CHAPTER 62

REALIZABLE WAVE PARAMETERS IN A LABORATORY FLUME

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ABSTRACT

In order to establish a sound basis for the methodology deployed for the generation of realistic waves under laboratory conditions, a comparison is presented between numerical and physical realizations derived from the Random Phase and the Random Complex Spectrum method for wave synthesis. The comparisons are made in terms of 12 critical wave parameters, including three wave grouping parameters. The results indicate that, for the physical realizations of the limited conditions tested, the two methods give compatible results which fall within the expected band of variability. All physical waves undergo some evolutionary change during propagation which affects predominantly the spectral characteristics. For physical waves produced by the Random Phase method, this change increases the variability of some wave parameters. A sample analysis of one case, applying second order wave and wave generation theory to a numerical simulation, suggests that certain differences between numerical and physical simulations can be explained by non-linear wave theory.

INTRODUCTION

For the laboratory evaluation of designs for coastal and offshore structures, it is common practice to simulate wave trains which satisfy a given variance spectral density. This simulation can be achieved through a variety of synthesis techniques. Among these are two commonly used Fourier techniques which have been referred to as the Random Phase method (RPH) and the Random Complex Spectrum (RCS) method (Mansard & Funke, 1986). The RPH method is a spectrally deterministic technique whereas the RCS method is spectrally non-deterministic.

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Both the RPH and the RCS methods are based on the inverse Fourier transform of a given target spectral density. In the case of the RPH method, the square root of the given spectral density (i.e. the amplitude spectrum) is paired with a randomly selected phase spectrum. From this a complex spectrum is produced which is then inverse Fourier transformed to produce a time series of the synthesized wave train. Different random selections of the phase spectrum will produce different time series. If any one of these time series is spectrum analyzed, the spectral density so produced will be smooth and match the target spectrum.

In contrast, the Random Complex Spectrum method creates a situation in which the specified distribution of energy in the frequency domain is preserved only within the bounds of probability. It consists of generating a Gaussian distributed white noise complex spectrum which is then filtered by multiplication with the desired amplitude spectrum. The complex product is then inverse Fourier transformed. Individual time series realizations from this synthesis will produce spectra which are not smooth because of the variability of spectral estimates. Only the average of a large number of sample spectra will match the target spectrum.

Each of the above two methods have their own proponents who justify their use in physical models. However, some controversy has arisen around the question of validity of the RPH method (Tucker et al. 1984, Elgar et al 1985, and Medina & Aguilar, 1985). The essence of the criticism is the claim that the RPH method produces insufficient variability of wave parameters and therefore does not represent nature correctly. One wave parameter of concern is wave grouping.

Perhaps the most important comment which can be made at this point, is that the differences are only noticeable for relatively short wave-record lengths. As the length of a synthesized, non-repetitive time series approaches infinity, the two methods are absolutely identical. Evidently, in practice, one cannot make simulations infinitely long. Any meaningful simulation must be carried out over a finite duration of time and that is where one finds the source of the present problem.

The second point which must enter into the consideration is the question of how well numerical simulations represent the conditions which actually prevail in wave flumes for physical model studies. Although, for modern wave generation systems, the numerical synthesis of a wave record forms the input to the control system of the wave machine, the wave train measured in the flume at different locations, may not carry the same statistical characteristics of its progenitor. Linear wave generation has its own way of affecting a simulation. As long as physical model studies are an essential part of our research and design engineering repertoire, this question is relevant.

Mansard and Funke (1986) carried out a numerical study to evaluate the differences in simulations caused by these two techniques. By varying the random numbers used in the synthesis, 200 different realizations of a 200 second long time series were simulated numerically from a given target spectrum with a peak frequency of 0.55 Hz. At a scale of 1 in 36, this record length corresponds to a full scale sample duration of 20 minutes, which is a typical record length for full scale wave measurements. The resulting series contained approximately 110 waves and were subjected to several frequency and time domain analyses. Twelve different parameters were computed and then assembled into independent wave parameter lists for subsequent statistical analysis.

