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# Wave Kinematics in a Groin Field—Time Domain Analysis

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**ABSTRACT**

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The time histories of wave elevation and the two horizontal in line and transverse velocity components measured in a groin field were subjected to time domain analysis. The variation of the wave and velocity characteristics with respect to the time of measurement at a particular location and its variation at different locations within the groin field at a particular instant of time are presented and discussed in detail in this paper. In addition, the validation of the linear theory in predicting the wave kinematics in the direction of the wave propagation from the measured wave elevations is examined on assumption that wave directional variability is small. Such investigations for the nearshore zone are scanty especially for a groin field.

ADDITIONAL INDEX WORDS: *Wave climate, kinematics, application of linear theory, groin field.*

## INTRODUCTION

The prediction of the wave kinematics in the nearshore is important in the study of coastal sediment transport and to understand the flow field. This information sometimes becomes very essential in the planning and the design of shore defense works. The linear theory has been applied for deriving fluid particle kinematics for deep waters satisfactorily (REID, 1957).

This has been followed up by several investigators in modifying the linear theory for the prediction of wave kinematics in the nearshore where the waves are quite nonlinear and their characteristics are being influenced by phenomena like shoaling, cross currents and surf beat. The problem becomes still more complicated if one is interested in predicting the kinematics inside a groin field.

The present investigation deals with the analysis of waves and orbital velocities measured in a groin field of the East Frisian Island of Norderney at the Southern North Sea Coast, the location map is presented in Figure 1. The groin field along with the locations of measurement M1, O1, W1, M2, O2, W2, M3, O3 and W3 are presented in Figure 2a and b. The sea bed profile of these locations is shown in Figure 2c.

Time histories of the water surface with pressure gauges and with two horizontal inline and transverse velocity electromagnetic current meters were measured simultaneously. The details of the measurement programme have been discussed by NIEMEYER (1990). The results of the analysis reported in this paper pertain to the data collected from 7 November 1988 to 22 November 1988. About twenty five records were considered for a particular location for analysis.

The wave and the velocity records of length 1200 sec, with a sampling interval of 0.17 sec, from the different locations were subjected to detailed analysis. Though both spectral and statistical methods have been employed, only the results of the statistical methods are discussed in this paper. Probabilistic approaches in addition to the average wave and velocity characteristics have been carried out. The time series of inline velocity have been predicted with the measured wave elevation time history using linear wave theory and the comparison between predictions and measurements are herein reported. The data for location W2 alone could not be obtained since the sensors at this location failed.

## BACKGROUND

Measurement and analysis of currents in the open sea have been reported by several investigators. Notable are the studies reported by OCHI and MCMILLEN (1988), FORRISTALL (1986), VAN HETEREN and STIVE (1984), GUZA and THORNTON (1980), MIZUGUCHI *et al.* (1980), and BATTJES and

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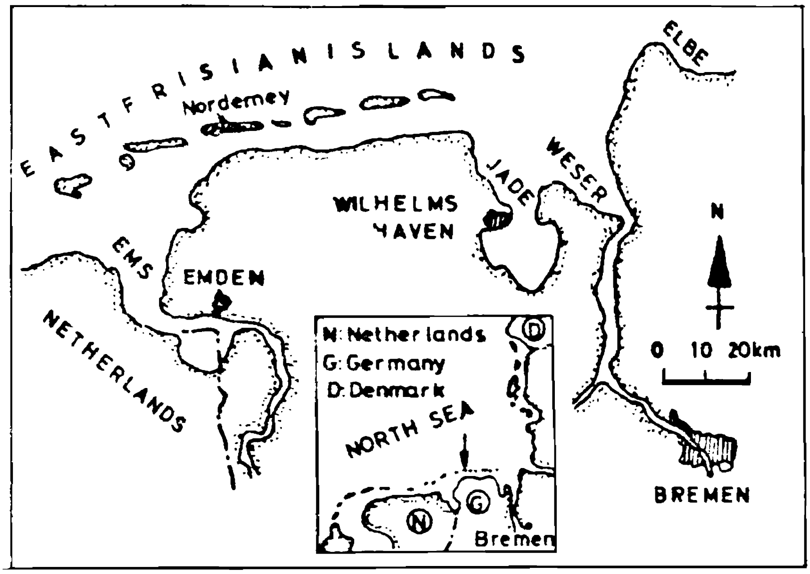


Figure 1. Location map of the island of Norderney.

VAN HETEREN (1980). Similar studies have been carried out in the laboratory by ADEYEMO (1970), IWAGAKI *et al.* (1973), VIS (1980), and DAEMRICH *et al.* (1980).

It was concluded by DAEMRICH *et al.* (1980) that the prediction of the water kinematics by linear theory is good. IWAGAKI *et al.* (1973) and ISHIDA and IWAGAKI (1978) computed the kinematics under random waves based on linear filters proposed by REID (1957) and found that the correlation between the predicted and measured was quite satisfactory.

REID (1957) developed the simple superposition method for predicting water particle kinematics from a measured sea surface that could be either random or periodic. This method is based on linear long-crested wave theory. LO and DEAN (1986) have compared this method with the stream function theory method of DEAN (1965) in simulating the particle kinematics and concluded that the simple superposition method provides reasonable agreement with the stream function tables and that this method can be used to analyse any length of irregular wave records. GUZA and THORNTON (1980) have reported that the linear theory overestimates wave induced horizontal velocities by 10 to 30 percent. Similarly, VAN HETEREN and STIVE (1984) have reported that the linear theory overpredicts the horizontal velocities in the surf zone by 20 percent.

The refinements of the linear wave theory for prediction of particle kinematics especially in coastal waters have been reported by DEAN (1965), NADAOKA (1986), and KOYAMA and IWATA (1986).

The foregoing discussion reveals that while considerable work has been done on wave kinematics in an open coast, the literature on the variation of wave climate and its kinematics in a groin field is limited.

## THEORETICAL CONSIDERATIONS

In the present investigation, the onshore–offshore or online particle velocity of time u(t) has been simulated from the measured time history of wave elevation of time $\eta(t)$ by using the methodology proposed by REID (1957) which is described below. The measured time history of wave elevation $\eta(t)$, represented in a Fourier integral form, can be written as

$$\eta(t) = \int_0^\infty A_n \cos(\sigma_n t - \phi_n)\, d\sigma \qquad (1)$$

The amplitudes, $A_n$, and their associated phase,

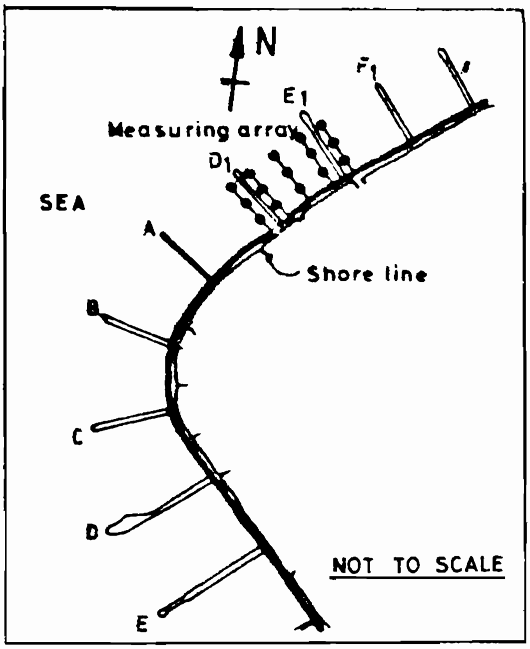


Figure 2a. Groin fields as shore protection for Norderney.

