CHAPTER 73

INCIDENT WAVE GROUPS AND LONG WAVES IN THE NEARSHORE ZONE

Y Foote* , D Huntley*, M Davidson*, P Russell*, J Hardisty† and A Cramp‡

ABSTRACT

Variations of the wave groupiness, cross-correlation between the incident wave envelope and long wave motion, and skewness of the near-bed velocity were measured on a macrotidal beach at Spurn Head, UK, as part of an experiment by the B-BAND (British Beach And Nearshore Dynamics) programme.

Wave groupiness persisted throughout the surf zone, and did not decay immediately at the breakpoint as is often assumed. The cross-correlation between the incident and long wavefields varied systematically across the nearshore, with negative values outside the surf zone and positive values near the shoreline. Offshore of the breakpoint, the skewness of the cross-shore current was dominated by three contributions - (i) the skewness of the incident waves, (ii) the interaction between the incident wave energy and the mean flow and (iii) the correlation between the incident and long waves. Onshore of the breakpoint, contributions (i) and (ii) remained important, along with the interaction between the long wave energy and the mean flow. The relative importance of these contributions to the skewness was unaffected by the incident wave characteristics.

1. INTRODUCTION

Incident waves travelling towards the shoreline are known to have a groupy structure, with an alternating sequence of high waves and low waves. Longuet-Higgins and Stewart (1962,1964), Larsen (1982) and Shi and Larsen (1984) proposed that associated with this incident wave 'groupiness' are gradients in the radiation stress generating a forced long wave (of infra-gravity frequency) where a depression of mean sea-level is correlated with groups of high waves and a rise in mean sea-level corresponds with groups of low waves. The radiation stress is proportional to the square of the amplitude of the incident waves.

* University of Plymouth, Plymouth, PL4 8AA, UK
† University of Hull, Hull, HU6 7RX, UK
‡ University of Wales, Cardiff, CF1 3YE, UK

Shi and Larsen (1984) suggested that the passage of a wave group and bound long wave over an erodible bed causes the re-suspension of sediments under high waves, which in conjunction with a negative long wave flow will result in net reverse sediment transport. Hanes (1988) observed the suspension of sand at both the incident wave frequency and at frequencies corresponding to wave groups. Whilst few studies have examined the variations in wave groupiness across the surf zone, where waves are radically transformed by the breaking process, it is generally understood that groupiness of ocean waves is an important characteristic of the climatology of waves both within and beyond the surf zone. Incident wave groupiness contributes significantly to the nearshore wave field. This is demonstrated through use of groupiness as a driving mechanism in models of long wave generation both in the offshore and nearshore zones, through its relationship with nearshore sediment transport and through its effect on coastal and marine structures (List, 1991).

This paper describes observations of incident wave groups and long waves from the large data set collected during the B-BAND (British Beach and Nearshore Dynamics) field experiment at Spurn Head, UK (Russell *et al*, 1991) in order to estimate the variation of wave groupiness across the nearshore zone over a range of wave and tidal conditions on a macrotidal beach and to investigate the theory that the long wave motion is forced outside the surf zone and that the short incident waves are modulated inside the surf zone.

In addition, this study describes the second stage of data analysis which involves the examination of cross-shore current data and certain velocity moments which are expected to determine sediment transport. Relatively recent studies (*e.g.* Bailard, 1981) of the processes which operate in the nearshore zone and the mechanisms which drive sediment transport, have shown the important role of velocity moments. Several field measurements of the velocity field on beaches have displayed features not explicitly present in many of the existing sediment transport models (Doering and Bowen,1985). The examination of velocity moments, which are essentially current velocity components to some power, enables a more detailed understanding of the wave motion climatology and is vital to determining the processes which must be included in models of wave-driven coastal change.

