CHAPTER 16

Directional nearshore wave propagation over a rip channel: an experiment

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ABSTRACT

The aim of these tests was to study wave propagation on a beach, including the surf zone, and nearshore circulation produced by breakers in the presence of a rip channel. The tests were carried out in a multidirectional wave tank. The initial series of tests concerned the case of a plane beach sloping at 1 in 30. The second series was performed with a rip channel excavated in the beach. Conventional wave measurements were taken at 50 different points. Measurements of the multidirectional waves and rip current were taken at 7 points along the channel centre line. During the tests, various types of wave (monochromatic, random monodirectional and multidirectional) were tested and the results obtained were compared with identical starting conditions.

1. INTRODUCTION

Wave tanks capable of simulating real multidirectional (short-crested) waves are a relatively common means of studying offshore structures, but they are less frequently used in the field of coastal engineering. Nevertheless, this field is rapidly developing at the present time and many shallow-water, multidirectional wave tanks have been built in recent years in Europe and North America. Mention should be made of three recent studies conducted in tanks of this type, which have been devoted to the study of wave propagation in the nearshore area, including the surf zone. Dingemans et al. (1986) studied the propagation of breaking waves on a submerged bar creating a rip current. In this case, where the energy slope is very localised, directional effects do not appear to affect the results to any great extent. Vincent and Briggs (1989) studied the effect of directional spectrum width on the concentration of wave

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disturbance behind a shoal. They showed that the results were highly sensitive to this parameter in the case of non-breaking waves. Lastly, Briggs and Smith (1990) and Elgar et al. (1992) have presented results for propagation on a plane beach with a slope of 1 in 30, including a wide range of unimodal and bimodal frequency spectra.

The main interest of these tests was to provide data sets that can be used to validate numerical models of real wave propagation (Dingemans, 1986; Grassa, 1990; Panchang et al., 1990). The tests described here were carried out in line with this philosophy. The bed configuration adopted aims at combining a moderately sloping beach with the creation of a water circulation cell produced by breaking waves.

2. EXPERIMENTAL SET-UP

The model was built in a wave tank at the Laboratoire d'Hydraulique de France in Grenoble. The tank measures 30 m by 30 m and is fitted with a multidirectional wave generator consisting of 60 paddles, each 0.5 m wide and 1.40 m high. The sea bed consists of a plane beach sloping at 1 in 30, with a rip channel excavated in the centre (fig. 1).

Direct OXYZ co-ordinates are defined as follows. The OX axis is perpendicular to the generator and forms the axis of symmetry of the wave tank. OY is parallel to the generator and marks the foot of the beach. OZ is vertical, running from the bottom to the top, with its origin at 0.50 m above the flat bed of the wave tank.

The bathymetry may be represented by the following analytical expression (Noda, 1974):

$$Zf\ (x,y) = 0.1 - \frac{X}{30}\left[1 + 3\exp\left(-\frac{X}{3}\right)\cos^{10}\left(\frac{\pi y}{30}\right)\right] \tag{1}$$

with $X = 18 - x$

x varies between 0 and 18 m and y between -15 and +15 m. The longitudinal profile along the centre line of the channel is shown on fig. 2d.

During construction of the sea bed, the channel was temporarily filled in order to carry out prior tests on the plane beach. It should also be noted that the beach only starts at a distance of about 5 m from the generator. This makes for better wave generation and for clear access to the tank.

