CHAPTER EIGHTY

FIELD AND LABORATORY VERIFICATION OF THE WAVE PROPAGATION MODEL CREDIZ

M.W. Dingemans[1)], M.J.F. Stive[1)], A.J. Kuik[2)], A.C. Radder[3)] and N. Booij[4)]

ABSTRACT

Both the effects of refraction and diffraction may be efficiently modeled in wave propagation models by introduction of the parabolic approximation. The performance of the model CREDIZ, which is based on this parabolic approximation, was investigated in three verification studies. Two of these studies concern laboratory situations, i.e. one having a simple geometry and one having a more complicated geometry. The third study concerns a field situation, i.e. a shoal dominated area in an estuary mouth. It is found that despite the schematization to monochromatic, nearly linear wave propagation, the model CREDIZ performs remarkably well for engineering purposes.

1.0 INTRODUCTION

For the prediction of wave behaviour in coastal regions numerical wave propagation models are common engineering practise nowadays. The majority of the models are based on linear wave propagation. The physical processes usually accounted for are: shoaling, refraction and diffraction. The various approximations can be derived from the now well-known mild slope equation in which refraction and diffraction effects are both modeled. Because of the elliptic nature of this equation the numerical solution is quite involved. Neglecting the diffraction altogether in the mild slope equation results in the wave ray (geometric optics) approximation. An intermediate case is obtained by neglecting the diffraction only in the main wave propagation direction and maintaining it in the transverse direction, which results in the socalled parabolic approximation.

A wave propagation model, frequently used in the current Dutch advisory practice, is CREDIZ. This numerical model is based on the parabolic approximation and determines the combined effect on a monochromatic wave field of arbitrary bottom topographies and current patterns, including energy dissipation effects due to wave breaking and bottom friction (Radder, 1979, Booij, 1981). To assess the accuracy of CREDIZ, two verification sdtudies in laboratory wave basins have been carried out. Recently, a field study in a coastal region in the SW part of the

1) Delft Hydraulics Lab., Delft, the Netherlands
2) Rijkswaterstaat, Delta Department, The Hague, the Netherlands
3) Rijkswaterstaat, Department of Data Processing, Rijswijk, the Netherlands
4) Delft University of Technology, Delft, the Netherlands.

Netherlands, offshore the Haringvliet sluices, was conducted. Results of these verification studies are reported here.

2.0 MATHEMATICAL FORMULATION OF CREDIZ

Without sources and sinks, the mild slope equation, including currents reads

$$\nabla.(cc_g \nabla\phi) + 2i\omega\vec{U}.\nabla\phi - (\omega_r^2 - \omega^2 - k^2 cc_g)\phi = 0 , \tag{1}$$

where terms with $\nabla.\vec{U}$ and $\vec{U}^{\,2}$ are neglected. $\vec{U}$ is the (steady) current velocity, ∇ is the horizontal gradient operator, $\phi(x_1,x_2)$ is the complex wave potential function, k is the wave number, ω is the absolute angular frequency and ω_r is the relative angular frequency. The absolute and the relative frequency are related by

$$\omega = \omega_r + \vec{k}.\vec{U} , \tag{2}$$

where ω_r fulfils the linear dispersion relation

$$\omega_r = [gk \tanh kh]^{\frac{1}{2}} \tag{3}$$

with g being the gravity acceleration and h the local depth.

In the parabolic approximation the assumption is made that the waves propagate mainly into a specific direction s. Introducing the coordinate n, which is orthogonal to s, an operator M can be defined by

$$M\phi = (\omega^2 - \omega_r^2)\phi + \frac{\partial}{\partial n}(\beta \frac{\partial\phi}{\partial n}) + 2i\omega\, U_n \frac{\partial\phi}{\partial n} \tag{4}$$

where $\beta = cc_g$ and U_n is the current component in the direction n. The parabolic approximation to (1) is then given by

$$(\frac{i\omega U_s}{\beta} + \frac{\partial}{\partial s})[\sqrt{\beta k}\, \phi + \frac{p_1}{k\sqrt{\beta k}} M\phi] - ik\sqrt{\beta k}\, \phi - i \frac{p_2}{\sqrt{\beta k}} M\phi = 0 , \tag{5}$$

where the coefficients p_1 and p_2 result from the approximation of pseudo operators by differential operators and are related by

$$p_2 = p_1 + 1/2,\ 0 \leq p_1 \leq 1/2 \text{ (optimal, } p_1 = 1/4). \tag{6}$$

Because of the intended use in coastal areas, wave dissipation is also modeled in CREDIZ, i.e. both dissipation due to bottom friction and dissipation due to wave breaking are accounted for. Introduction of dissipative terms leads to the addition of the following expression to the left-hand side of (5)