The results of the study showed that the differences between the RPH method and the RCS method, in terms of the selected parameters, are small, even for these relatively short wave records. This conclusion was based on a statistical analysis of average, standard deviation as well as maxima and minima of the twelve parameters, computed for 200 realizations of each case.

When waves are produced in a laboratory flume for simulation purposes, it is common practice to adjust the wave generator stroke gain until the waves produced have the specified significant wave height; a condition generally specified by the client. However, waves synthesized by the RCS method must be expected to exhibit variability of variance from record to record, and as a result the significant wave height will also show variability. By adjusting the wave machine stroke gain, one does intervene in the natural process. For the study by Mansard and Funke (1986), each record was rescaled so as to fix the variance of each wave record to that specified in accordance with laboratory practice. On the other hand, in the study presented here, the simulations with the RCS method are performed in two ways, once with rescaling and once without rescaling.

The 1986 study was restricted to only 12 wave parameters which were considered important at that time. This investigation, however, looked at a total of 27 wave parameters, 12 of which are included in this publication. The remainder are to be published in a separate report later. The study presented here complements the 1986 study and, furthermore, adds insight into the question of physical realizability.

EXPERIMENTAL SET-UP

The experimental set-up is shown in Figure 1. Experiments were carried out in a flume of dimensions 1.2 x 1.2 x 67 m. Waves were generated in a depth of 0.7 m and were monitored at a distance of 8.7 m and 25.3 m from the paddle. An effective dissipation of the incident energy was ensured by a mildly sloping permeable gravel beach (1:25 slope) designed to minimize the reflection of long wave components. Previous evaluation of a beach of this type indicated that its average reflection coefficient can be expected to be below 5% for the frequency band from 0.3 Hz to 1.3 Hz.

The wave generator was operated in the piston mode. Much care was used in its calibration to ensure that the wave paddle excursions corresponded to the theoretical values. All wave generation was carried out with the application of linear wave generation theory.

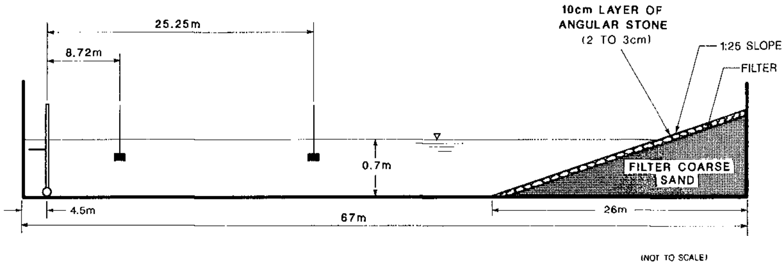

FIGURE 1

SKETCH OF THE EXPERIMENTAL SET-UP

Repeatability tests were carried out on several specimen wave records. The following table gives repeatability values for four different parameters.

TABLE I

Repeatability Results over 22 Tests at x = 8.7 m

	% AVERAGE ABSOLUTE DIFFERENCE	% MAXIMUM DIFFERENCE
H_{m0}	0.64	1.3
$H_{1/3}$	1.00	2.6
H_{max}	1.48	3.1
GF	0.83	3.1

TEST CONDITIONS

The investigation described here was limited to a JONSWAP target spectral density with a peak frequency f_p = 0.55 Hz, a peak enhancement factor γ = 3.3, and a significant wave height H_{m0} = 0.15 m.

From the target spectral density, a total of 600 time series were generated using both the RPH and the RCS methods of wave synthesis, i.e.

- 200 time series using the Random Phase method,
- 200 time series using the Random Complex Spectrum method, and
- 200 time series using the Random Complex Spectrum method, with the record variance rescaled to the target value of the variance.

Measurements for physical model tests were initiated after the wave trains had stabilized in the tank. This involved generally a waiting period of 3 minutes after wave generation commenced. Following each test, the tank was allowed to settle before a new test was started. The measurement duration was fixed to be identical to the recycling period of the synthesized wave trains.