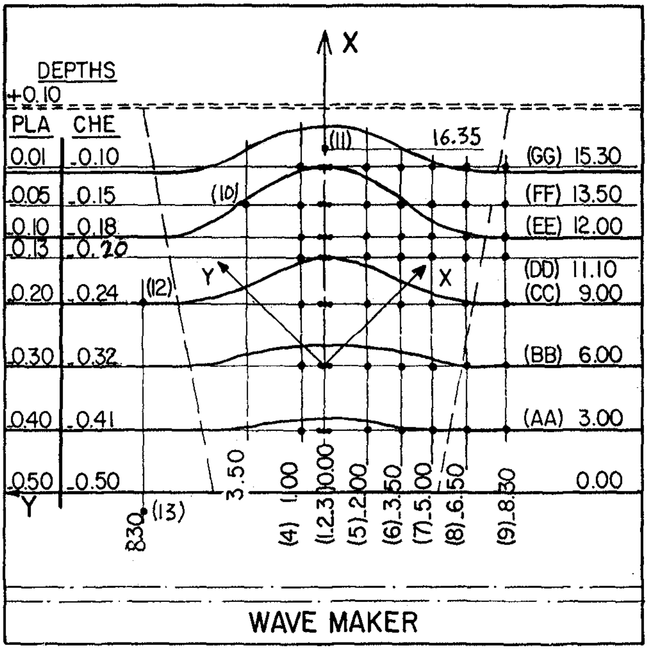

Fig. 1 Experimental set-up

3. INSTRUMENTATION

Ten standard wave gauges and a wave direction gauge were installed in the tank. Visual observations (comprising photographs and video films) were also made under rather poor lighting conditions, which it was impossible to improve during the study.

The wave gauges are accurate to within 2%, with 1-5% linearity and very little drift. They were calibrated once a week. The direction gauge consists of a classic resistive wave gauge coupled to an electromagnetic current meter capable of making two-directional horizontal measurements. The main drawbacks encountered with resistive gauges, namely lack of stability, drift and linearity of measurement, were largely offset by using a small platinum electrode that compensates for deviations. In this way, linearity was 0.5% and calibration only had to be performed during maintenance operations.

The electromagnetic current meter is a disk 40 mm in diameter and 18 mm thick, accurate to within about 1%, and covering a measurement range of 0 to 1 m/s. It is calibrated during maintenance operations.

4. MEASUREMENT POSITIONS

The ten wave gauges and wave direction gauge were installed in two groups in the wave tank.

The first group (comprising the direction gauge and six wave gauges) was fixed on a mobile beam running along the axis of the wave tank. These gauges scan an area between $y = 8.3$ m to $y = +1$ m and $x = 1.0$ m to $x = 15.30$ m. This last position ($x = 15.30$ m) was only reached by certain gauges when the depth of water was sufficient for the measurement to be taken.

The other four gauges were arranged in a fixed pattern over the tank. They were used to check the repeatability of the measurements and replace any gauges on the beam that might prove to be defective during the tests.

In practice, the beam was moved along 7 axes during each test. This meant that wave disturbance was measured at 53 points in the case of the plane beach and 50 with the channel. The positions of the measuring points are shown on fig. 1 for the tests carried out with a channel.

The electromagnetic current meter was placed at 0.05 m above the bed, except at the last point near the coast, where the distance was reduced to 0.03 m.

5. INCIDENT WAVE CONDITIONS

The wave generator is of the piston type and each paddle is controlled independently by a hydraulic system. The paddle control signal is generated by a program that uses the white noise filtering technique described by Gilbert and Huntington (1991). This method can only be used for waves that are perpendicular to the generator. With oblique waves, the superimposed sinusoidal wave method must be used. During this study, only frontal waves were generated with the white noise filtering technique. 17 wave conditions were selected in order to cover a wide range of steepness values and frequency and direction spectrum widths.

The spectra generated were of the form:

$$S\,(f, \Theta) = S_\gamma(f) \cos^n \Theta \qquad (2)$$

$S_\gamma(f)$ corresponds to the Jonswap spectrum dependent on the parameter γ, with a value of 3.3 or 7. The angular distribution function depends on the exponent n, which has the value 2 or 6 in this case. Table no. 1

lists the theoretical incident wave conditions. Wave measurements in front of the generator gave values between 0.95 and 1.15 times the set height. No adjustment was made to correct these deviations.

Each wave condition was generated by identical repetitive cycles. A cycle had a period equal to 260 times the peak period, corresponding to about 320 waves. Repeatability of the waves was found to be very good at the fixed offshore gauges (variance less than 1% in most cases).