Early models for nearshore sediment transport employed bulk empirical formulae based upon the general properties of the incident waves. Existing transport models are generally extensions to these theories, developed originally for the uni-directional conditions of aeolian or fluvial transport (Bagnold, 1963; Einstein, 1972; Yalin, 1972) and such models examine either bedload or suspended load transport. A more significant contribution to cross-shore sediment transport modelling has been provided, however, by those modellers who relate net sediment transport to the small deviations from symmetry which occur in the on-offshore fluid velocity field (Bowen, 1980; Bailard, 1981; Guza and Thornton, 1985; Roelvink and Stive, 1989). Theories such those by Bowen and Bailard generate a number of current velocity moments, but as yet the relative magnitudes of these moments is poorly known for field conditions. Guza and Thornton (1985) indicated that the

moment contributing most to the cross-shore suspended transport, for their particular wave and beach slope conditions, is the skewness. The present work examines the importance of several cross-shore velocity moments derived from the skewness (including mean, low-frequency and high-frequency components) within the nearshore zone, over a range of wave and tidal conditions.

2. FIELD SITE AND DATA COLLECTION

Field measurements were made at Spurn Head, Humberside, UK. during 16th to 25th April 1991 by the B-BAND (British Beach and Nearshore Dynamics) group. Ten tidal cycles of data in total were collected. This extensive data-set was collected on the eastern, seaward face of Spurn Head, a sand spit approximately 5km in length, which is located between the mouth of the Humber Estuary and the North Sea (Figure 1).

The beach at Spurn Head generally comprises a mobile shallow sand lens in conjunction with some superficial deposits of gravel which cover the underlying layers of boulder clay. The mean grain size of the predominant sand at the Spurn Head field site is 0.35mm. The beach profile at the field site (Figure 2) displays the characteristics of this East Coast beach, with a narrow sandy inter tidal terrace and a steep upper beach face and berm, backed by an extensive area of vegetated dune.

Gradients vary across the beach profile from 0.0230 over the inter tidal terrace, comprising well sorted sands and the underlying local glacial deposits, to a value of 0.0975 for the steeper high tide beach face which comprises fine to medium gravel (Figure 2). This range of beach slopes results in a morphodynamic regime which can alternate between dissipative at low water and reflective at high-water, but which can generally be considered to be intermediate (Wright and Short, 1984).

Wave conditions during the measurement period covered a wide range, from calm to the 2-year return period storm (with breaking wave heights in excess of 3m). The wave climate included not only the irregular and short period local wave motions, but also regular swell with pronounced groupiness characteristics. The tidal variation at Spurn Head is macrotidal and characterised by tidal currents which flood in a south-westerly direction parallel to the shoreline and ebb in a north-easterly direction.

Data logging occurred over 10 tidal cycles from 8 sensor rigs which extended to approximately 120m offshore. The four central A-Rigs (Figure 3), each comprising 3 electro-magnetic current meters spaced at heights of 0.10, 0.25 and 0.63m above the bed, 3 optical back-scatter sensors positioned at 0.04, 0.10 and 0.25m above the bed, plus one pressure sensor; formed the most detailed and comprehensive component of the instrumentation deployed (see Russell *et al.*, 1991).

3. DATA ANALYSIS

Data analysis in this study examines two complete tidal cycles, Tides 184PM and 234PM, in addition to Tide 164PM a partial tidal cycle. The data discussed here comes from a point source (Rig A2). Tide 164PM, comprising