ANALYSIS

The measured water surface elevations for each of the 600 tests were subjected to several conventional and non-conventional analyses. Spectral density analysis was used to demonstrate that the target spectra were achieved with adequate fidelity. Figure 2 gives eight samples of these, two pairs for the RPH and two for the RCS methods. The spectra shown correspond to measurements taken at 8.7 m and 25.3 m.

Twenty-seven different spectral and time domain wave parameters were computed. Of these twelve are presented here. These are:

f_p the peak frequency as determined from the frequency at which the spectral density is a maximum,

f_{pD} the peak frequency as determined by the Delft method (IAHR List of Sea State Parameters),:

$$f_{pD} = \frac{\int_{f1}^{f2} f \cdot S_\eta(f)\ df}{\int_{f1}^{f2} S_\eta(f) \cdot df}$$

where f1 is the first and f2 is the last crossing of a threshold that is 80% of the spectral peak value.

$H_{1/3,d}$ the significant wave height by zero down-crossing analysis,

$H_{max}/H_{1/3}$ the ratio of the maximum and the significant wave height as computed from zero down-crossing analysis,

$\overline{s}_{z,d}$ the average steepness of all waves as computed from zero down-crossing analysis. This is given as:

$$\overline{s}_{z,d} = (1/N)\ \mathrm{SUM}[H_i/L_i] \text{ for } i=1,N$$

where H_i and L_i are the ith down-crossing wave height and wave period respectively.

$\overline{s}_C'$ the average crest front steepness as computed from zero down-crossing analysis (Kjeldsen & Myrhaug 1979). This is defined as:

$$\overline{s}_C' = (1/N)\ \mathrm{SUM}[a_{C,i}/L'_i]$$

where $a_{C,i}$ and L'_i are the ith wave crest and wave crest front length respectively.

$\overline{\mu}_H$ the average horizontal asymmetry as computed by Kjeldsen & Myrhaug (1979),

$$\overline{\mu}_H = (1/N)\ \mathrm{SUM}[a_{C,i}/H_i] \text{ for } i=1,N$$

where $a_{C,i}$ and H_i are the ith wave crest and wave height respectively.

$\overline{\mu}_V$ the average vertical asymmetry. This parameter differs from that given by Kjeldsen & Myrhaug (1979) and is based on a definition suggested by Goda (personal communication), i.e.

