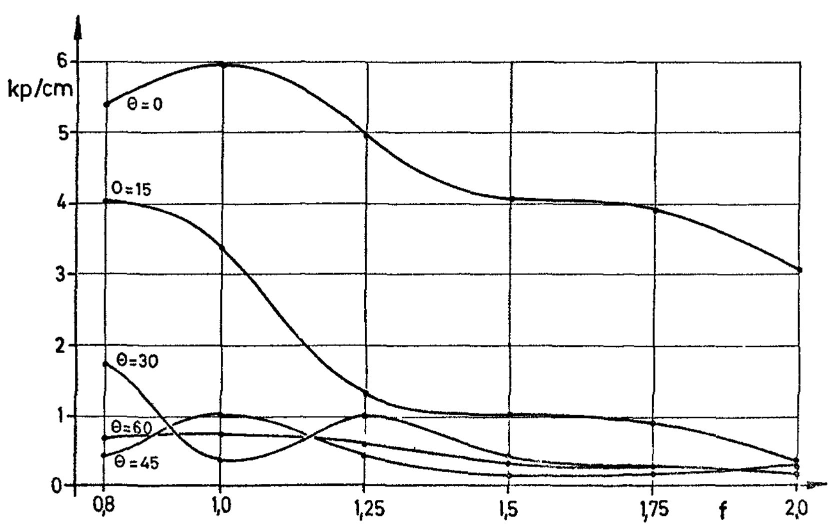


FIG 8 THE TRANSFER FUNCTION K (Θ, f)