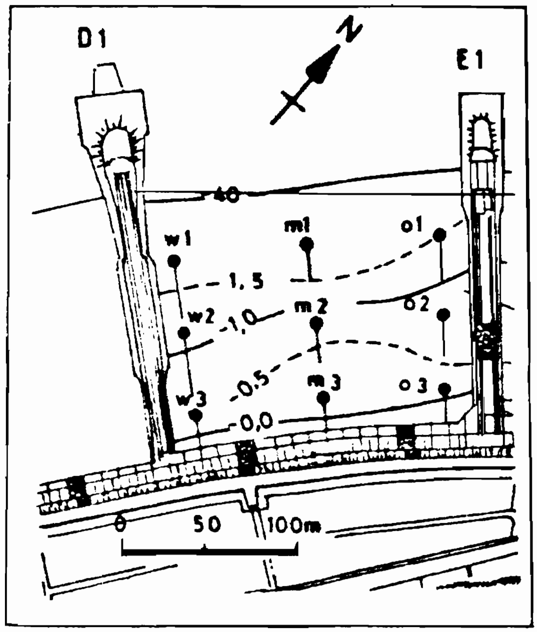


Figure 2b. Groin field with locations of measurement.

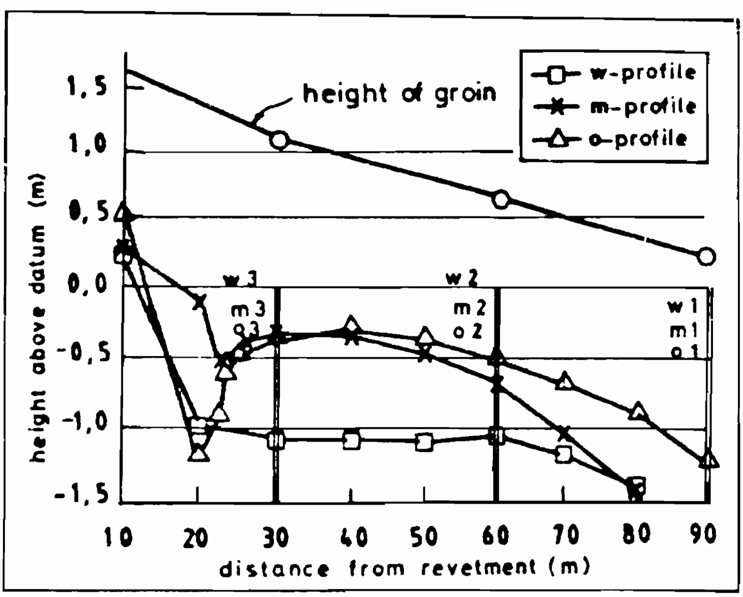


Figure 2c. Sea bed profile of locations of measurement.

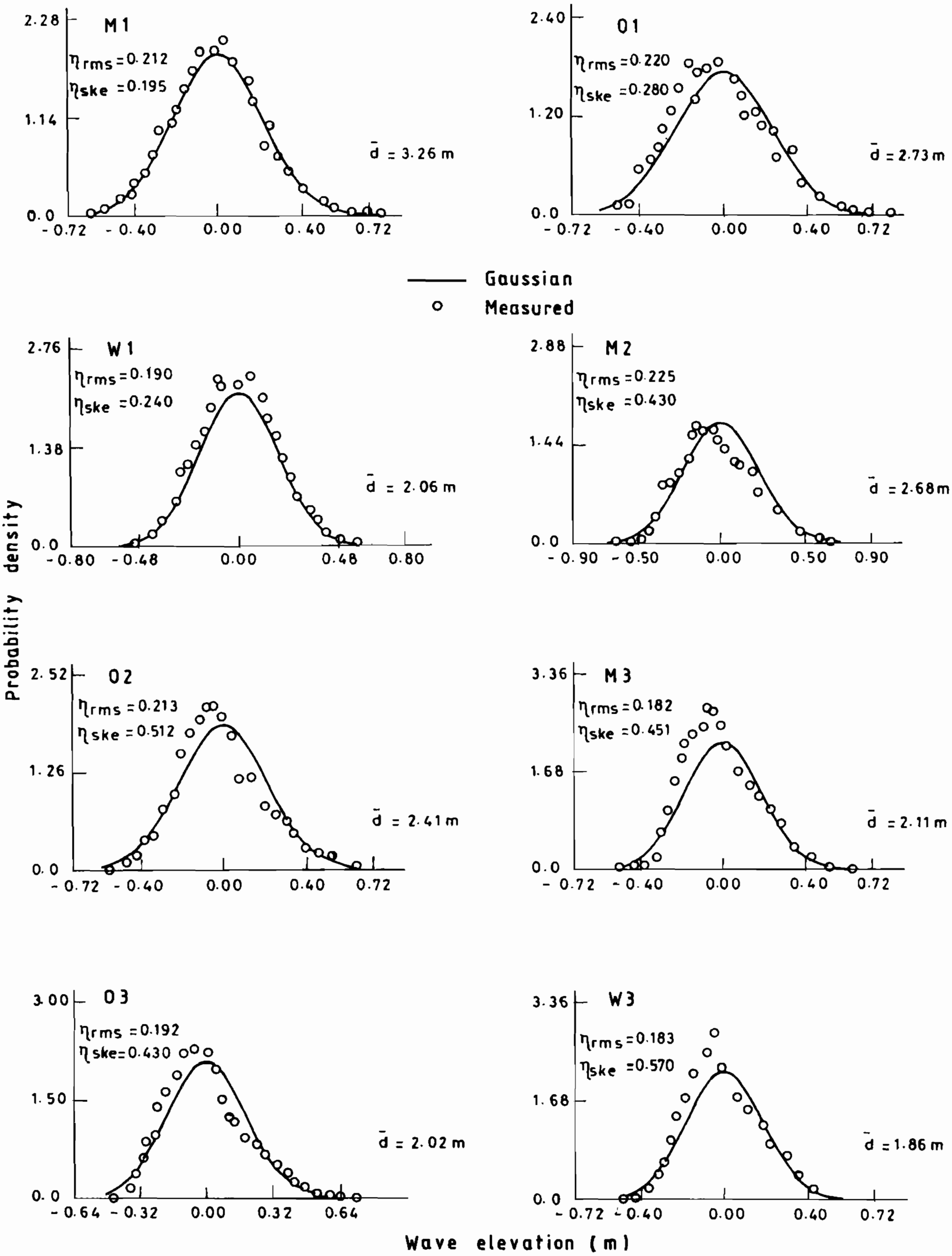


Figure 3. Comparison between measured and theoretical probability distributions of $\eta(t)$.