$$\overline{\mu}_V = (1/N)\ \mathrm{SUM}[L_i'/(L_i'+L_i'')] \text{ for } i=1,N$$

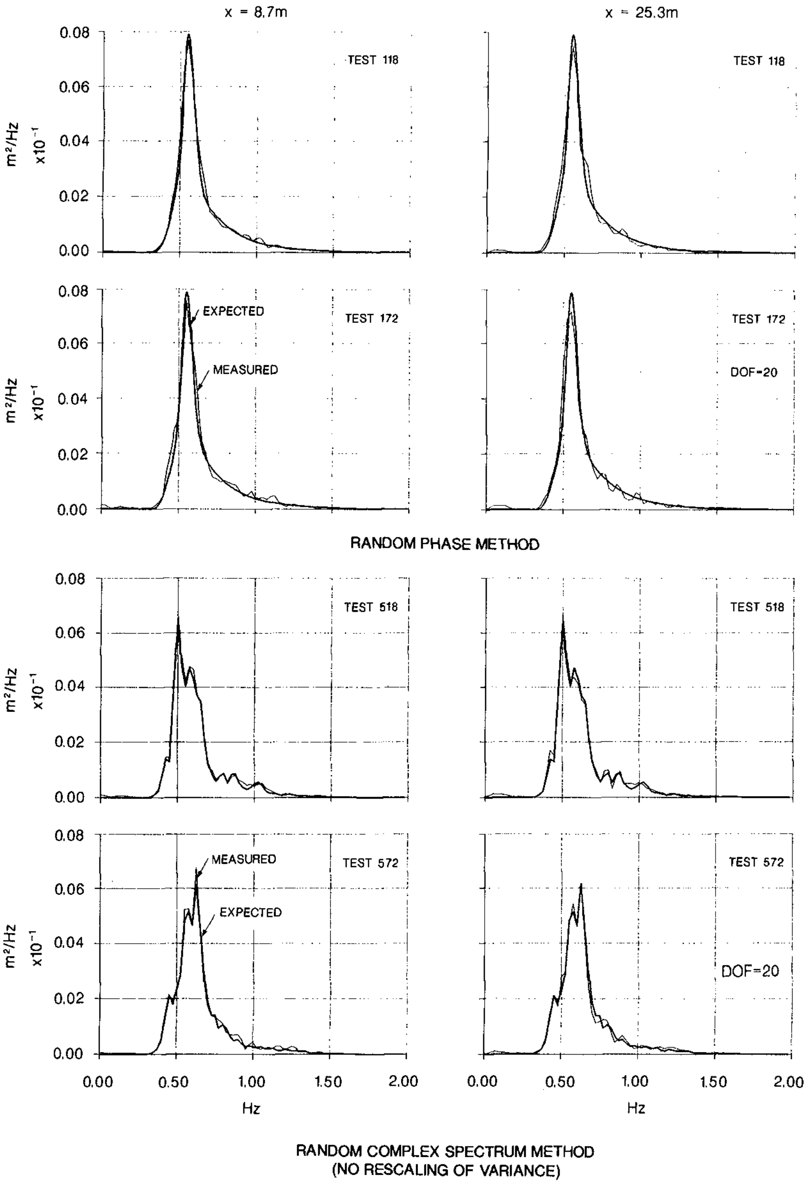

FIGURE 2

REALIZATIONS OF SPECTRAL DENSITIES IN A LABORATORY FLUME

(Hm_0=0.15m fp=0.55Hz γ=3.3)