	Hs (mm)	Tp (s)		n		Hs (mm)	Tp (s)		n
Monochromatic	40	1.25			Unidirectional	80	1.25	7	
Unidirectional	40	1.25	3.3		Multidirectional	80	1.25	7	6
Multidirectional	40	1.25	3.3	2	Monochromatic	100	1.25		
Unidirectional	40	1.976	3.3		Unidirectional	100	1.25	3.3	
Multidirectional	40	1.976	3.3	6	Unidirectional	100	1.25	7	
Monochromatic	70	1.25			Multidirectional	100	1.25	3.3	2
Unidirectional	70	1.25	3.3		Unidirectional	100	1.976	3.3	
Multidirectional	70	1.25	3.3	6	Unidirectional	130	1.60	3.3	
					Multidirectional	130	1.60	3.3	2

Table 1 Incident wave conditions

6. TEST PROCEDURE

This comprised three main phases, as described below:

Preparation of the test: The water surface at rest was measured at each measurement point in order to determine the reference level for subsequent calculation of the set-up and mean rip current. This procedure was essential as the gauges were submerged at different depths from one measurement line to another so as to be adapted to decreasing water depths. The generator was then started up and allowed to run for about 15 minutes in order to achieve a stable rip current pattern.

Measurements: Measurements were made simultaneously on the 13 channels over a period equal to one generation cycle (i.e. about 320 waves) with a frequency of between 20 and 25 Hz depending on the peak period. The trolley was then moved to the following measurement line and the gauges submerged at a suitable level for the water depth in this new position. These operations were repeated seven times during each test, without stopping the generator. They lasted about three hours.

End of test: At the end of the test, all the measurements were checked and any incidents during acquisition noted. Certain tests were repeated when serious incidents had occurred. An initial statistical analysis of measurements from the fixed gauges was also made to check the reproducibility of the wave conditions during the test. The recorded data were then stored on magnetic tape, translated into ASCII and stored on PC-compatible floppy disks.

7. STANDARD DATA PROCESSING

The mean values from each measurement point were first of all calculated by comparison with the measurements at rest. The set-up and mean current values were estimated in this way.

Standard processing then involved performing a statistical analysis of all the recordings. The main characteristics ($H_{1/3}$, $H_{1/10}$, H_{max} and associated periods and H_σ) were then gathered in the summary tables shown in the complete report (Hamm, 1992).

Graphic representation of these values revealed acquisition anomalies on certain channels. Generally speaking, the checks carried out showed that 90% of the measurements were reliable. Figures 2 to 4 show examples of the results obtained for three series of tests. These figures show a comparison between the significant wave height values ($H_{1/3d}$) and an estimate made on the basis of the variance of the free-surface elevation (H_σ) for unidirectional and multidirectional waves.

These figures are divided into four parts, designated a) to d). Figures a) present the results obtained on the plane beach and b) those obtained in the centre line of the rip channel. Figures c) give the mean rip current measured near the bed in the centre line of the channel. Lastly, figures d) recall the bed contour profiles. It can be seen that there is little difference between $H_{1/3}$ and H_σ except in the case of waves with low steepness (fig. 2) in the surf area. Similarly, there is little difference between unidirectional and multidirectional wave cases. This result appears a little surprising at first, in the presence of the channel, as the rip current tends to generate wave concentrations which should be more attenuated in the case of a multidirectional wave (Vincent and Briggs, 1989). Indeed, the opposite trend may be observed on figure 3b). This may be due to the breaking process.

Figures 5a) and b) give an overall view of the wave heights measured in the case of waves of low steepness. Figure 5a) shows an abnormal value along the channel centre line (line D), which had already been observed on figure 2a). These abnormal results are currently being analysed.

8. SPECTRUM ANALYSIS

Measurements with the wave direction gauge were subjected to a conventional spectrum analysis and directional spectrum analysis using the maximum entropy method (MEM) published by Sand and Mynett (1987). This method is one of the most accurate currently available (Benoit, 1992). However, it is not always easy to interpret the results (Van de Meer, 1990) and detailed analysis is currently in progress.

By way of example, figure 6 shows the frequency spectra obtained with unidirectional waves of low steepness in front of the generator and in the surf zone on the plane beach and in the channel centre line. The results are comparable and show a classic type of evolution with the development of sub- and super-harmonics during propagation towards the coast.