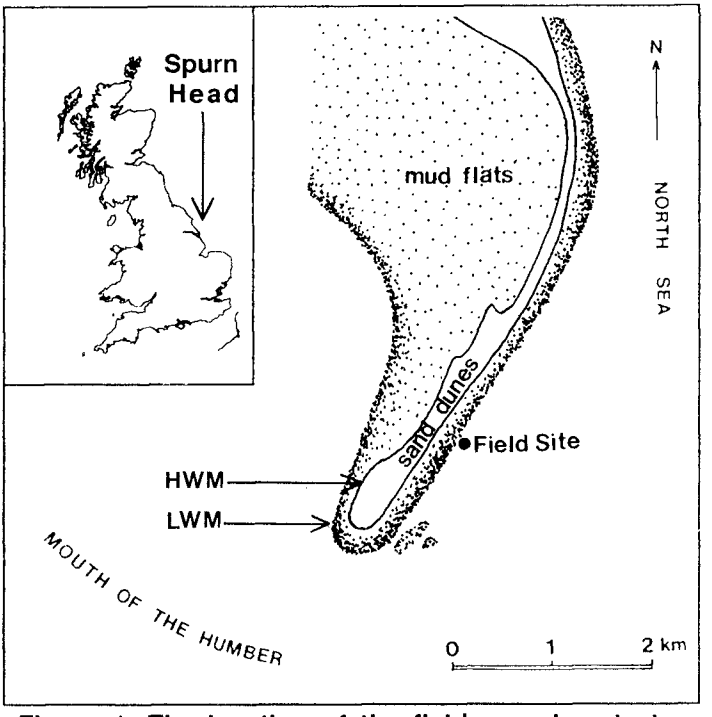

Figure 1. The location of the field experiment at Spurn Head

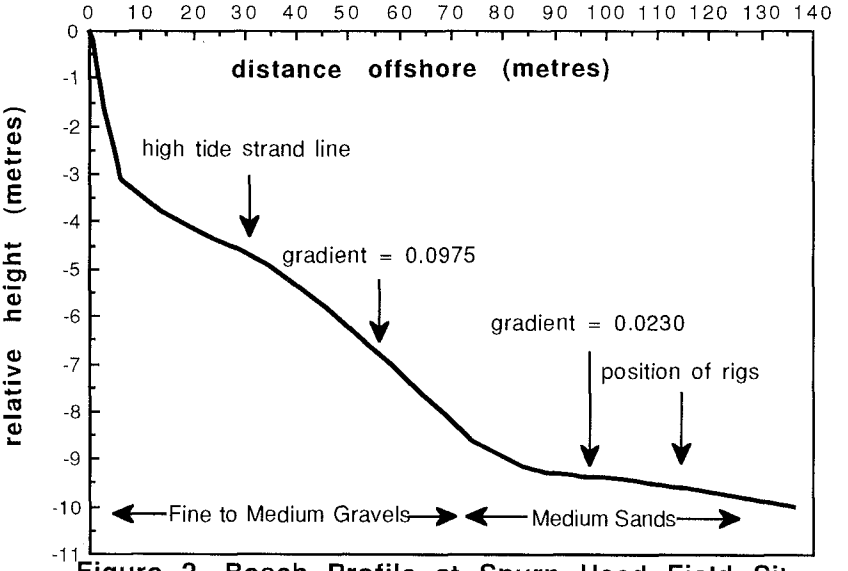

Figure 2. Beach Profile at Spurn Head Field Site, 18 April, 1991.