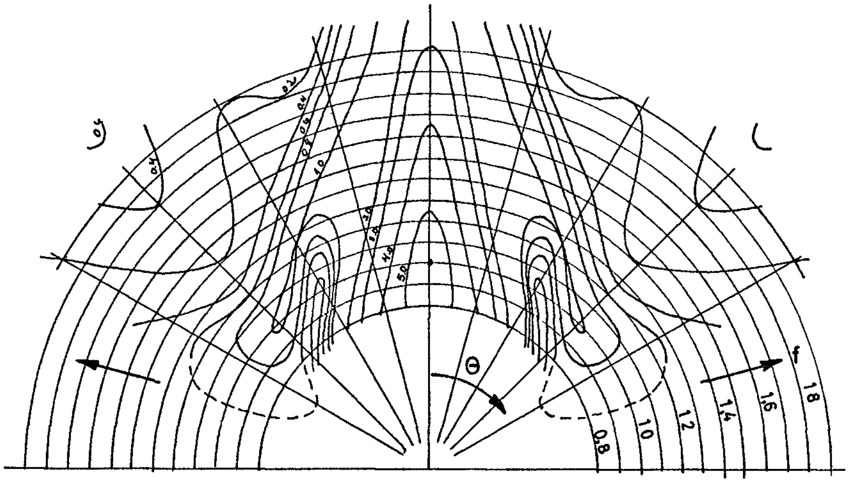


FIG 9 THE TRANSFER FUNCTION K (Θ, f), kg/cm, AS A CONTOUR MAP

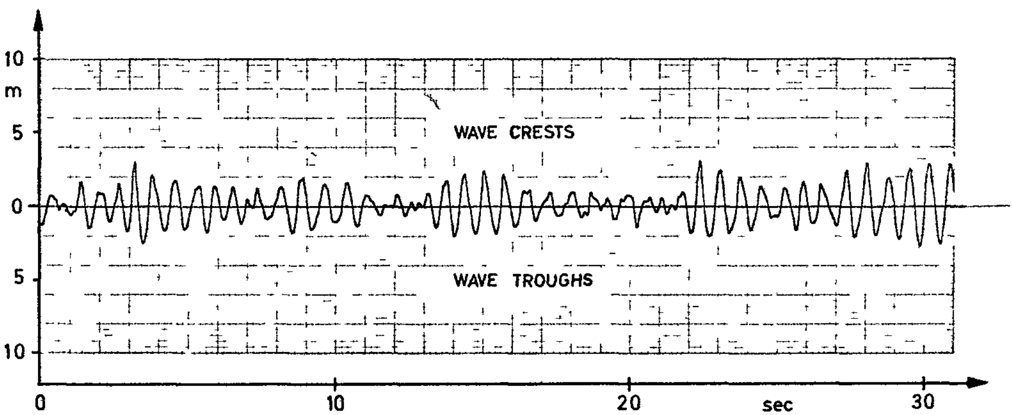


FIG 10 SAMPLE OF IRREGULAR WAVES

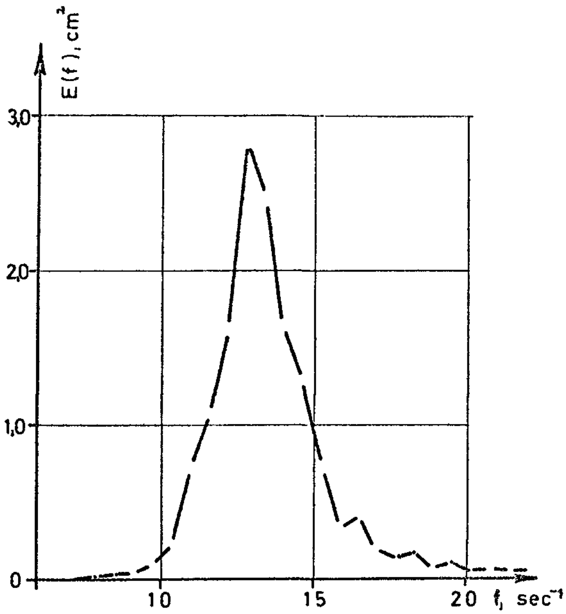


FIG 11 WAVE POWER SPECTRUM

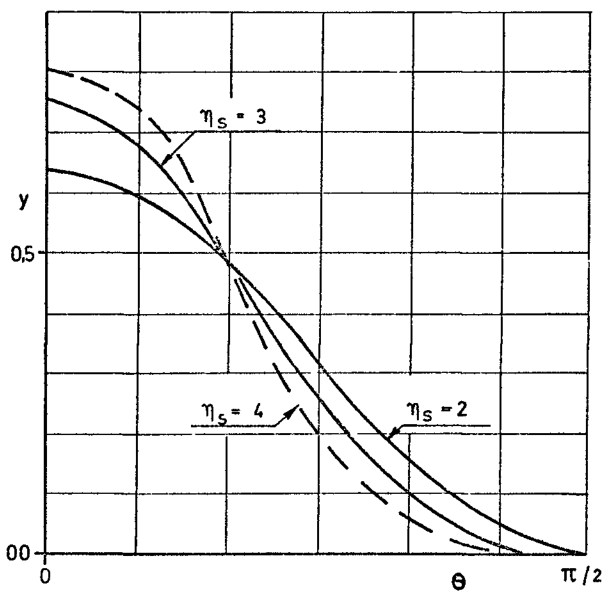


FIG 12 SPECTRUM DIRECTIONALITY FUNCTION

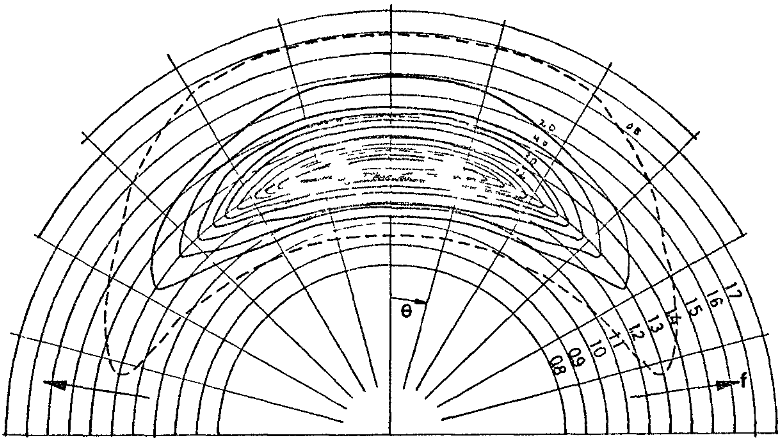


FIG 13 ESTIMATED DIRECTIONAL WAVE POWER SPECTRUM ($COS^4\theta$-LAW)