Figures 7 and 8 show the change in directional spectrum for these same waves between offshore and the coast, on the plane beach. There is similarity with the change in frequency spectrum observed previously and a marked narrowing of the directional distribution.

9. GENERAL COMMENTS AND CONCLUSIONS

The tests presented here represent a valuable data set for validating numerical models of wave transformation and rip current generation. The huge amount of data is still under analysis and the first results presented here tend to show that the directional spreading does not seriously affect the magnitude of the return current and the significant wave heights.

On the other hand, in spite of the large number of recording points (53), the impression given is one of a fairly loose measuring network, particularly in the channel. Indeed, the instability of the rip current could be observed visually in most of the tests. This is clearly demonstrated by the dissymmetry of the wave crests on either side of the channel centre line, and in particular a shift in the breaking point, which varied with time. A denser measuring network would have been needed to quantify this instability. A possible alternative, which is currently being tested, would be to use a video technique of the type used in the field by Holman and Lippmann (1991) in addition to the conventional isolated measurements.

10 ACKNOWLEDGEMENTS

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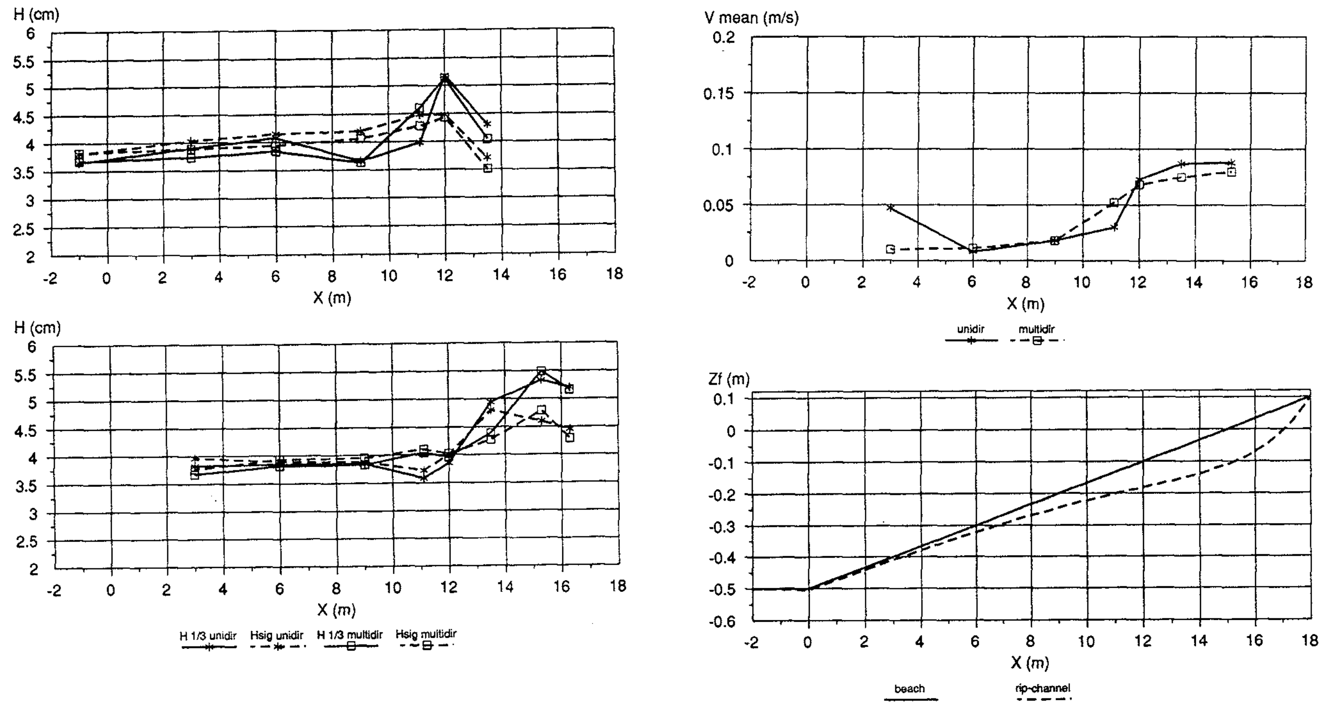