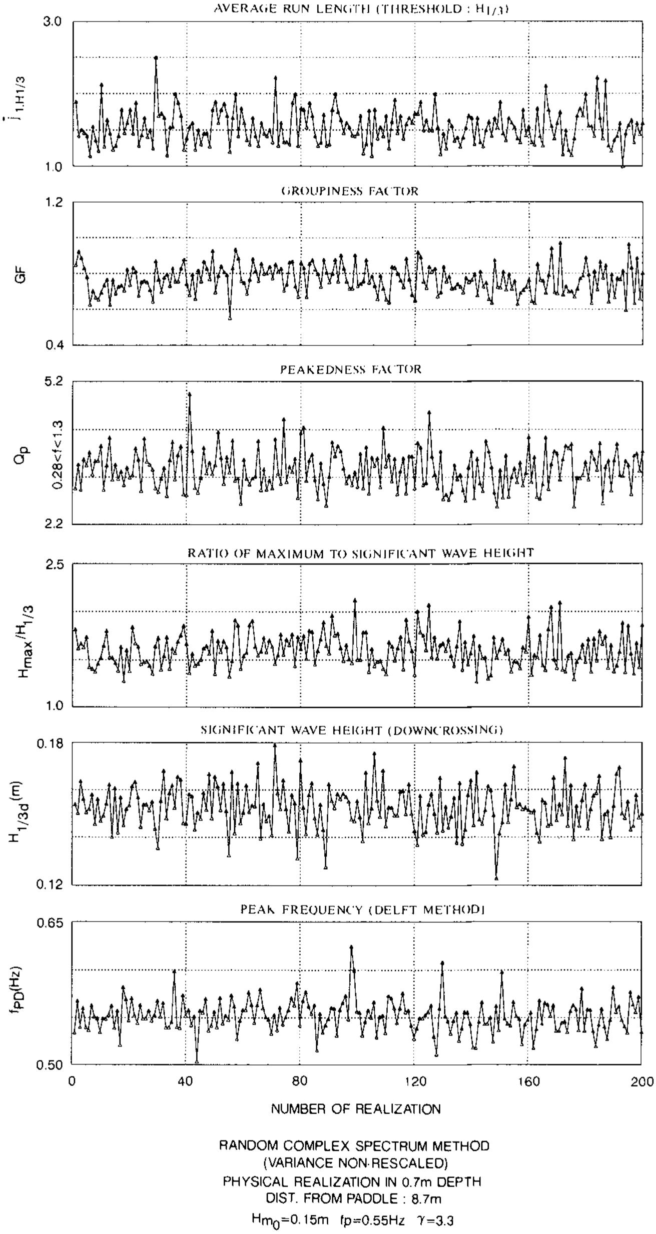

FIGURE 3

STATISTICAL VARIABILITY OF WAVE PARAMETERS

where L_i' and L_i'' are the ith crest front and crest rear wave lengths respectively. However, as Kjeldsen has pointed out (personal communication), this parameter can be expected to assume the value 0.5 under normal laboratory conditions and in the absence of wind and current.

Q_P the Goda peakedness factor (Goda, 1985). This is given as:

$$Q_p = (2/m_0^2) \int_{f2}^{f1} f \cdot S_\eta^2(f) \cdot df$$

where f1 = 0.28 and f2 = 1.38 Hz.

GF the SIWEH groupiness factor (Funke & Mansard, 1979). This is given as:

$$GF = \sqrt{m_{0,E} / m_0}$$

where $m_{0,E}$ is the zeroth moment of the groupiness spectrum.

$\bar{j}_{1,\bar{H}}$ the average run length of waves greater than the average wave height $\bar{H}_d$, as computed from zero down-crossing analysis (Goda, 1976), and

$\bar{j}_{1,H1/3}$ the average run length of waves greater than the significant wave height $H_{1/3,d}$, as computed from zero down-crossing analysis (Goda, 1976).

The chosen wave parameter values from each wave record were assembled in ordered lists, some of which are illustrated graphically as time series in Figure 3 for the case of a physical realisation of a non-rescaled, RCS method synthesized waves as measured 8.7 m from the wave board.

The lists of wave parameters were then subjected to statistical analysis to yield the average, the standard deviation, the maximum and the minimum values.

RESULTS

In order to facilitate comparison, the results of the analysis are presented in graphical form in Figures 4a, 4b and 4c. These are given in terms of the mean, the extrema, as well as the mean + and - one standard deviation. For each parameter the results are placed in three separate groups, i.e.

- results from the RPH method of synthesis,
- results from the RCS method of synthesis but rescaled to force the target variance on each wave record, and
- results from the RCS method of synthesis but without rescaling.

Then, for each group, results are again shown separately for:

- numerical synthesis only,
- a physical realization of the numerical synthesis as measured at 8.7 m from the wave board, and
- a physical realization of the numerical synthesis as measured at 25.3 m from the wave board.

DISCUSSION OF RESULTS

The main conclusions of the study are as follows:

- As could be expected the numerical realizations of the RPH method have no variability for the parameter f_p, and very little variability for f_{pD} and Q_P. In the case of the last two parameters, the small amount of variability must be attributed to computational noise.

- When a wave record synthesized by the RPH method is converted to a physical wave in a wave flume, then the variability of the f_p, f_{pD} and Q_P parameters increases, but will not equal the variability achieved by the RCS method.