$$(\frac{i\omega U_s}{\beta} + \frac{\partial}{\partial s})\, p_1 \frac{i\omega W}{k\sqrt{\beta k}} \phi + p_2 \frac{\omega W}{\sqrt{\beta k}} \phi . \tag{7}$$

where $W = W_b + W_f$, and W_b and W_f are the contributions due to wave breaking and bottom friction respectively. For the dissipation due to bottom friction is used

$$W_f = \frac{s_o^2}{2g}\left(\frac{8}{3\pi} f_w s_o H + 2f_s \vec{U}\right), \quad s_o = \omega_r/\sinh(kd). \tag{8}$$

where f_w and f_s are coefficients for the wave-induced and the wave-current induced parts of the shear stress. Standard values are $f_w = 0.01$ and $f_s = 0.005$. The dissipation due to wave breaking is modeled according to the model of Battjes and Janssen (1978) (see also Battjes and Stive (1984) in these proceedings).

The influence of the wave amplitude a on the propagation velocity is taken into account in an approximate way, following Walker (1976): for the depth h in the dispersion relation (3) is taken

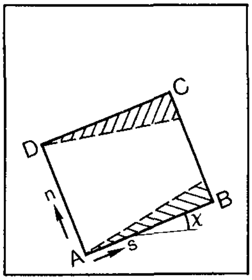
$$h = d + p_v * a,$$

where d is the actual mean water depth and p_v is an adjustable parameter, with a standard value of 1. It is noted that in the limit for shallow water the wave celerity of a solitary wave from the KdV equation results for $p_v = 1$. In the deep water limit the linear expression for c is recovered.

The solution of (5) requires the availability of initial and boundary conditions. The initial values can be derived from the incoming wave field, which may be (weakly) non-uniform with regard to amplitude and direction. For the lateral boundaries, one has to deal with the presence of open boundaries on which the wave field is generally not known. A simple boundary condition is

$$\cos\chi \frac{\partial\phi}{\partial s} + \sin\chi \frac{\partial\phi}{\partial n} = ik\phi ,$$

which ensures the absorption of waves with local wave number k approaching under an angle χ exactly, and waves in other directions are absorbed partially. A zone along the lateral boundaries in which the results are less accurate is indicated in the sketch.



3.0 VERIFICATIONS

3.1 Laboratory

In the laboratory both a simple and a realistic bottom topography were used; both periodic and random, unidirectional waves without currents were applied. In the simple situation, consisting of a parabolic shoal on a sloping bottom, small amplitude waves were applied to study the purely linear part of CREDIZ only: results are given by Berkhoff et al. (1982). Here we report results of a computation in which amplitude effects are taken into account. The more realistic situation pertained to a coastal topography at the NW coast of Spain. In this case also finite-amplitude waves were applied resulting in breaking waves in the model.

The shoal situation.

The simple laboratory situation consisted of a parabolic shoal (elliptic in the plane) placed on a 1/50 shoaling bottom, see Figs. 1 and 2. The measurements were conducted in a wave basin of 30 by 35 m in extent and a 20 by 20 m measuring areas was taken in which a measuring grid of at least .5 by .5 m was taken: locally this grid was reduced to .25 by .25 m. The comparison of the computed and measured wave field is specifically carried out along five sections tranverse to and three sections in the wave propagation distance, see Fig. 1. A comparison of the iso-amplitude contours for the situation of regular waves (incoming wave amplitude 2.32 cm and wave period T = 1 s) is given in Fig. 3. Here purely linear wave propagation in the computation is considered, seel also Berkhoff et al. (1982) from which this case is taken. The iso-amplitude contours show a satisfactory agreement, but locally, in the convergence zone, some deviations in lateral extent of the convergence region can be noticed. This is mainly due to the linear nature of the computation, as confirmed by Kirby and Dalrymple (1984) who took non-linearity into account. Because CREDIZ also allows the incorporation of an amplitude effect on the wave propagation characteristics by choosing $p_v \neq 0$, we recomputed the shoal situation at the end of September 1984, taking $p_v = 1$. The iso-amplitude contours for this situation are shown in Fig. 4, giving indeed a better correspondance with the measurements behind the shoal. The difference between the two computations ($p_v = 0$ versus $p_v = 1$) can be most clearly seen by considering sections 5 and 6. The results are given in Fig. 5 for both $p_v = 0$ and $p_v = 1$. For both sections 5 and 6 a much better correspondance with the measurements is obtained for the $p_v = 1$ case compared to the $p_v = 0$ case, although even in the purely linear situation a satisfactory correspondance is obtained. For both situations the rms deviations ε_{rms} and the bias b are defined by

$$b = n^{-1}\Sigma(a_c-a_m)/[n^{-1}\Sigma\, a_m]$$

$$\varepsilon_{rms} = [n^{-1}\Sigma(a_c-a_m)^2]^{\frac{1}{2}}/[n^{-1}\Sigma\, a_m].$$

We have for section 5 and 6 separately and for all sections together the following results (taken from Dingemans and Radder, 1984)

	$p_v = 1$		$p_v = 0$	
section	b	ε_{rms}	b	ε_{rms}
5	0.9	10.6	2.5	35.8
6	-1.2	10.8	10.2	36.7
all	3.0	10.2	3.0	22.5

Table 1 Bias b and rms deviation ε_{rms} in %

The realistic laboratory situation.