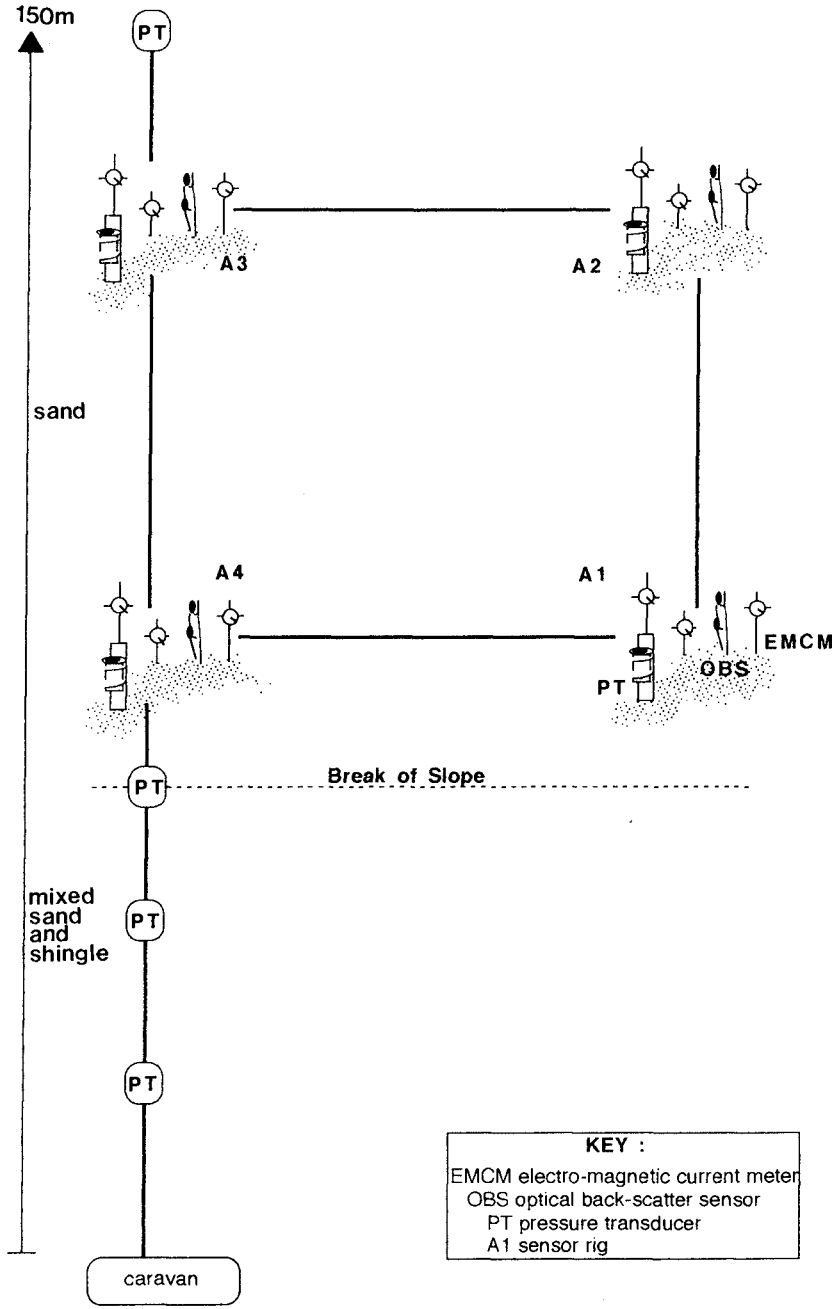

Figure 3. Field set-up used at Spurn Head, April 1991.

4 runs with each run containing 17 minutes or 1024 seconds of data, was logged on April 16th 1991 during a violent storm event with a very strong wind, a maximum H_S value of 1.6m and swell waves of up to 3m breaking height. (The significant wave height, H_S, is defined as 4σ where σ^2 is the total variance of the sea surface elevation data (Guza and Thornton, 1982)). Tide 184PM covers moderate swell and choppy conditions, maximum H_S of 1.1m, with a moderate wind, whilst Tide 234PM displays calmer conditions with smaller swell and chop waves and a maximum H_S value of approximately 0.8m.

(i) ESTIMATION OF WAVE GROUPINESS AND CROSS-CORRELATION ANALYSIS

Following the selection of the three tides (Tides 164PM, 184PM and 234PM) all pressure data runs are examined for spikes, glitches or any other incongruous values, which have to be removed prior to analysis. The trend of the pressure sensor data is removed and the record is additionally 'demeaned'; such procedures help to exclude the possibility of any distorting effects upon the data by creating a quasi-stationary time series. The pressure signal is then converted to an approximate sea surface elevation record using a correction factor for the depth attenuation effect of the pressure transducer (*e.g.* Skovgaard *et. al.*, 1974). Separation of the corrected data into both high- and low-passed components is achieved through use of a Kaiser-Reed (1977) digital filter. Spectral analysis of the pressure sensor time series indicates the presence of a trough near 0.05Hz between the incident wave peak and low frequency and sub-harmonic motion peaks and therefore, a cut-off value of 0.05Hz is applied to the separate low- and high-frequencies. The procedure for determining the incident wave groupiness involves the demeaning and squaring of the high-pass component of the surface elevation data, followed by application of the same filter used previously to produce high- and low-frequency wave height time series. The groupiness factor is then the square root of the root-mean-square of the wave envelope time series (Huntley and Kim, 1984).