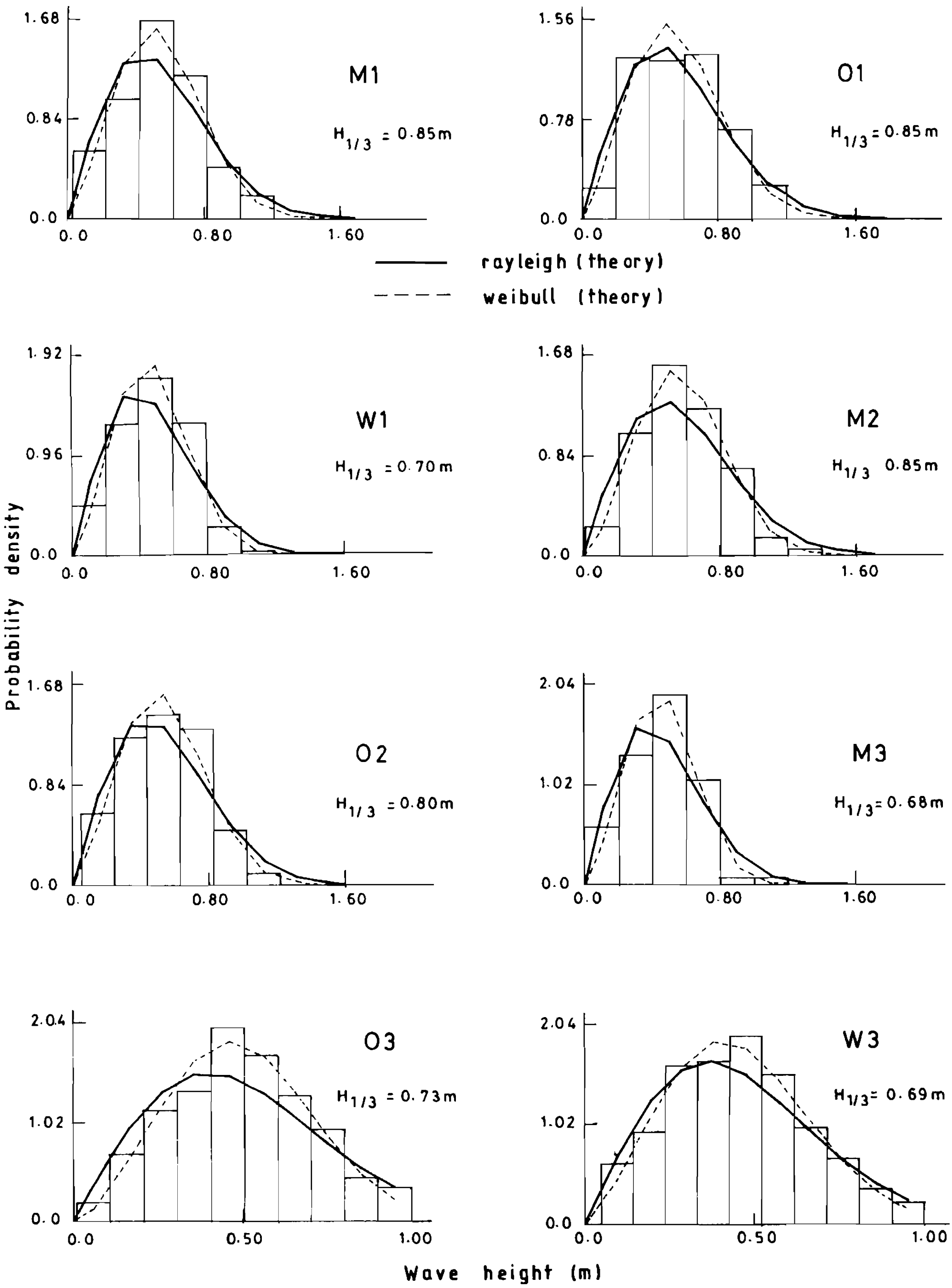


Figure 4. Comparison of probability distribution of wave height with Rayleigh and Weibull distributions.

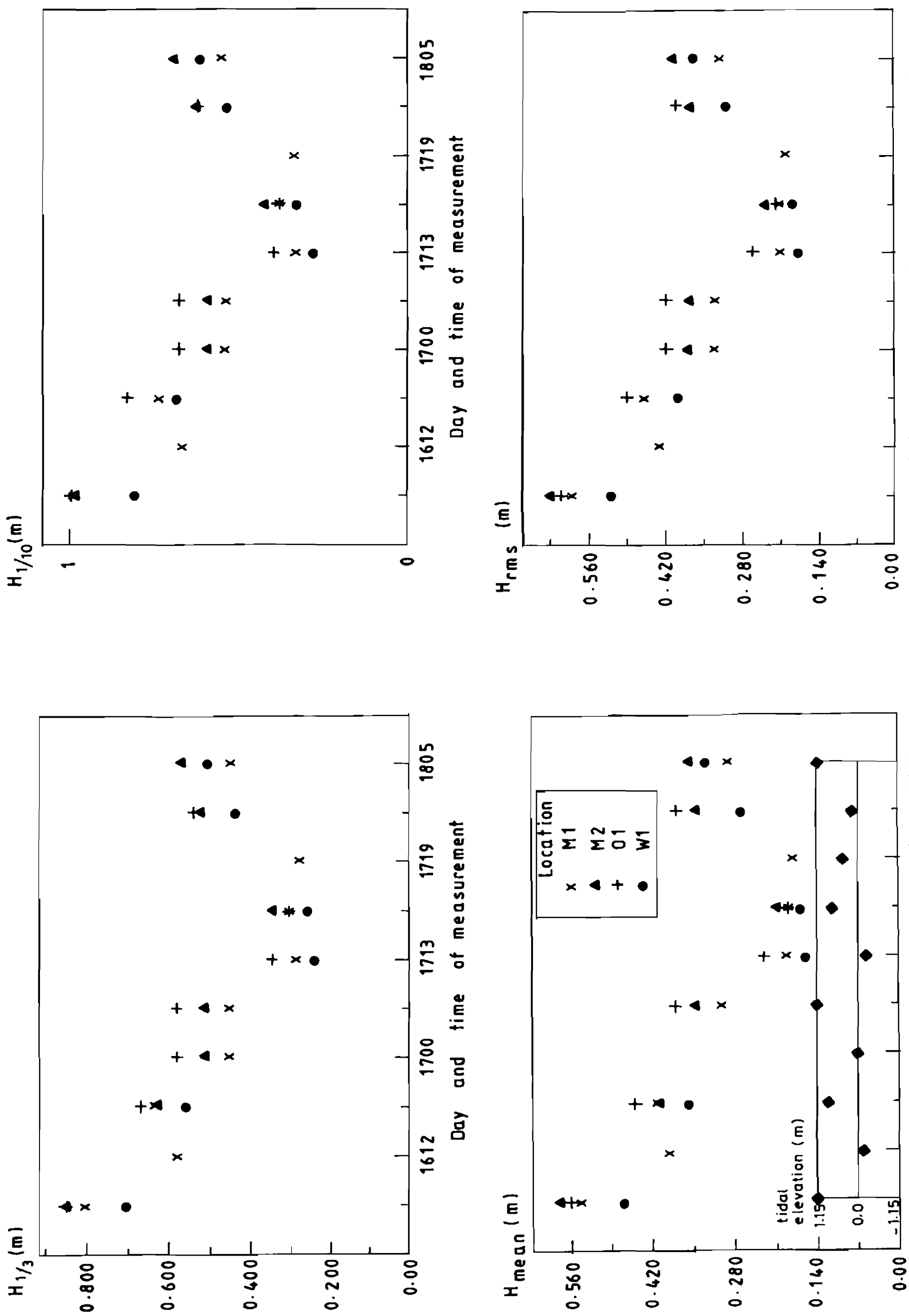


Figure 5. Time variation of wave height parameters.