The realistic bottom geometry concerns a coastal region near San Ciprian (NW Spain), built in a wave basin for other purposes, see Fig. 6. The region of interest is also shown in the Figure. Notice the cape just seawards from the proposed breakwater alignment. The measuring grid is shown in Fig. 7. Of the several tests in which the significant wave period, wave height, etc. were varied, the cases of run 6 with very high initial wave height and run 3 with moderate initial wave height are discussed here; in both tests random waves were applied. For the other cases reference is made to Stive and Dingemans (1983). The iso-wave height lines for both the measurement and the computation of run 6 are shown in Fig. 8, together with contour lines of the normalized difference (in %). The comparison is done point by point. The rms deviation is 16% with a bias of 9%. Along the breakwater the comparison is shown in Fig. 10. It is seen that the computed wave heights are essentially higher than the measured ones, but the trend is nearly the same. For this case much wave breaking occurred in the model experiment. For run 3 the results are shown in Figures 9 and 11; the rms deviation is 10.8% and the bias is 5.3%. Both computations for runs 3 and 6 were carried out with $p_v = 1$ and $\gamma = 0.8$, while no bottom friction effects were taken into account. For run 3 wave breaking is of no importance, but for run 6 it is (breaking waves were observed in the physical model). Estimating γ with the formula given by Battjes and Stive (1984) yields for run 3 $\gamma = 0.70$ and for run 6 $\gamma = 0.83$; therefore the deviation along the breakwater alignment for run 6 (Fig. 10) cannot be explained by differences in wave breaking characteristics (the value for γ used is lower than the optimal one and with the latter the deviation would become larger). It seems that the computed results are somewhat smeared out in CREDIZ; this is presumably due to an overemphasis of the diffraction effect. This can also be observed from Figs. 12 and 13 in which scatter plots of the results are given. The variation in computed wave heights is less than it is in the measured ones. From the other cases studied in Stive and Dingemans (1983) it was found that the correspondance of CREDIZ is closer in the random wave tests than it is in the periodic wave tests, which is fortunate because CREDIZ is meant to be applied in the field. The present measurements applied random wave without directional spreading sothat it may be expected that the correspondance between computations with the monochromatic model CREDIZ and measurements becomes even more close in situations in which tests are conducted with a two-dimensional spectrum.

3.2 Field

For the field measurements a region offshore the Haringvlietsluices was chosen. The area is characterized by a shallow shoal which falls partly dry during low tide, a region with nearly straight isobaths offshore the shoal, and a complicated bottom geometry inshore of the shoal, see Fig. 14. A measurement campaign was especially set up in order to assess the applicability of CREDIZ in realistic field situations. At the start of the project the results of the shoal experiment (see Berkhoff et al. (1982)) were available and therefore the main attention was directed to those aspects not yet studied, i.e. the dissipation processes and the effect of non-linearity on the wave celerity. Six waverider buoys were placed more or less around the Hinderplaat; the one available directional buoy (a WAVEC buoy) was expecially used to obtain good initial conditions for the computations. Furthermore, two wave staffs were present in the region. Further offshore also wave information was available from the platform LEG and the waverider EURO-3. The measurement campaign was conducted in Fall 1982 and lasted 13 weeks of which during the first 8 weeks the directional buoy was available.

The method of comparison in this case of a relatively small number of point measurements is done as follows. From the file of measurements, given in the form of wave parameters, measurements under specific conditions were selected. Several wave registrations meeting these conditions are usually found, sometimes several weeks apart. A computation is performed for the averaged boundary condition, usually provided by the WAVEC. The comparison is based on the averaged wave parameters at each sensor location. Another method concerns a hindcast in which single measurements are used. Computed wave heights are averaged afterwards over some spatial region because the wave measurement at a sensor location is taken to be characteristic for some region of space; here a region of 250 by 250 m is used.

One measurement condition was called "the ideal condition" because of the fact that a wave condition was selected for which the mathematical model may be expected to give reasonable results. The selection criteria consisted of: 1) registrations of good quality, 2) not too low water levels (water levels between 1.25 and 1.60 m with respect to chart datum (NAP)), 3) not too low waves (H_{mo} > .50 m), 4) waves from the North-West (principal wave direction between 300° and 330°), being the direction which is nearly perpendicular to the isobaths offshore the Hinderplaat, 5) not too much directional spreading, and 6) old waves, giving swell-type of waves. Five wave registrations were found to comply with these criteria, two on September 22 and three on October 16. Since not all sensors were sampled simultaneously, a time window was applied in order to obtain approximately simultaneous wave registrations at the various sensors. As time window was taken $t - 25$ min $\leq t_o \leq t + 35$ min. where t_o is the start time of the wave registration at either the WAVEC or at the staff Ha-1, which were samples starting at each whole hour (the WAVEC for one half hour duration and Ha-1, as were all other sensors, for 20 minutes).