The incident wave envelope time series is, therefore, used as the basis for estimating the groupiness factor. This has been determined for the three selected tides and plotted against depth (Figure 4) and significant wave height (Figure 5). Despite the examination of three very different tidal cycles the data exhibit a definite relationship whereby, outside the breakpoint, groupiness does not vary significantly (Figure 4), whilst shorewards from the breakpoint groupiness does not drop to zero but actually continues through the surf zone, decreasing to near zero only at the shoreline. Determination of the breakpoint position is achieved through examination of the current velocity mean and variance data (Davidson *et al*, 1992). As might be expected if wave heights obey a Rayleigh distribution, there is a linear relationship between wave height and the groupiness factor; Figure 5 suggests that this relationship persists to the shoreline. Thus whilst many numerical and laboratory models assume that groupiness decreases to zero at the breakpoint, the data analysed in this study based upon field results reveal a persistence of groupiness through the surf zone.

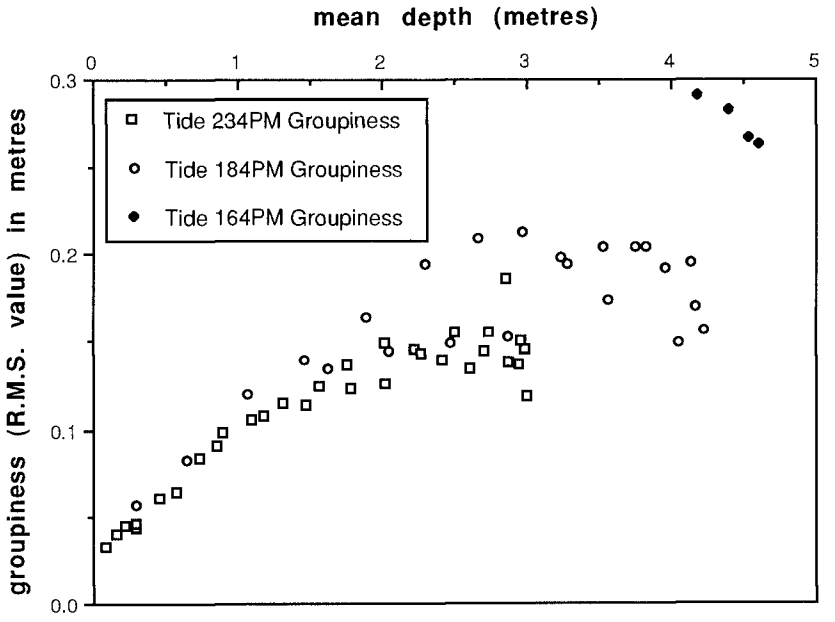

Figure 4. Variations in groupiness with depth across the nearshore zone.