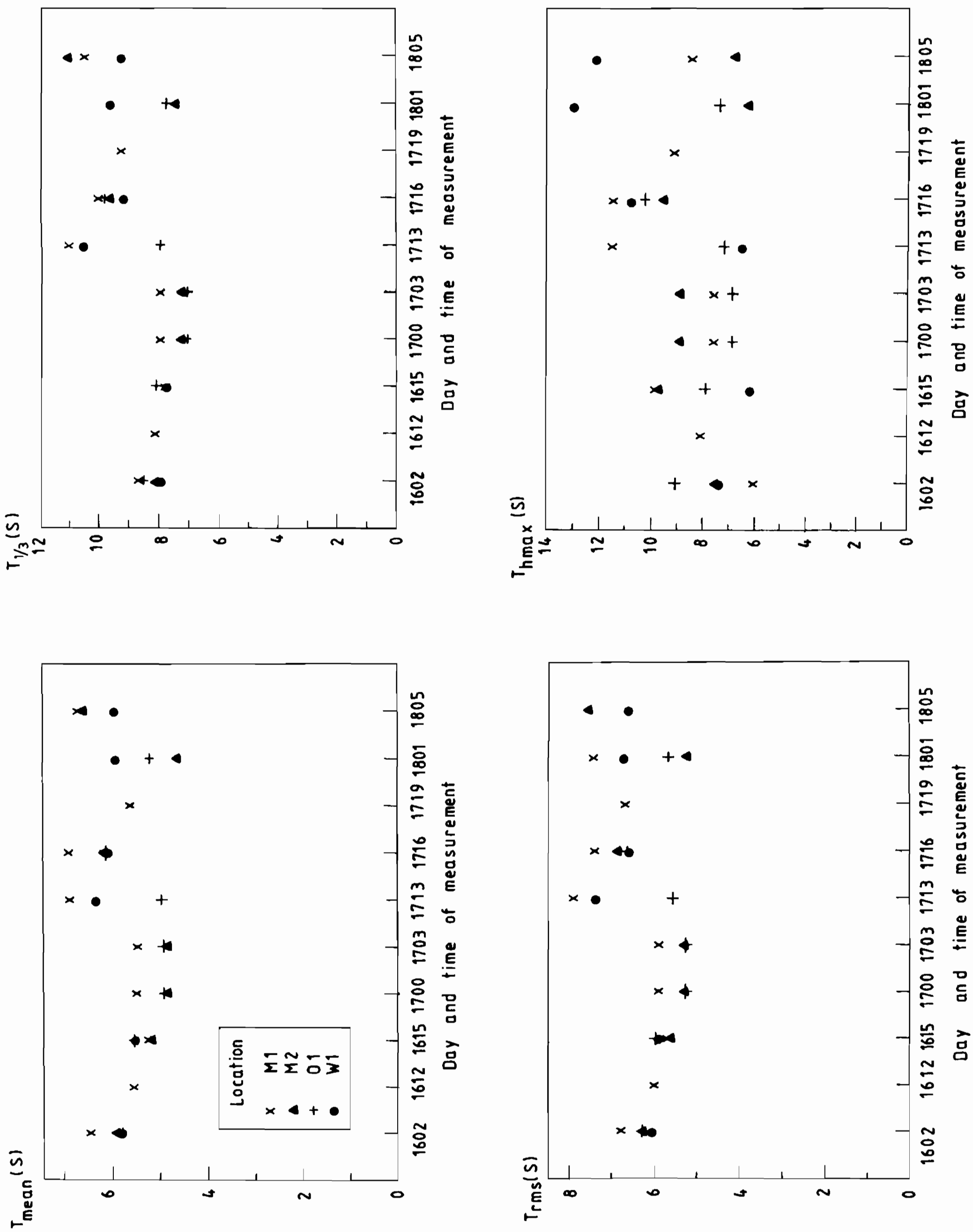


Figure 6. Time variation of wave period parameters.

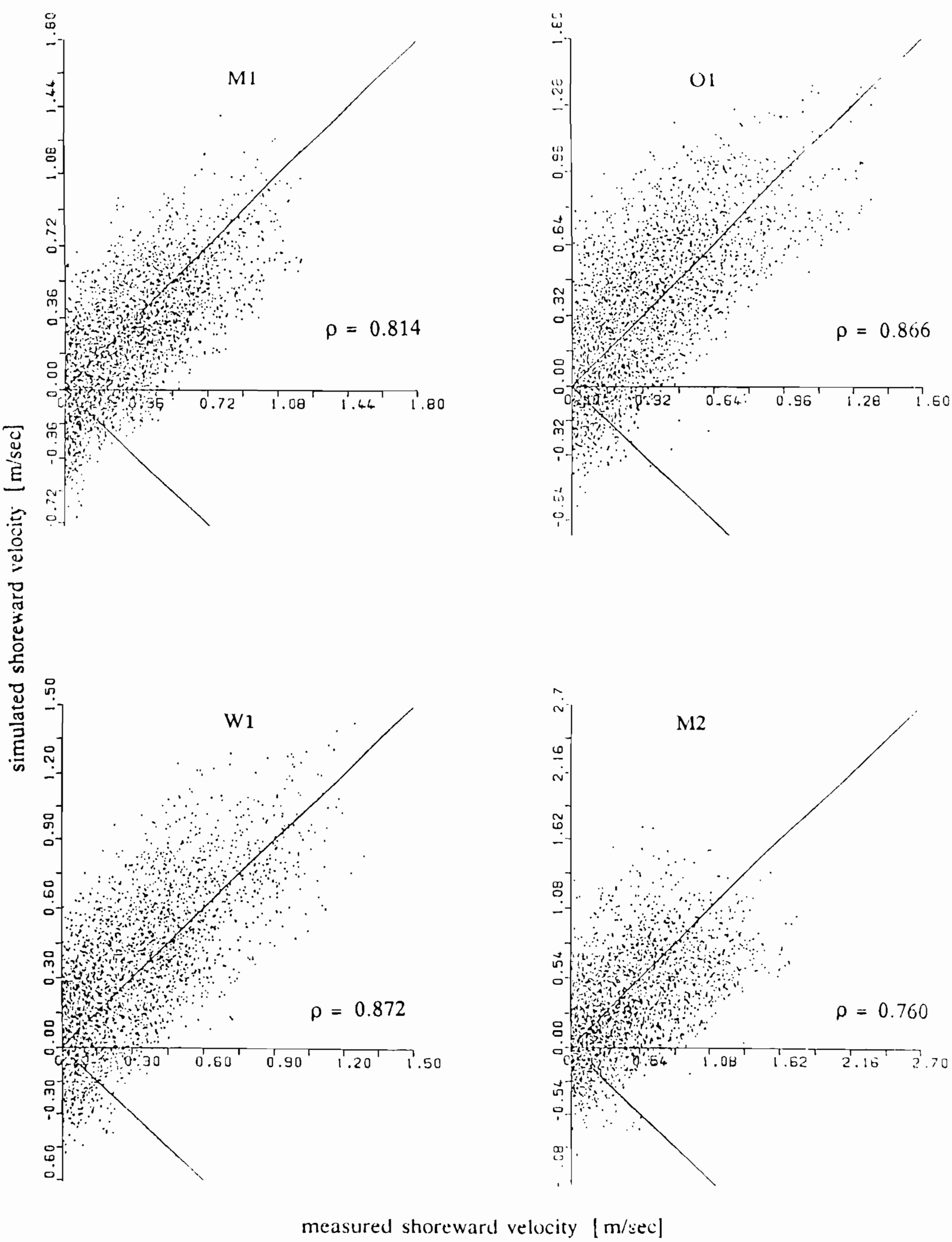


Figure 7a. Correlation between measured and simulated shoreward velocities.