The mean values of H_s ($=H_{mo}$), T_p, the principal wave direction θ_s and the water level, WST, at the WAVEC are $\langle H_s \rangle$ = 133 cm, $\langle T_p \rangle$ = 7.02 s, $\langle \theta_s \rangle$ = 321.4° and ⟨WST⟩ = 143 cm; the standard deviations are $s(H_s)$ = 11.0 cm, $s(T_p)$ = 0.2 s, $s(\theta_s)$ = 3.2° and s(WST) = 11.5 cm. The results of computation T26, with parameters $p_v = 1$, $\gamma = 0.70$, $f_w = 0.005$ are compared with the measurements in the Table below.

	measurement		computation	
sensor	$\langle H_s \rangle$	$s(H_s)$	$\langle H \rangle$	$s(H)$
WR1	133.7	8.4	130.0	5.4
WR2	127.5	20.5	126.2	7.1
WR3	133.3	21.2	135.3	2.6
WR4	52.0	7.7	54.4	22.0
WR5	108.9	9.5	103.6	7.5
WR6	124.3	4.7	115.8	8.5
Ha-1	137.5	17.7	134.4	7.7
E-75	59.0	1.4	34.2	6.1

Table 2 Comparison of ideal condition with CREDIZ computation T26. Wave heights in cm

A quite satisfactory correspondance is obtained at all sensor locations, except at location E-75, close to the sluices. At E-75 a relatively large discrepancy is found; the principal reason is that the location is far behind the breaker zone (visible in Fig. 15 for the iso-amplitude contours) and the characteristic wave period T differs much before and behind a strong dissipation zone. The relative error is defined by $\delta = (\langle H\rangle - \tilde{H}_s)/\tilde{H}_s$. Taken over all sensors we have $\langle \delta \rangle = 7.4\%$, where as for E-75 alone we have $\delta = -42\%$; without E-75 one has $\langle \delta \rangle = 3.0\%$ and $s(\delta) = 2.1\%$.

The hindcast.

The period of 14 and 15 October 1982 was selected for the hindcast; wind and water level time histories are shown in Fig. 16. In the hindcast period a rather constant wind direction from North-Westerly directions is present. An example of a wave spectrum of the directional buoy is shown in Fig. 17 and a nearly simultaneous spectrum of WR4 (behind the Hinderplaat) is given in Fig. 18. The results of the hindcast is shown in Figs. 19-21 in which the crosses denote the computed wave heights and the points the ones measure (H_{mo}). A scatter plot of all pairs computed and measured wave heights is given in Fig. 22. Especially E-75 is seen to give unsatisfactory results, and for low water levels, also WR4. In terms of the bias and the rms deviation the results as given in the following Tables are obtained. The bias b and the rms deviation ε_{rms} are defined by

$$b = n^{-1}\Sigma(\langle H\rangle - \tilde{H}_s)/[n^{-1}\Sigma\, \tilde{H}_s]$$

$$\varepsilon_{rms} = [n^{-1}\Sigma(\langle H\rangle - \tilde{H}_s)^2]^{\frac{1}{2}}/[n^{-1}\Sigma\, \tilde{H}_s].$$

test	T27	T32a	T29	T28	T30	T31
time	17:00	20:00	22:00	23:00	02:00	04:00
WST	-10	20	85	170	150	45
all sensors	-1.5	-2.4	+1.9	+6.9	-3.2	+0.5
not E-75	+3.6	+5.4	+6.1	+8.6	+0.9	+1.8
not E-75, WR4	+7.5	+11.8	+8.7	+9.4	+1.0	+5.1

Table 3 Bias b in %

test	T27	T32a	T29	T28	T30	T31
time	17:00	20:00	22:00	23:00	02:00	04:00
WST	-10	20	85	170	150	45
all sensors	19.2	26.1	16.5	12.4	15.3	13.4
not E-75	13.3	18.9	13.2	12.8	11.0	12.8
not E-75, WR4	8.7	13.4	11.7	12.4	10.7	9.9

Table 4 Deviation ε_{rms} in %

	T27	T32a	T29	T28	T30	T31
test	T27	T32a	T29	T28	T30	T31
time	17:00	20:00	22:00	23:00	02:00	04:00
WST	-10	20	85	170	150	45
all sensors	29.6	37.2	18.9	8.6	16.0	22.3
not E-75	21.3	27.6	13.9	7.9	9.5	22.7
not E-75, WR4	8.2	12.5	8.9	8.5	7.3	13.5