Fig. 2 Experimental results. $H_s = 0.04$ m - $T_p = 1.976$ s

a. Wave heights along the plane beach profile

b. Wave heights along the rip channel axis

c. Mean return current near the bottom in the channel axis

d. Beach and rip channel profiles

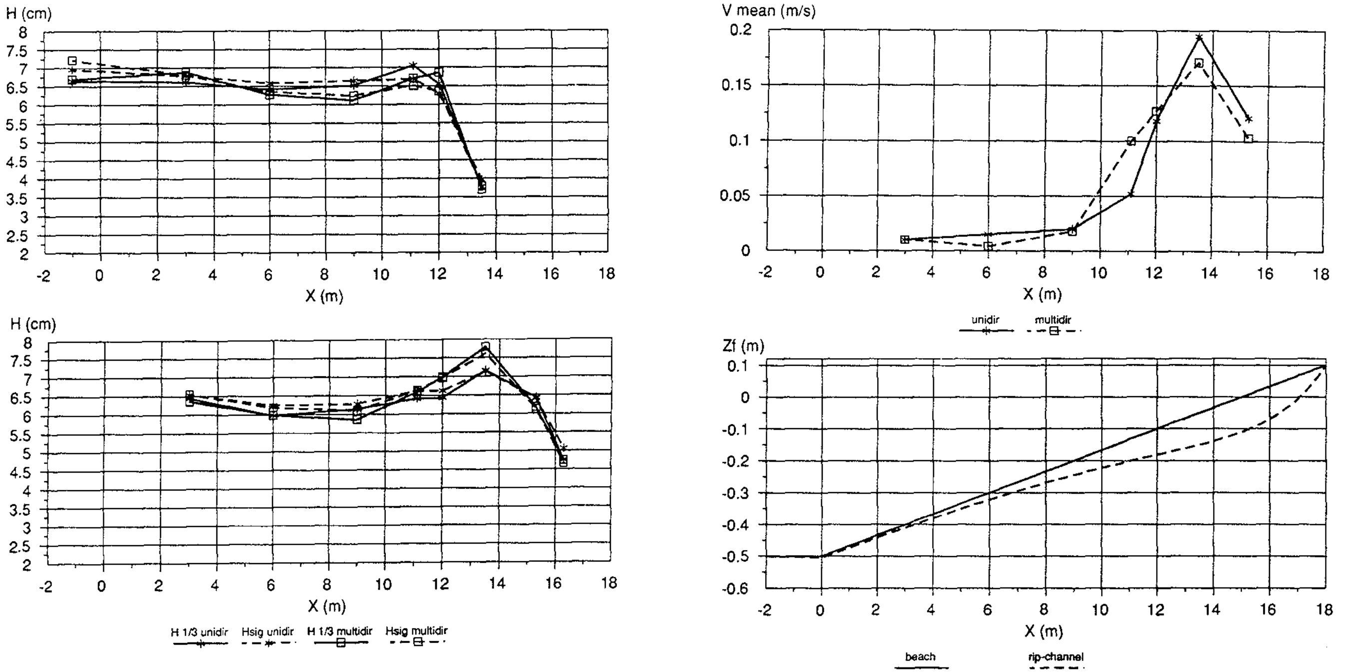


Fig. 3 Experimental results. $H_s = 0.07$ m - $T_p = 1.25$ s
a. Wave heights along the plane beach profile
b. Wave heights along the rip channel axis
c. Mean return current near the bottom in the channel axis
d. Beach and rip channel profiles