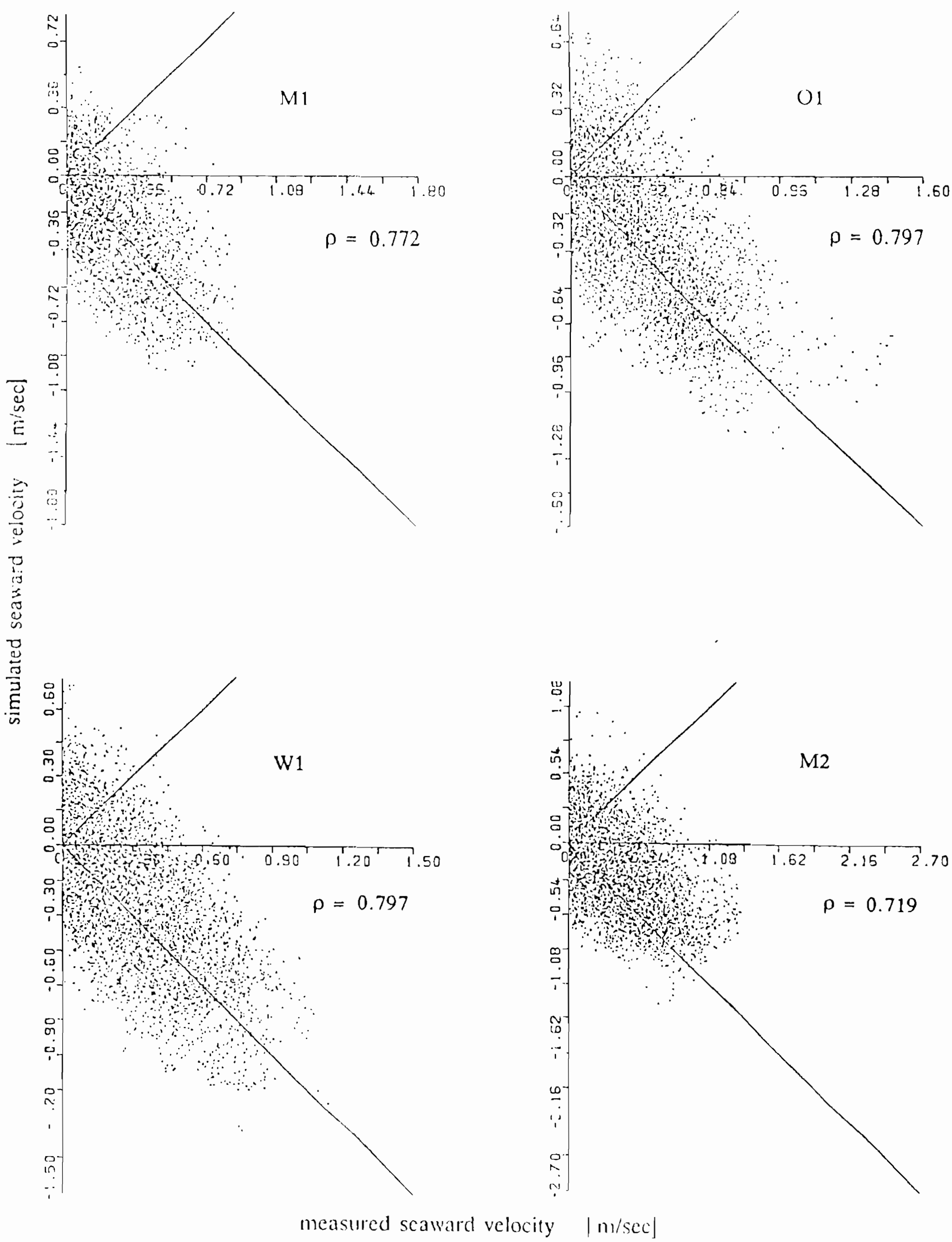


Figure 7b. Correlation between measured and simulated seaward velocities.

Table 1a. *Statistical parameters for wave periods.*

| Period Parameter | Location | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | M1 | O1 | W1 | M2 | O2 | M3 | O3 | W3 |
| $T_{mean}$ | 6.4 | 5.8 | 5.8 | 5.9 | 5.6 | 5.5 | 5.9 | 5.1 |
| $T_{rms}$ | 6.7 | 6.3 | 6.1 | 6.3 | 6.1 | 6.1 | 6.4 | 5.4 |
| $T_{max}$ | 13.0 | 14.1 | 13.3 | 13.1 | 14.0 | 15.0 | 14.9 | 11.6 |
| $T_{1/3}$ | 8.6 | 8.1 | 8.2 | 7.9 | 8.3 | 8.4 | 9.0 | 7.2 |
| $T_{hmax}$ | 6.0 | 9.1 | 7.4 | 7.5 | 9.2 | 15.0 | 6.2 | 6.2 |

Table 1b. *Statistical parameters for wave heights.*

| Period Parameter | Location | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | M1 | O1 | W1 | M2 | O2 | M3 | O3 | W3 |
| $H_{1/3}$ | 0.80 | 0.85 | 0.70 | 0.85 | 0.80 | 0.68 | 0.73 | 0.69 |
| $H_{1/10}$ | 0.98 | 1.00 | 0.82 | 0.99 | 0.96 | 0.82 | 0.88 | 0.84 |
| $H_{mean}$ | 0.54 | 0.56 | 0.47 | 0.58 | 0.54 | 0.46 | 0.50 | 0.46 |
| $H_{rms}$ | 0.59 | 0.61 | 0.52 | 0.63 | 0.59 | 0.50 | 0.54 | 0.50 |
| $H_{max}$ | 1.20 | 1.10 | 1.10 | 0.94 | 1.10 | 1.17 | 1.00 | 1.00 |

$\phi_n$, of the n-th Fourier component can be evaluated. The particle velocity is given as

$$u(t) = \int_0^{\infty} A_n FR_u(\sigma_n)\cos(\sigma_n t - \phi_n)\, d\sigma \qquad (2)$$

where $FR_u(\sigma_n)$ at circular frequency ($\sigma_n$) based on the linear wave theory is given as

$$FR_u(\sigma_n) = \sigma_n \frac{\cosh k_n(d + z)}{\sinh k_n d} \qquad (3)$$

in which d is water depth and z is the point of simulation of kinematics measured negatively below the still water level. The wave number $k_n$ of the n-th component associated with frequency $f_n$ is related by the dispersion relationship given by

$$(2\pi f_n)^2 = g k_n \tanh(k_n d) \qquad (4)$$

The above methodology is applied for a groin field considered in the present study.