Tabel 5 Overall error $< \delta >$ in %

Because of the before mentioned fact that CREDIZ is not suited to predict the wave height at E-75, the station far behind the dissipation zone, with reasonable accuracy and because for low water levels the predicted wave height at WR4, just behind the Hinderplaat is not accurate, the figures for the case that both E-75 and WR4 are excluded have most significance. Notice that the shallowest part of the Hinderplaat is only 10 cm below chart datum and that the bottom soundings at the Hinderplaat are relatively less accurate than elsewhere in the region. It thus follows from the hindcast that wave heights are predicted with an accuracy of at least 15%.

4.0 CONCLUSION

Despite the schematization to monochromatic waves and nearly linear wave propagation the model CREDIZ performs remarkably well for engineering purposes in a variety of conditions in coastal areas, as indicated by both the laboratory and the field verification studies. The findings may be stated as follows.

- For those situations in which the (random) wave field can be characterized by a single frequency and a single wave height measure, CREDIZ gives quite accurate results for the wave height in coastal areas, typically better than 15% deviation. For regions far behind a dissipation zone the results are less accurate, but then the wave field can hardly be characterized by a single frequency.
- From the laboratory studies it followed that the computed wave height field is smoother than the measured one for periodic waves. CREDIZ is more suited for application to random wave fields for not too broad spectra.
- The field comparisons are carried out without accounting for current due to lack of simultaneous current measurements. Currents are typically less than 1 m/s maximum.
- Better results may be obtained by choosing input parameters such as γ for the breaking process and the firction coefficient more carefully than was done here. As an example serves the ideal condition for which deviations of less than 5% were obtained after a short sensitivity study.

ACKNOWLEDGEMENT

The performance and analysis of the field experiments has been carried out by the Advisory Branch Hellevoetsluis of Rijkswaterstaat, under the direction of Mr. W.R. Abels. For the numerical computations we were assisted by Mr. P. v.d. Bosch of Delft Hydraulics Laboratory and Mr. G.M. Visser of the Delta Department of Rijkswaterstaat.

REFERENCES

BATTJES, J.A. and J.P.F.M. JANSSEN, 1978: Energy loss and set-up due to breaking of random waves. Proc. 16th Coastal Eng. Conf., Hamburg 1978, pp. 569-587

BATTJES, J.A. and M.J.F. STIVE, 1984: Verification of a dissipation model for random breaking waves. Proc. 19th Coastal Eng. Conf., Houston 1984

BERKHOFF, J.C.W., N. BOOIJ and A.C. RADDER, 1982: Verification of numerical wave propagation models for simple harmonic linear water waves. Coastal Engineering 6, 1982, pp. 255-279

BOOIJ, N., 1982: Gravity waves on water with non-uniform depth and current. Ph.D. thesis, Delft Univeristy of Technology

DINGEMANS, M.W., 1983: Verification of numerical wave propagation models with field measurements; CREDIZ verification Haringvliet. Delft Hydraulics Laboratory, Report W488 part 1, December 1983

DINGEMANS, M.W. and A.C. RADDER, 1984: Note on the verification of the parabolic wave propagation model CREDIZ: a simple non-linear extension; preprint, Oct. 1984

KIRBY, J.T. and R.A. DALRYMPLE, 1984: Verification of a parabolic equation for propagation of weakly-nonlinear waves. Coastal Engineering 8, 1984, pp. 219-232

RADDER, A.C., 1979: On the parabolic equation method for water-wave propagation, J. Fluid Mech. 95, pp. 159-176.

STIVE, M.J.F. and M.W. DINGEMANS, 1983: Verification of the refraction-diffraction wave propagation model CREDIZ in a realistic laboratory situation. Delft Hydraulics Laboratory, Report S581, December 1983

WALKER, J.R., 1976: Refraction of finite-height and breaking waves. Proc. 15th Coastal Eng. Conf., Hawaii 1976, pp. 507-524