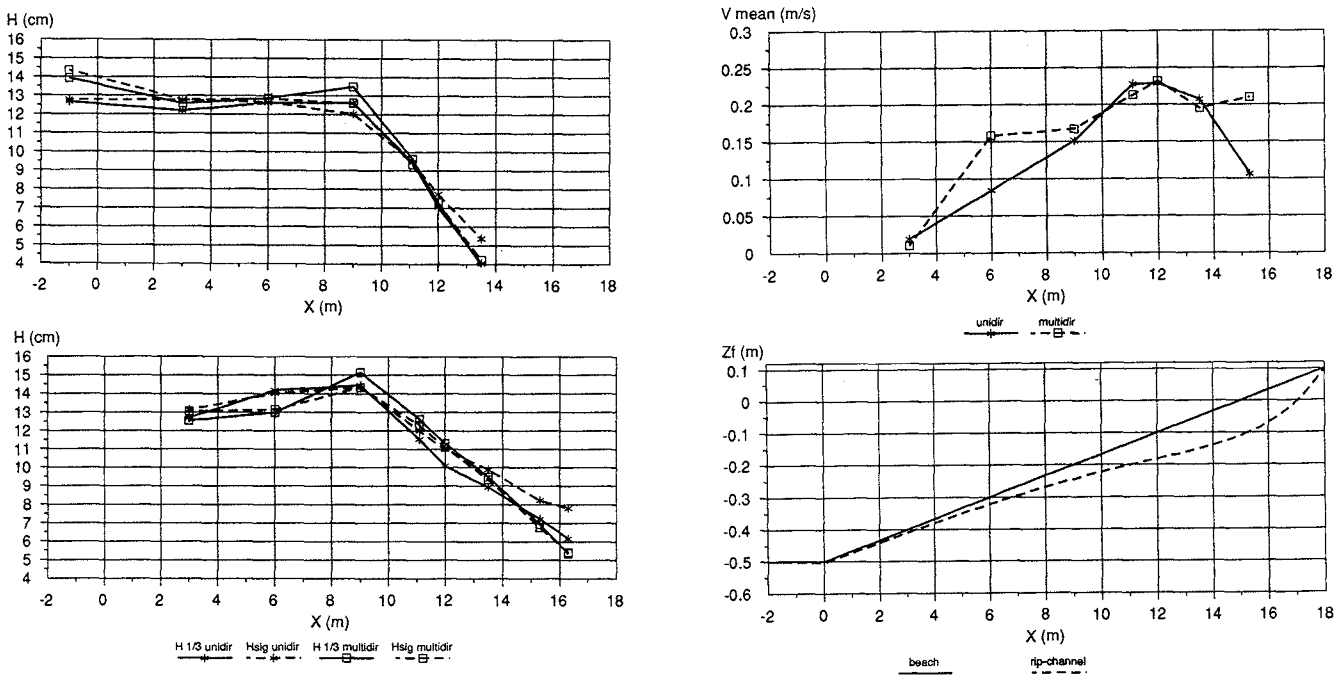


Fig. 4 Experimental results. $H_s = 0.13$ m - $T_p = 1.60$ s
a. Wave heights along the plane beach profile
b. Wave heights along the rip channel axis
c. Mean return current near the bottom in the channel axis
d. Beach and rip channel profiles