## RESULTS AND DISCUSSION

### Wave Elevation

The instantaneous water surface elevation is generally assumed to follow the Gaussian distribution given as

$$p = p(\eta)\, d\eta = \frac{1}{\sigma_n\sqrt{2\pi}} \exp\left[\frac{-(\eta - \bar{\eta})^2}{2\sigma_\eta^2}\right] d\eta \qquad (5)$$

in which p is the probability of occurrence $p(\eta)$ is the probability density of function $\eta$, $\bar{\eta}$ and $\sigma_\eta^2$ are the mean and variance of $\eta$, respectively.

Though the analysis was carried out for all the records maintained under sec. 1, only typical results for the record measured on 16 November 1988 at 02 hrs are presented in this paper.

The comparisons between the measured and theoretical probability of $\eta$ for all the locations except for location W2 are shown in Figure 3. The average water depths are indicated in the figure as $\bar{d}$. It is observed that the agreement is quite reasonable for location M1, which is away from the groins. For other locations, the deviation of measured from Gaussian is observed being greater for locations closer to the groins and in relatively shallower water (W3 and O3). The time history was found to exhibit sharper crests at locations nearer to the shore and to the groins. The root mean square values of $\eta$, $\eta_{rms}$ and its skewness $\eta_{ske}$ are indicated in the figure for the corresponding locations. The skewness is seen or generally found to increase towards the shore and is found to be greater for the locations closer to the groins.

### Wave Heights

The individual wave heights and periods from $\eta(t)$ for all locations were derived by the zero upcross method. The probability densities of measured wave heights are compared with the theoretical Rayleigh and Weibull distributions shown in Figure 4.

The corresponding values of $H_{1/3}$ for all the locations are indicated in this figure. The expressions for these two distributions have been clearly presented by SHAHUL HAMEED and BABA (1985).

Table 2. *Correlation coefficient for different portions of time history.*

| Location | ND*: | 1 | 1,025 | 1 | 2,049 | 3,173 | 2,049 | 1 | 1,025 | 1 | 1,025 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | NS: | 1,024 | 1,024 | 2,048 | 1,024 | 1,024 | 2,048 | 4,096 | 4,096 | 7,000 | 2,048 |
| M1 | | 0.91 | 0.87 | 0.89 | 0.87 | 0.89 | 0.88 | 0.88 | 0.88 | 0.87 | 0.87 |
| W1 | | 0.91 | 0.91 | 0.91 | 0.88 | 0.86 | 0.87 | 0.89 | 0.86 | 0.87 | 0.89 |

* ND is the number of the starting data point and NS is the total number of data points considered

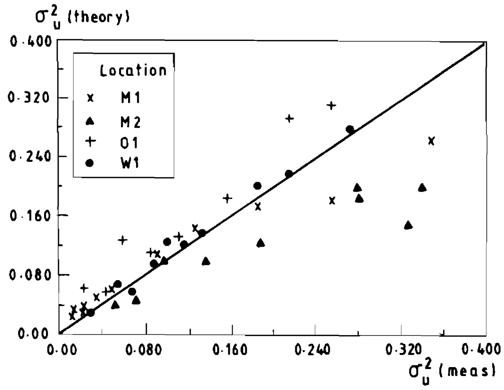


Figure 8. Comparison between the variances of measured and simulated velocities.

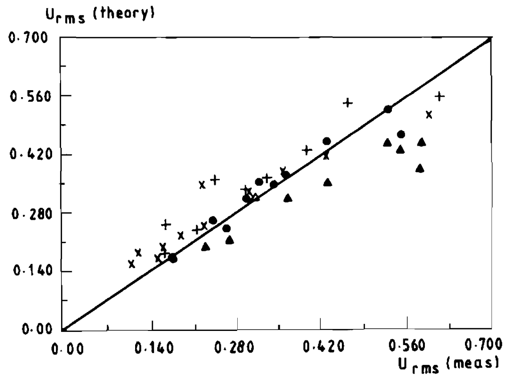


Figure 10. Comparison between the rms of measured and simulated velocities.

It is seen that the Weibull distribution fits the observed wave heights better. This was the case for ninety percent of the records tested. LEE and BLACK (1978) made a similar observation for the wave data at different locations of a reef. Thus, it is noticed that the Weibull distribution accounts for the pronounced steepening of waves in the nearshore zone. The wave periods ranged from 2 to 15 sec and the most frequently occurring wave period ranged from 4 to 8 sec at all the locations in the groin field.

### Time Variation of Wave Height and Periods

The variation of the different wave height parameters, highest one third, $H_{1/3}$, highest one tenth, $H_{1/10}$, mean height, $H_{mean}$ and root mean square height, $H_{rms}$ only for the locations M1, O1, W1 and M2 are considered and shown in Figure 5. In this figure and wherever a four digit number occurs on the abscissa, the first two digits indicate the day of measurement and the last two digits indicate the time of measurement in hours. It is observed that the average wave height characteristics change significantly with the time of measurement, indicating the influence of the tidal variation. The tidal range around the coast considered in this study is approximately 2 m and is marked in the above figure. However, the change in the wave height parameters within the groin field at a particular time of measurement is not significant.

The time variation of different wave period pa-

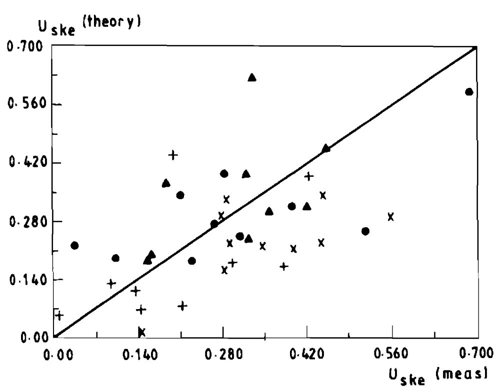


Figure 9. Comparison between the skewness of measured and simulated velocities.

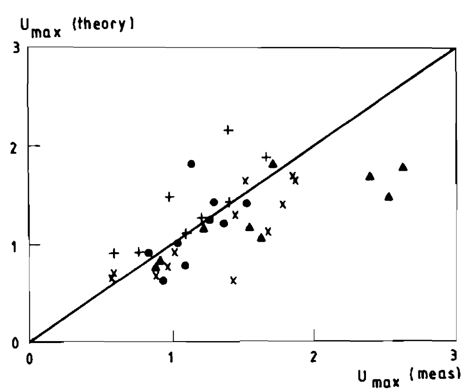


Figure 11. Comparison between the maximums of measured and simulated velocities.