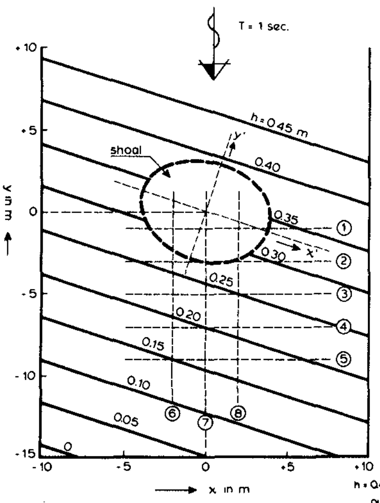


Fig. 1

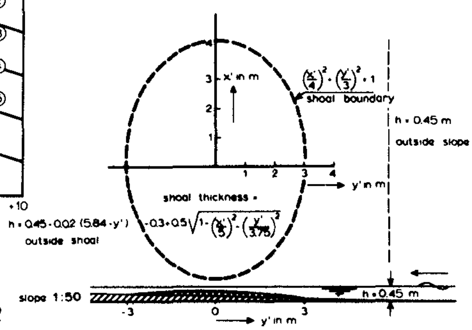


Fig. 2

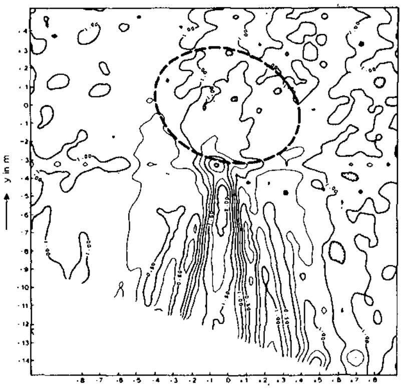


Fig. 3a

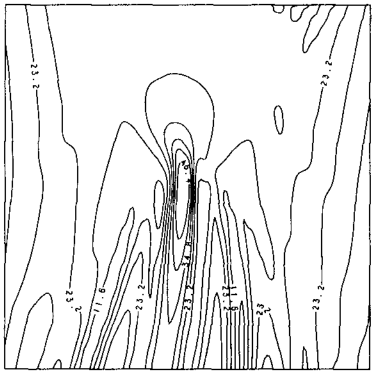


Fig. 3b

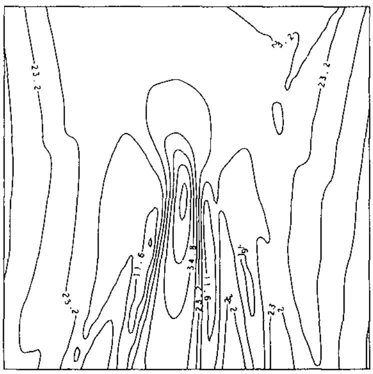


Fig. 4

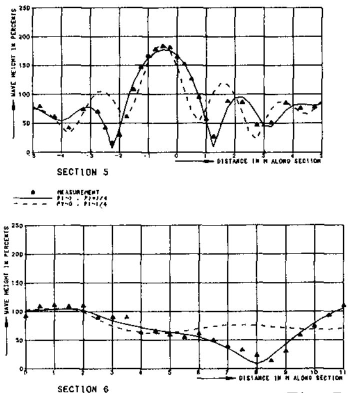


Fig. 5

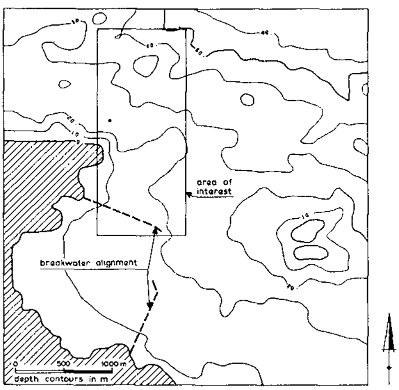


Fig. 6

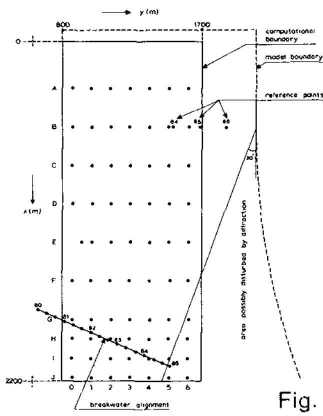
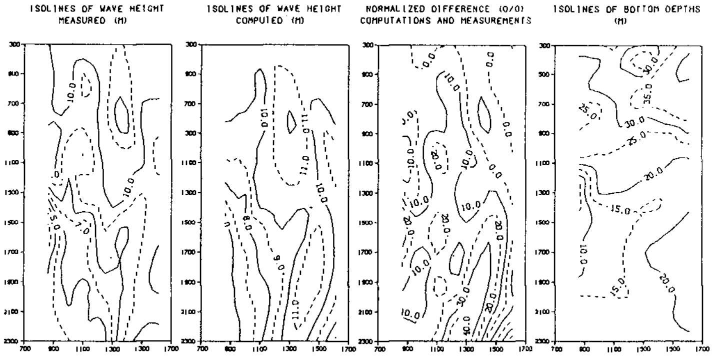