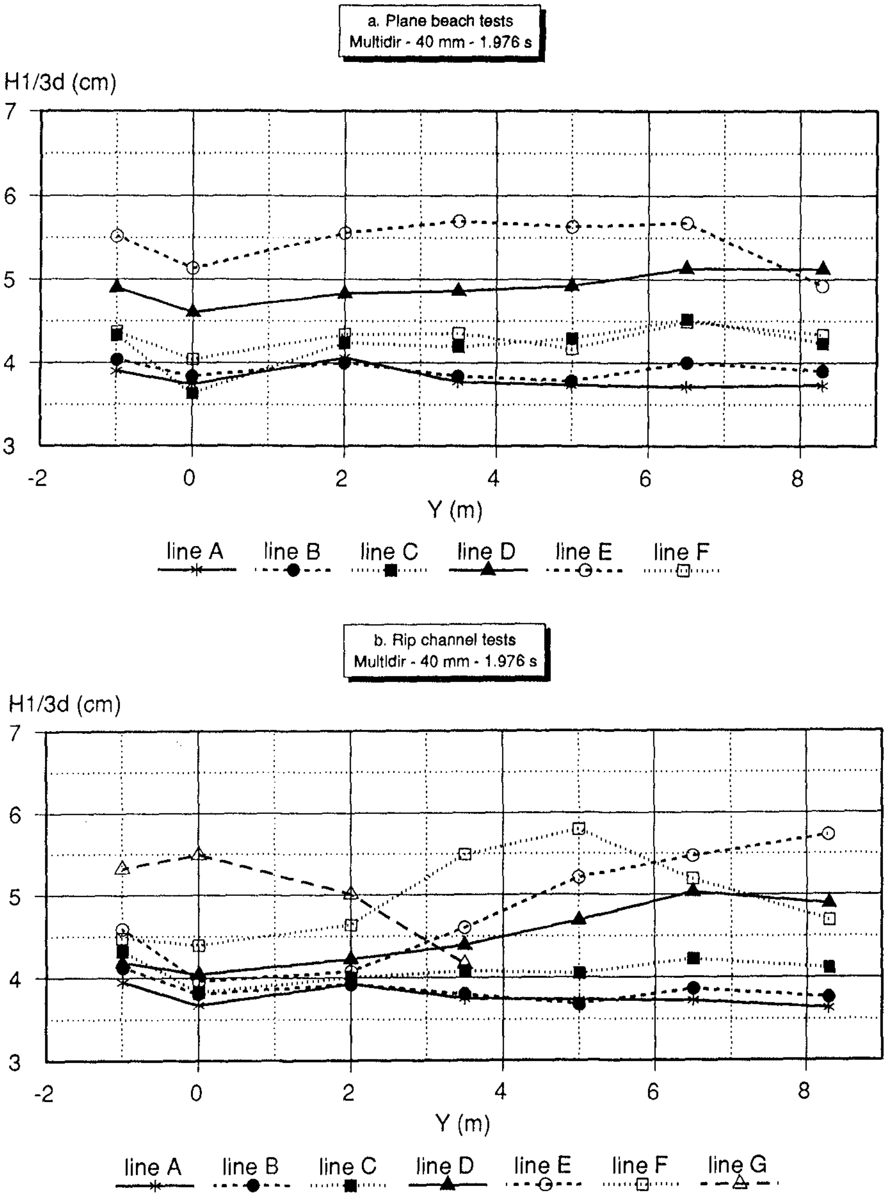
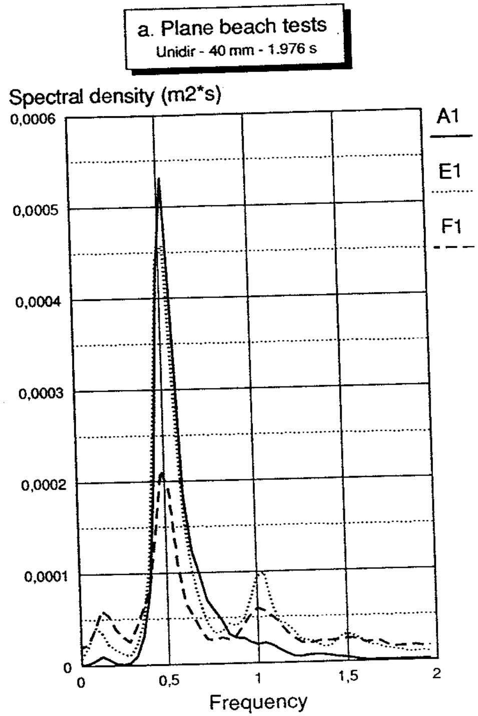


Fig. 5 Wave heights along transversal sections. H_s = 0.04 m - T_p = 1.976 s
Multidirectional incident spectrum
a. Plane beach test b. Rip channel test