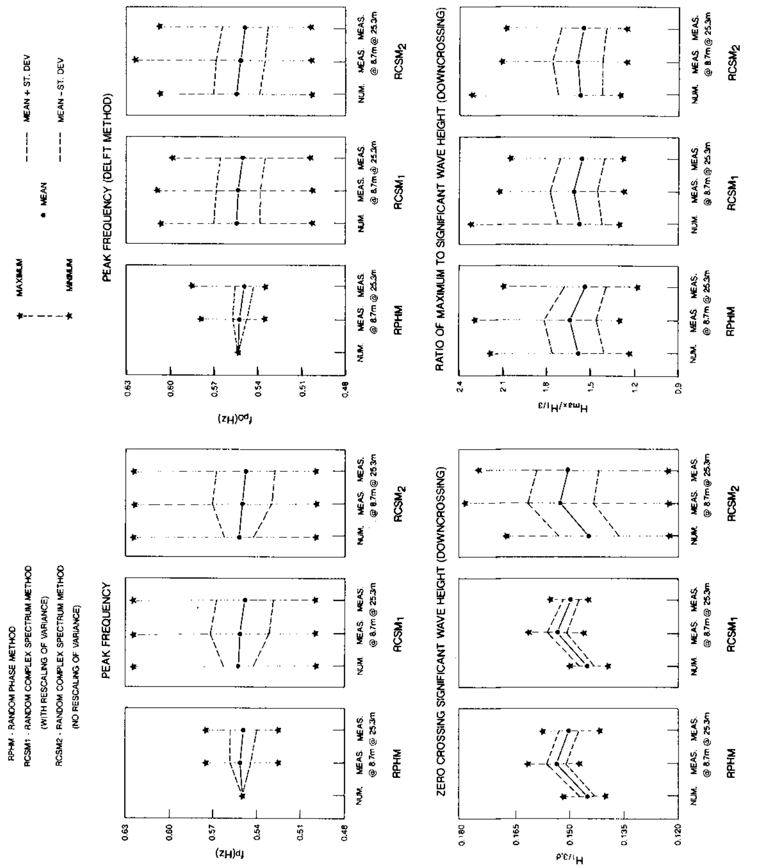

FIGURE 4a.
STATISTICAL VARIABILITY OF WAVE PARAMETERS

- The mean value and the variability of the parameter $H_{1/3,d}$, as derived by the RPH and the rescaled RCS methods, are almost identical.

- As could be expected, the variability of $H_{1/3,d}$ is significantly larger for the non-scaled RCS than for the rescaled RCS method.

- The following parameters exhibit little differences between the RPH and the RCS method:
  - o $H_{max}/H_{1/3}$ the ratio of the maximum and the significant wave height,
  - o $\overline{\mu}_H$ the average horizontal asymmetry,
  - o $\overline{\mu}_V$ the average vertical asymmetry,
  - o GF the SIWEH groupiness factor,