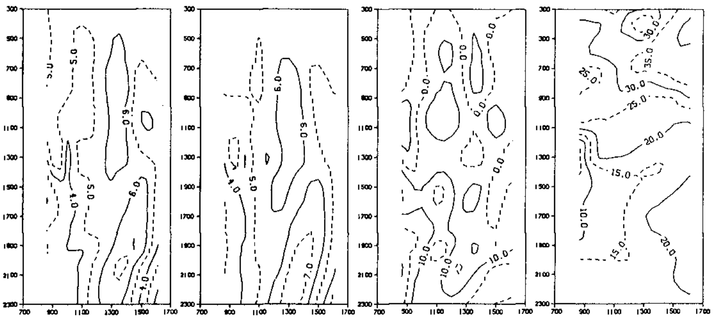
Fig. 7



TOTAL RMS-DEVIATION = 16.1 0/0
TOTAL BIAS = 9.0 0/0

INCIDENT WAVE FIELD :
- UNIFORM , RANDOM
- SIGNIFICANT WAVE HEIGHT = 10.62 M
- WAVE PEAK PERIOD = 12.50 S

Fig. 8



TOTAL RMS-DEVIATION = 10.8 0/0
TOTAL BIAS = 5.3 0/0

INCIDENT WAVE FIELD :
- UNIFORM , RANDOM
- SIGNIFICANT WAVE HEIGHT = 5.43 M
- WAVE PEAK PERIOD = 12.50 S

Fig. 9

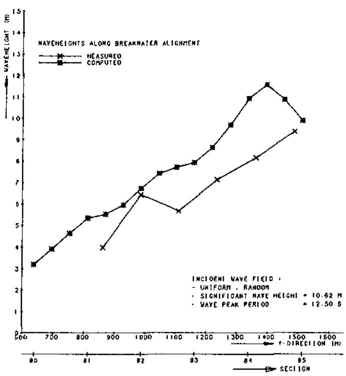


Fig. 10

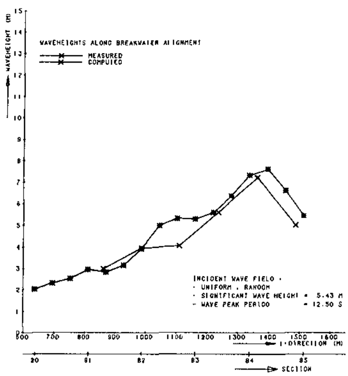


Fig. 11

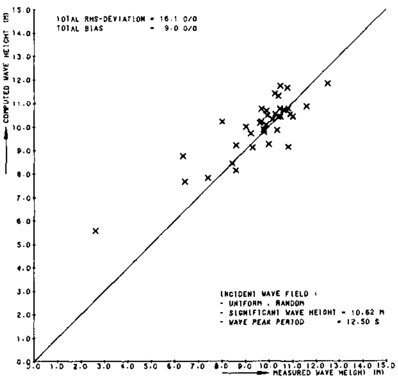