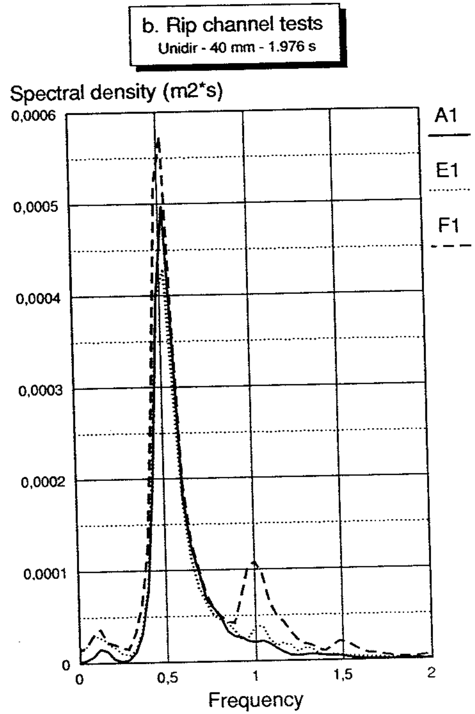
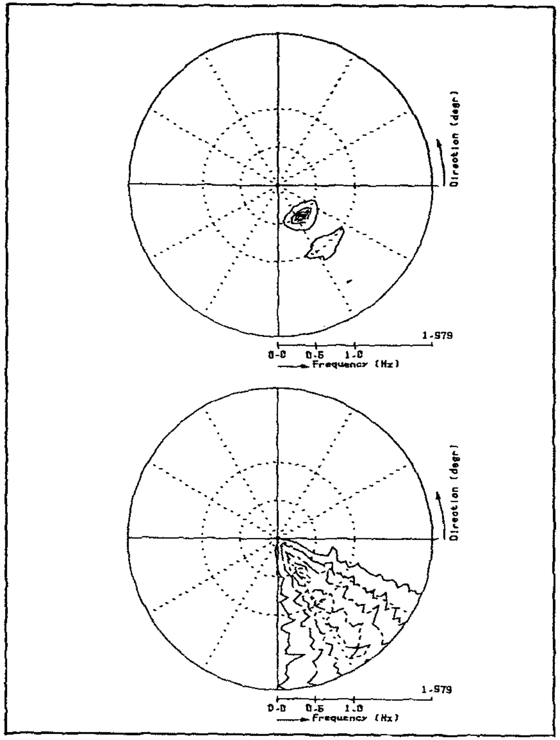


Fig. 6 Frequency spectra at three points along the channel axis
$H_s = 0.04$ - $T_p = 1.976$ s. Unidirectional incident spectrum.
a. Plane beach test b. Rip channel test

Fig. 8 Directional spectra on the plane beach. Surf zone condition (point G1). $H_s = 0.04$ m - $T_p = 1.976$ s.
a. Equidensity curves (10 - 30 - 50 - 70 - 90%) of the spectral density
b. Equidensity curves of the spreading function →



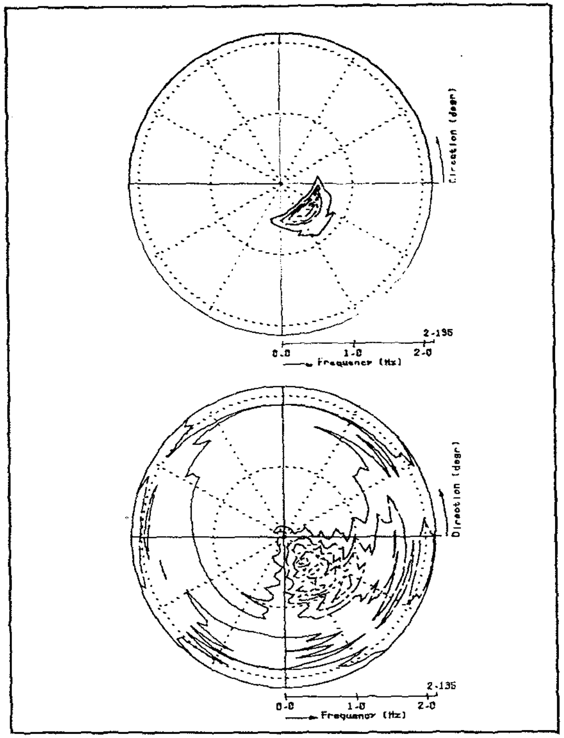


Fig. 7 ← Directional spectra on the plane beach. Offshore condition (point A1). $H_s = 0.04$ m - $T_p = 1.976$ s.
a. Equidensity curves (10 - 30 - 50 - 70 - 90%) of the spectral density
b. Equidensity curves of the spreading function