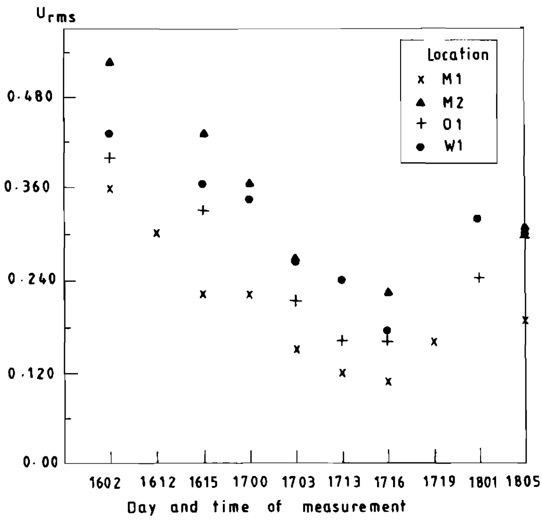


Figure 12. Time variation of $U_{rms}$ in the groin field.

rameters, mean period, $T_{mean}$, root mean square period, $T_{rms}$, highest one third, $T_{1/3}$, and period corresponding to maxium wave height, $T_{hmax}$, are shown in Figure 6. It is seen here that except $T_{hmax}$, all other period parameters do not significantly change with change in the tidal elevation.

The variation of the different wave periods and height parameters for all the locations in the groin field is shown in Table 1a and b, respectively. It is seen that all the average statistical parameters except $T_{hmax}$ do not change significantly within the groin field.

## Comparison Between Measured and Simulated Velocity Time Histories

In order to predict the onshore–offshore orbital velocity from the measured $\eta(t)$ by the method discussed earlier, different portions of the wave record were considered only for locations M1 and W1. The correlation coefficient between the simulated and the measured velocity presented in Table 2 is found to be quite encouraging.

In general, the agreement between measured and simulated data is satisfactory except that deviations are observed in very shallow waters especially for locations closer to the groins; *i.e.*, O2, O3, W3 and M3, which is expected due to nonlinearities, surf beat and effects due to cross flows. Detailed comparisons between simulated and measured velocities only for locations M1, O1, W1 and M2 are reported in the following sections.

The comparison between the simulated and measured shoreward velocity in the groin field is presented in Figure 7a. The correlation coefficient for each location is indicated in this figure. It is generally seen that the agreement between theory and measurement for locations in relatively deeper waters (M1, O1 and W1) is found to be quite satisfactory; whereas, deviations are observed for location M2. The correlation coefficient for the locations O1 and W1 to the extent of nearly 0.9 with the application of linear theory is quite reasonable in spite of these locations being closer to the groins where one would expect the predominant non-linear effects due to secondary reflections from the groin. A similar trend is observed for the seaward velocity in Figure 7b with a slight-

Table 3. *Comparison between present study and Draper's method.*

| | Location | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | M1 | | M2 | | W1 | | O1 | |
| Time Point | Meas ($u_{rms}$) | Draper ($u_{rms}$) | Meas ($u_{rms}$) | Draper ($u_{rms}$) | Meas ($u_{rms}$) | Draper ($u_{rms}$) | Meas ($u_{rms}$) | Draper ($u_{rms}$) |
| 1602* | 0.36 | 0.37 | 0.53 | 0.50 | 0.40 | 0.41 | 0.43 | 0.39 |
| 1612 | 0.30 | 0.32 | — | — | — | — | — | — |
| 1615 | 0.22 | 0.23 | 0.43 | 0.45 | 0.33 | 0.30 | 0.36 | 0.31 |
| 1700 | 0.22 | 0.21 | 0.37 | 0.37 | — | — | 0.34 | 0.33 |
| 1703 | 0.15 | 0.14 | 0.27 | 0.28 | 0.21 | 0.18 | 0.26 | 0.21 |
| 1713 | 0.12 | 0.12 | — | — | 0.16 | 0.19 | 0.24 | 0.18 |
| 1716 | 0.11 | 0.10 | 0.23 | 0.25 | 0.16 | 0.16 | 0.18 | 0.19 |
| 1719 | 0.16 | 0.15 | — | — | — | — | — | — |
| 1801 | — | — | — | — | 0.24 | 0.22 | 0.32 | 0.31 |
| 1805 | 0.19 | 0.18 | 0.31 | — | 0.30 | 0.32 | 0.30 | 0.33 |

* The first two digits of the four digit number in the first column indicate the day while the last two digits indicate the time in hours of the measurement

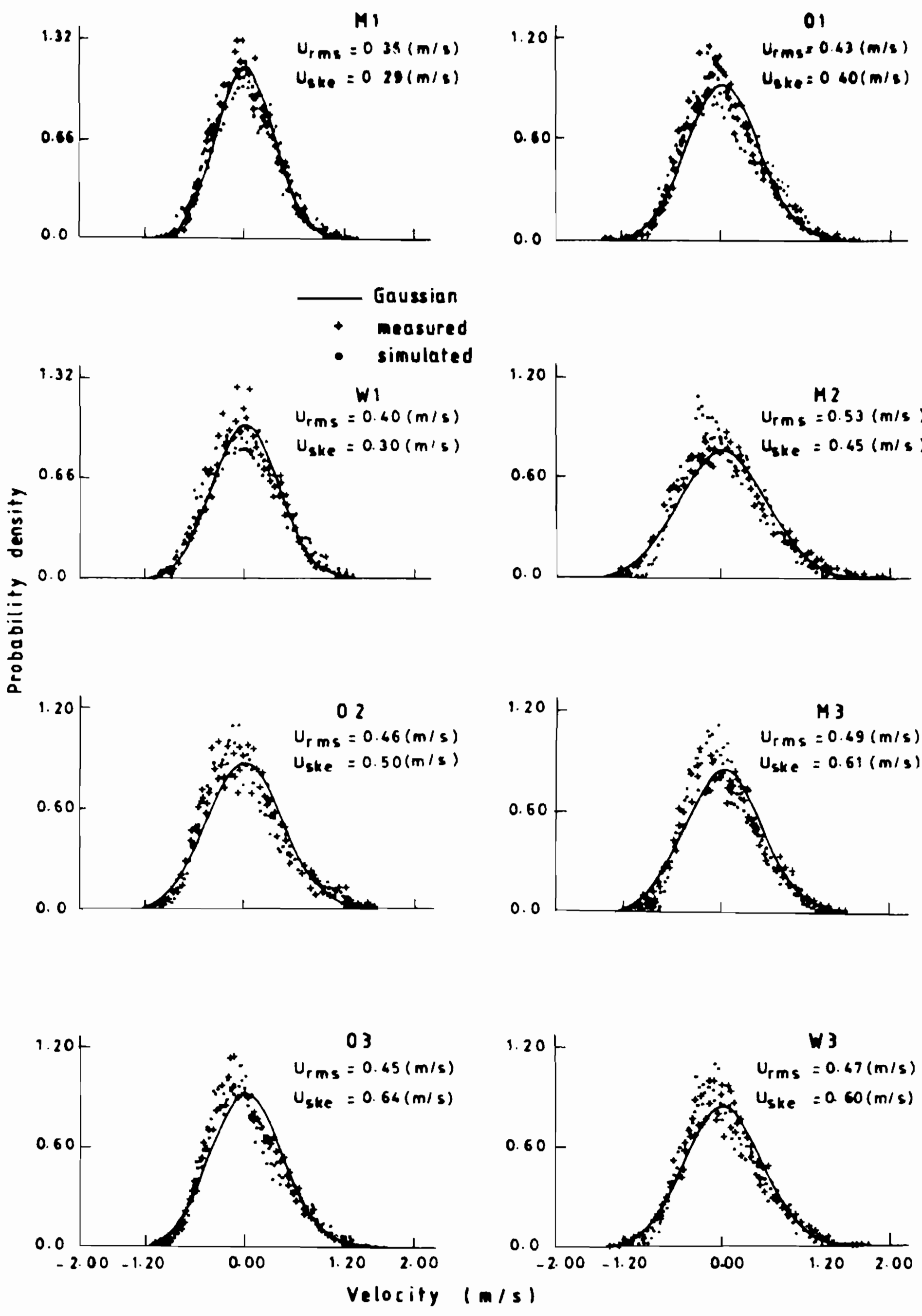


Figure 13. Probability density of onshore–offshore velocity.