Fig. 12

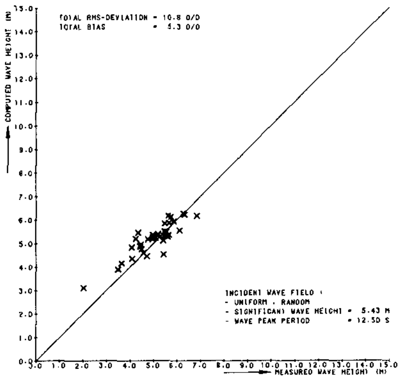


Fig. 13

Bottom contours 1981 bottom , 500 m mesh, with STROBO

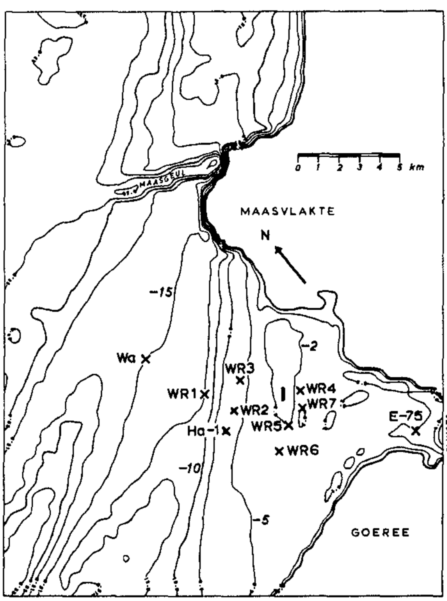


Fig. 14

Fig. 15

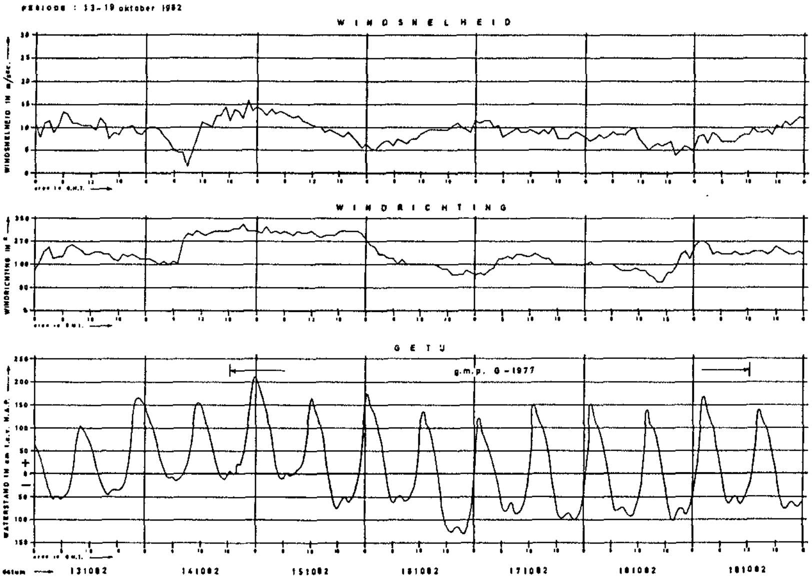


Fig. 16

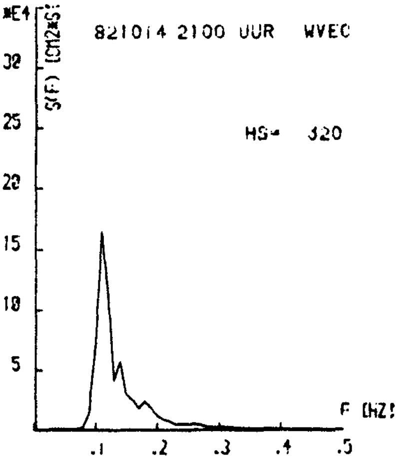


Fig. 17

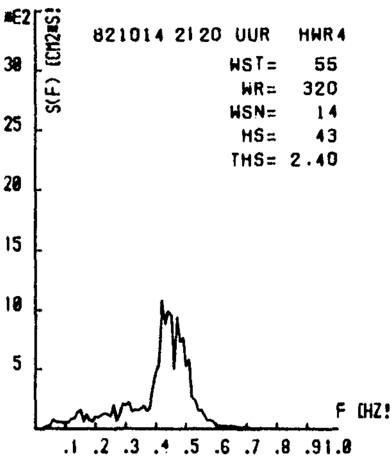


Fig. 18

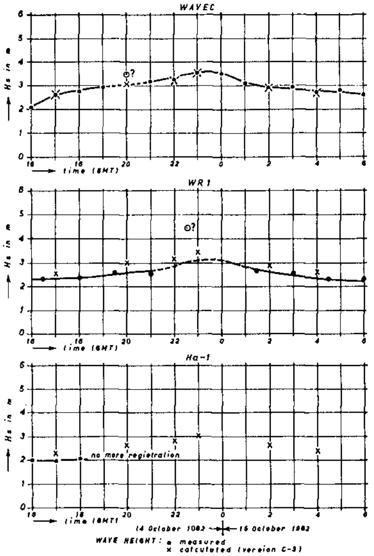


Fig. 19

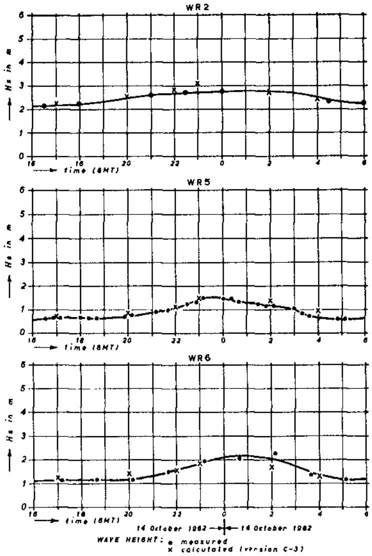


Fig. 20

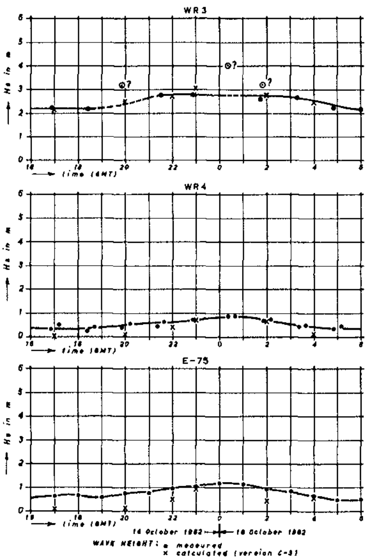


Fig. 21

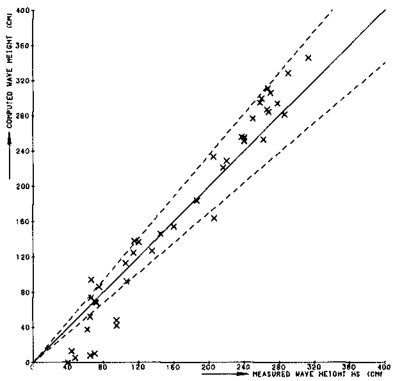


Fig. 22