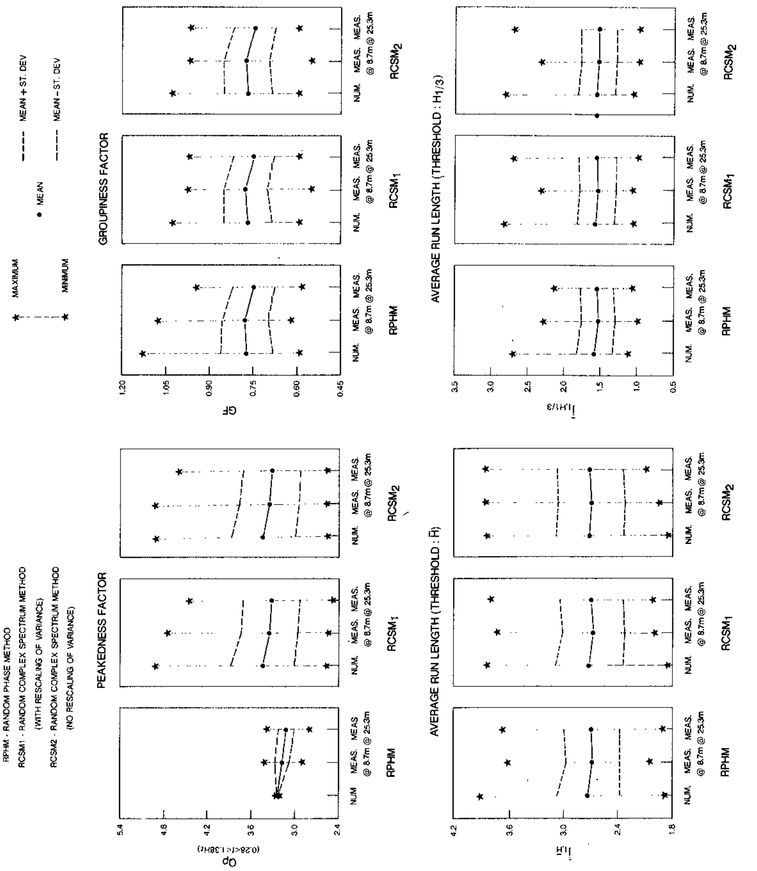

FIGURE 4b.
STATISTICAL VARIABILITY OF WAVE PARAMETERS

- $\mathfrak{j}_{1,\bar{H}}$ the run length of waves higher that the average wave height, and
- $\mathfrak{j}_{1,H1/3}$ the run length of waves higher than the significant wave height.

This favourable comparison with regard to wave grouping diminishes one of the concerns expressed by Tucker et al. (1984).

- the conversion of a numerical simulation into a physical realization has a remarkable impact on several parameters whose definition depend on the wave crest. From this it can be concluded that, for the conditions which prevailed for the test under study, the crest

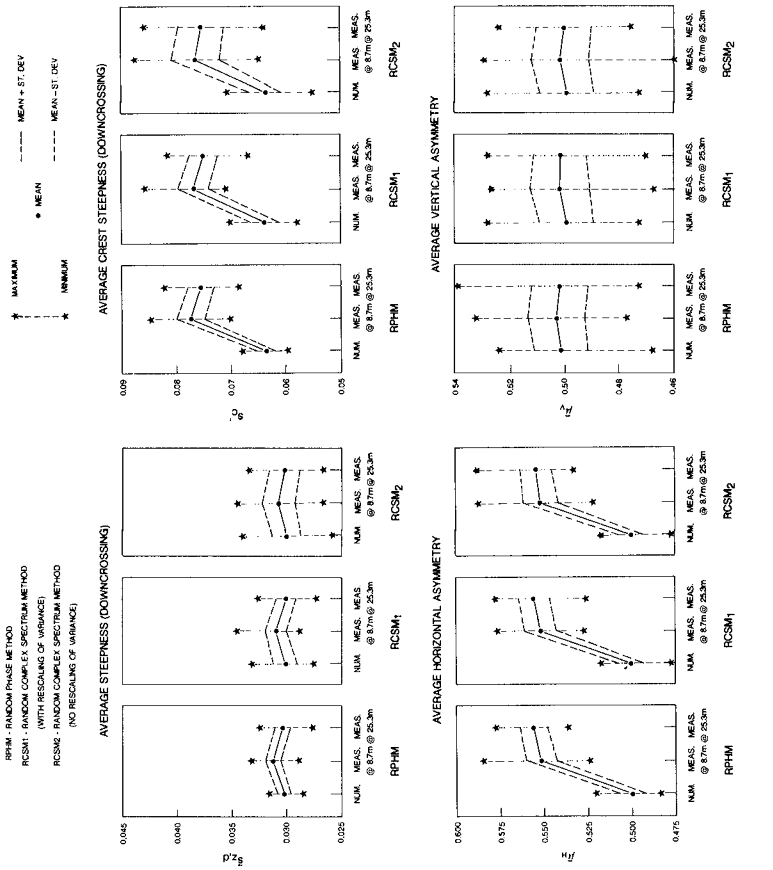

FIGURE 4c.
STATISTICAL VARIABILITY OF WAVE PARAMETERS

heights in physical simulations are greater than those obtained by numerical simulations. These parameters are:

- $H_{1/3,d}$ the significant wave height by zero crossing analysis,
- s'_C the crest front steepness, and
- $\bar{\mu}_H$ the average horizontal asymmetry.