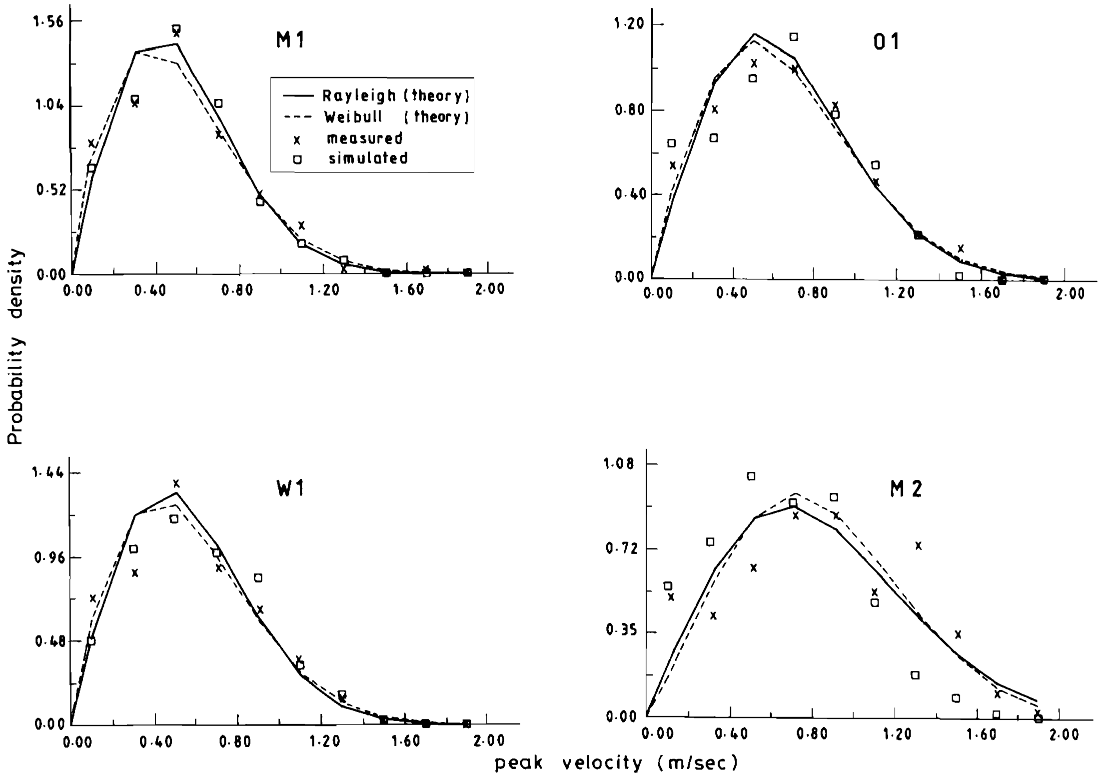


Figure 14. Comparison of measured and simulated shoreward peak velocity with theoretical distributions.

ly lesser value for the correlation coefficient compared to that for the shoreward velocity.

The comparisons of statistical parameters variance, $\sigma_u^2$, skewness, $u_{ske}$, root mean square, $u_{rms}$, and maximum, $u_{max}$, of the measured and simulated onshore–offshore velocity time histories for locations M1, O1, W1 and M2 are presented in Figures 8–11, respectively. The agreement is found to be satisfactory. Further, the skewness for location M1 (Figure 9) is found to be minimum compared to other locations. This trend is expected for location M2 which is in shallower waters, thus leading to asymmetries in the velocity fluctuations. Though locations O1 and W1 are in relatively deeper water, the asymmetries may be due to secondary reflections from the groins.

The variations of measured $u_{rms}$ with the time of measurement (tidal variation) at locations M1, M2, O1 and W1 presented in Figure 12 reveal that the $u_{rms}$ is maximum for location M2 and is found to be minimum for location M1. The variation of $u_{rms}$ within the groin field is maximum between M1 and M2 to the extent of about thirty percent. Its variation between locations O1 and W1 is less significant.

Furthermore, the root mean square of onshore–offshore current velocity measured at locations M1, M2, W1 and O1 from the direct averaging of total time series and that obtained using the peak amplitudes and average crest and crossing periods as prescribed by DRAPER (1963) for deep waters are shown in Table 3. The agreement is good similar to the agreement reported by HUNTLEY and BOWEN (1975).

## PROBABILITY DENSITY OF ONSHORE-OFFSHORE VELOCITY

The comparison of the probability density of the measured and simulated onshore–offshore velocity time histories along with Gaussian distribution for the different locations in the groin field is depicted in Figure 13. The root mean square and the skewness values of the measured velocity time history are also reported. The comparison is quite satisfactory. However, deviations are observed, being greater for larger skewness especially for locations in relatively shallower waters and closer to the groins similar to the observations for wave elevations. The velocity is found to range up to 2 m/sec.

The probability densities of the measured and simulated shoreward peak velocity are compared with the Rayleigh and Weibull distributions for the above four locations in Figure 14. The agreement between observed and simulated is reasonable for the locations M1, W1 and O1, with deviations observed for location M2. No appreciable difference is seen between the Rayleigh and Weibull distributions in fitting the observed peak velocities. This implies that the linear velocity over-predicts the peak velocities in shallow waters similar to the observations of GUZA and THORNTON (1980) and VAN HETEREN and STIVE (1984).

## CONCLUSIONS

Time domain analysis of time histories of wave elevation and particle velocity in a groin field have been carried out. Salient conclusions of the present study are reported below.

The analysis reveals that the wave elevation deviates from the Gaussian distribution with decreasing water depth and its increasing skewness.

The individual wave heights defined by upcross method are found to follow the Weibull distribution for the groin field considered in this study, indicating that it better describes the steepening of waves in shallower waters.

The average wave parameters, $H_{mean}$, $H_{1/3}$, $H_{rms}$ and $T_{rms}$, do not change appreciably within the groin field. However, their variation with the tidal variation is quite significant.

The average wave period parameters, $T_{mean}$, $T_{1/3}$ and $T_{rms}$, do not change significantly within the groin field and their variation with tidal change is also almost insignificant. The simple superposition method of simulating the onshore–offshore velocity with measured $\eta(t)$ is found to be reasonable in predicting the velocities in the groin field with deviations up to 30 percent in very shallow waters. The agreement is generally found to be better for the prediction of shoreward velocity compared to the prediction of seaward velocity.

The variation of root mean in-line velocity within the groin field is about 50 percent and its variation with the tidal variation is quite significant.

The measured and simulated in-line velocities in the groin field reasonably follow the Gaussian distribution and the peak shore velocity reasonably follows the Weibull distribution.

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