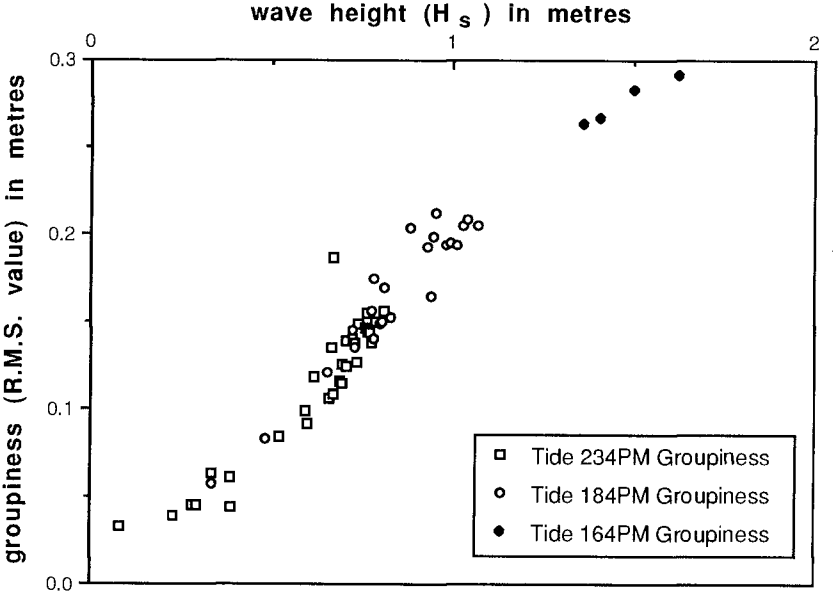

Figure 5. Variations in groupiness with wave height across the nearshore zone.

Cross-correlation coefficients between the incident wave envelope and the low-frequency motion are calculated for all data runs of three selected tidal cycles. The cross-correlation function, C_R, describes the degree of linear agreement between two data sets in the time domain thus :

$$C_R = \frac{\sum (x_i - \bar{x})(y_{i+k} + \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 (y_i - \bar{y})^2}} \quad (1)$$

where $\bar{\psi}$ and ψ_n are the mean and nth value of the ψ time series respectively, and ψ represents x or y.

Figure 6a illustrates the cross-correlation function between the incident wave envelope time series and the low-frequency motion time series for a high tide data run of Tide 234PM, whilst Figure 6b illustrates the equivalent cross-correlation function for a low tide data run, also from Tide 234PM. It is interesting to note in Figures 6a and 6b that for the large water depth of the high tide example, a large negative correlation value is obtained at zero time lag and for the shallower state of the low tide example, there is a considerable positive value. Values of the cross-correlation coefficient at zero time lag for all data runs are plotted in Figure 7 against depth. There appears to be a definite trend in the data. The positive cross-correlation values within the surf zone could be explained by the modulation of short wave breaker heights through the depth variations induced by long waves (Roelvink and Stive, 1989), although it is not known whether this depth-modulation is induced by the forced waves or the free waves. The negative correlation coefficient values outside the surf zone reflect the forcing of the long wave motion by the radiation stress of the incoming wave groups. Consequently, in agreement with other field data (Abdelrahman and Thornton, 1987) and laboratory data (Roelvink and Stive, 1989; Roelvink, 1991), there does appear to be significant direct coupling between the high- and low-frequency motions. The correlation near zero which occurs just inside the breakpoint may be explained by the occurrence of a standing long wave nodal point or by the competing effects of forced and free long wave energies. The fact that data from all three tides show the same trends, within the scatter, in both the cross-correlation and the groupiness suggests that both factors are independent of the offshore wave climate.

(ii) VELOCITY MOMENT ANALYSIS

The process of examining velocity moments and attempting to establish the moments which contribute most significantly to nearshore sediment transport (Guza and Thornton, 1985), is adapted in this study for electro-magnetic cross-shore current velocity data (bottom sensor of Rig A2) from the B-BAND Spurn Head field experiment. The present study is concerned with cross-shore sediment transport and therefore only the cross-shore velocity (u) is used. The cross-shore current velocity is assumed to comprise a mean flow ($\bar{u}$), a high frequency wave component (u_S) and a low frequency wave component (u_L) thus:

$$u = (\bar{u} + u_S + u_L) \quad (2)$$

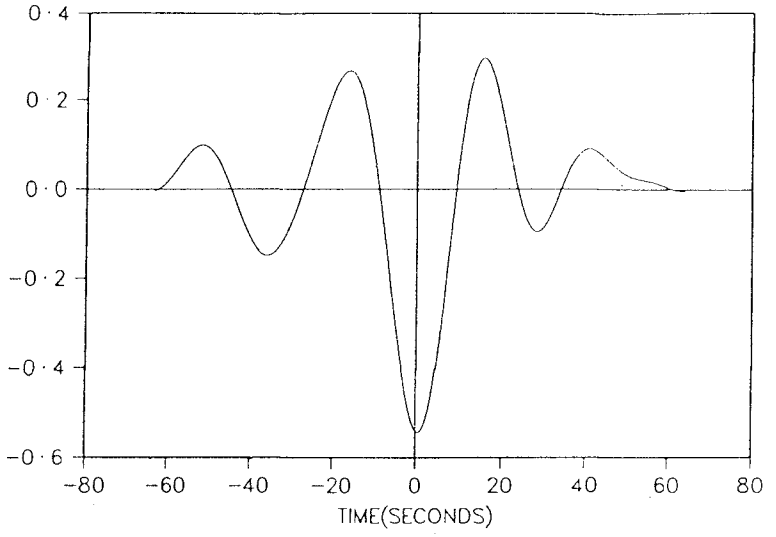

Figure 6(a). Cross-correlation between wave envelope and low frequency motion near high tide

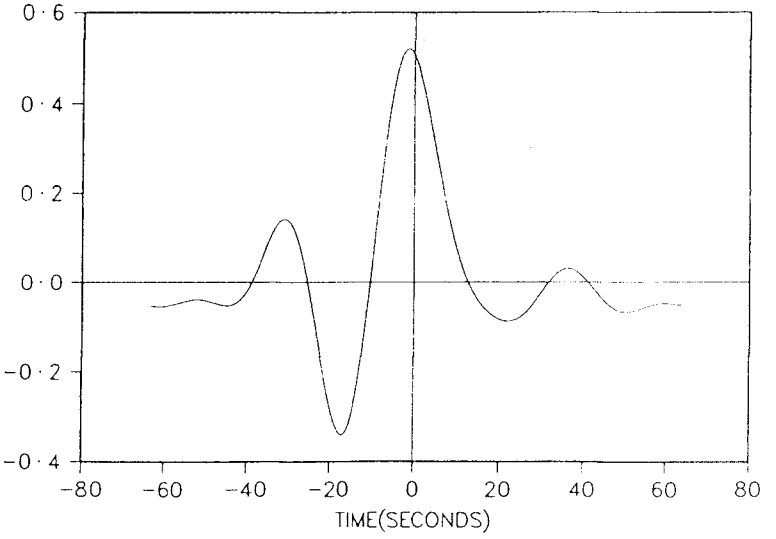

Figure 6(b). Cross-correlation between wave envelope and long wave motion near low tide.