- There is no significant difference in the average vertical asymmetry $\bar{\mu}_V$ between numerical and physical simulations in the absence of wind and currents. In other words, the physical waves are, on the average, symmetrical.
- In general, the differences between the RPH and the RCS methods are small for physical simulation. In fact, it can be seen that there is almost as large a difference between two records selected at random from one method than there is between records selected from the two different methods.
- There is no apparent relationship between the wave run length parameter and the SIWEH groupiness factor. Both evidently measure different aspects of the wave grouping phenomenon. This is apparent from Figure 3.

To further investigate the differences between numerical and physical simulations, an attempt was made to reconstruct one wave train through the application of second order effects. As stated above, the conversion of numerical simulations to physical realizations was undertaken by means of linear wave generation theory. By applying second order wave and wave generation theory to one of the numerical simulations, it was possible to calculate the second order wave components which were naturally locked to the wave and those which were inadvertently produced because of the first order approximation. These were predicted for the one case at the two probe positions (Barthel et al 1983, Sand & Mansard, 1986).

A comparison is made in Figure 5 between this second order reconstruction and the corresponding wave trains measured. From this it is apparent that most of the differences between numerical and physical simulations are predictable. This result also suggests that numerical simulations for wave conditions in the coastal zone should be carried out with the inclusion of second order effects.

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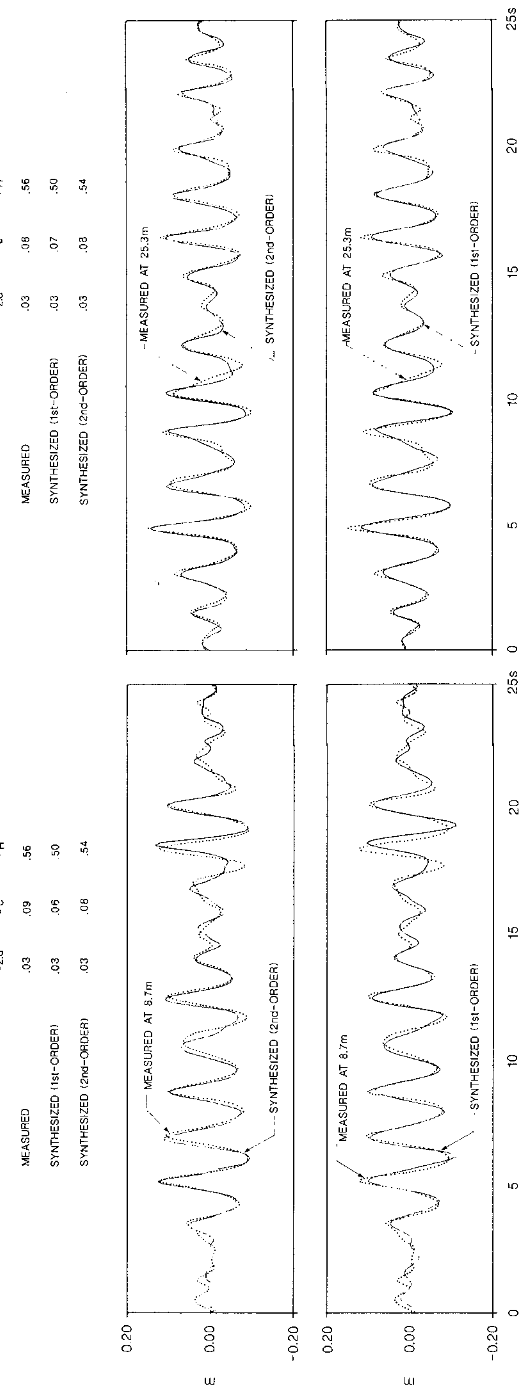

FIGURE 5
COMPARISON BETWEEN MEASURED AND SYNTHESIZED WAVE PROFILES

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