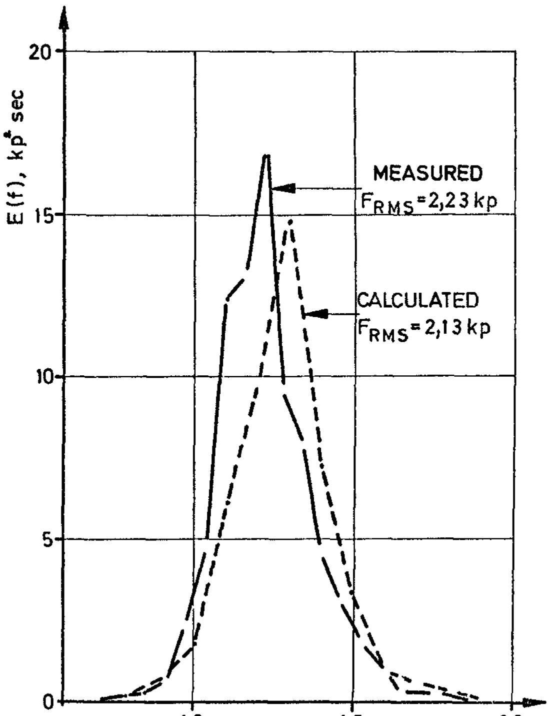


FIG 14 FORCE POWER SPECTRA

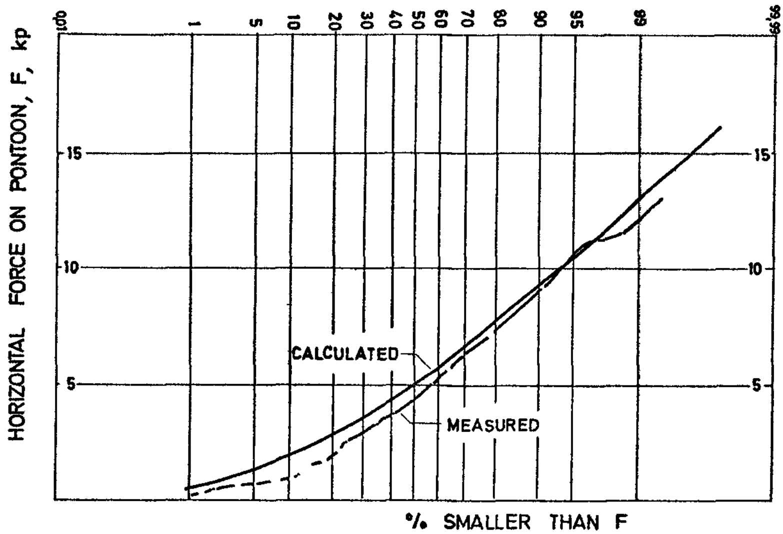


FIG 15 WAVE FORCE PROBABILITY DISTRIBUTIONS

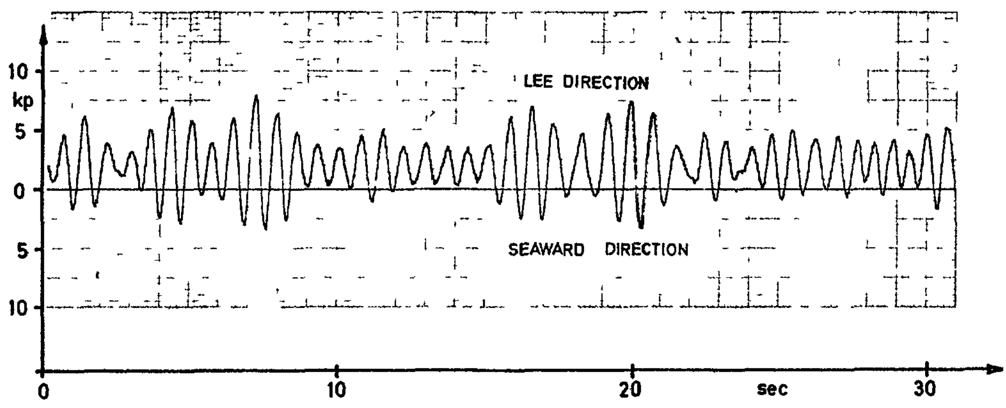


FIG 16 SAMPLE OF FORCE REGISTRATION IN IRREGULAR WAVES