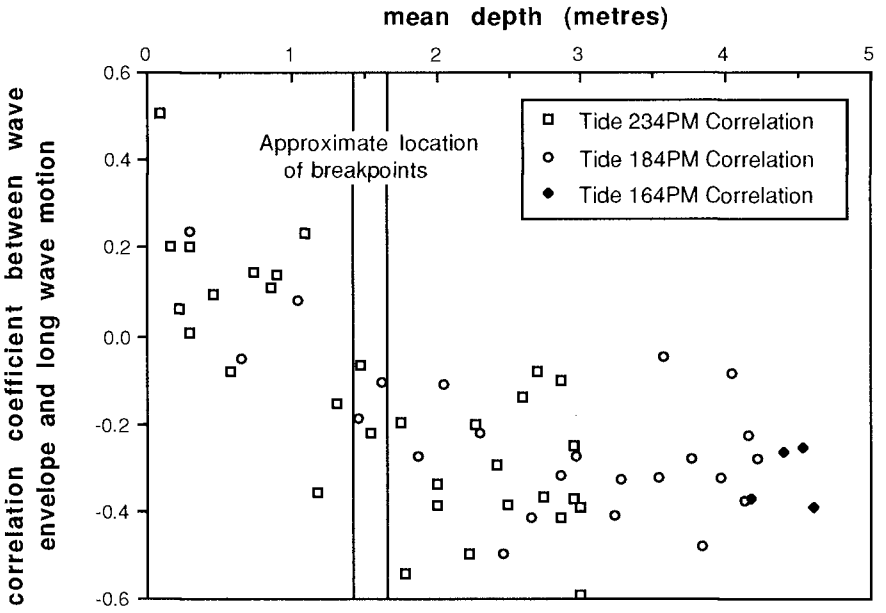

Figure 7. Correlation coefficient between wave envelope and long wave motion across the nearshore zone.

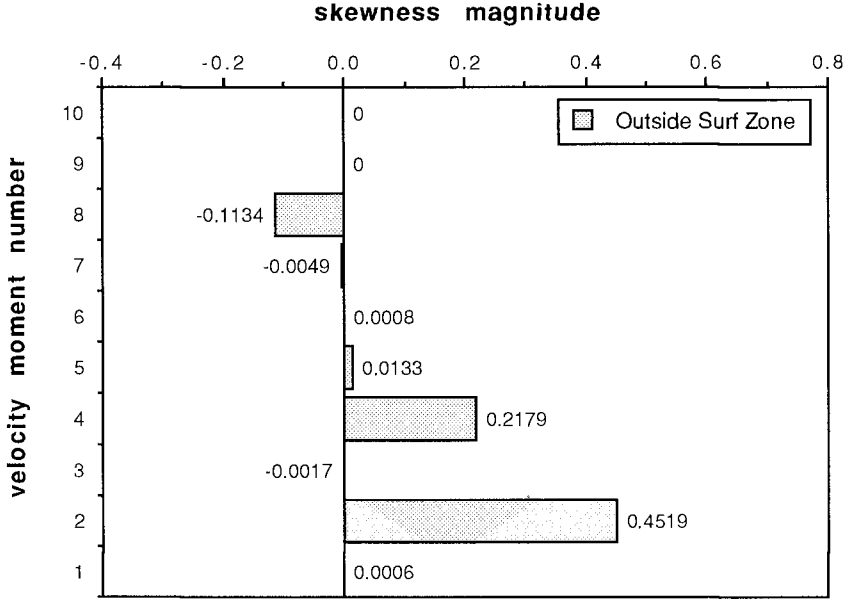

Figure 8(a). Tide 164PM skewness outside the surf zone.

When expanded in terms of these three components, the normalised cross-shore velocity skewness, defined as $(u^3)/(u^2)^{3/2}$ consists of ten distinct terms since :

$$\overline{u^3} = \left(\overline{\bar{u}+u_S+u_L}\right)^3 \quad (3)$$

$$= \bar{u}^3+\overline{u_S^3}+\overline{u_L^3}+\overline{3\bar{u}u_S^2}+\overline{3\bar{u}u_L^2}+\overline{6\bar{u}u_Su_L}+\overline{3u_L^2u_S}+\overline{3u_S^2u_L}+\overline{3\bar{u}^2u_S}+\overline{3\bar{u}^2u_L} \quad (4)$$

(Each of the above ten terms are normalised by dividing through by $(u^2)^{3/2}$). These ten skewness terms describe various mechanisms which operate within the nearshore system as follows:

$\bar{u}^3$ = Term 1, mean flow cubed

u_S^3 = Term 2, skewness of the short wave velocity component

u_L^3 = Term 3, skewness of the long wave velocity component

$3\bar{u}u_S^2$ = Term 4, short waves mobilise sediment which then moves with the mean flow *

$3\bar{u}u_L^2$ = Term 5, as Term 4, but with long waves mobilising sediment *

$6\bar{u}u_Su_L$ = Term 6
$3u_L^2u_S$ = Term 7 } correlations between short and long wave components
$3u_S^2u_L$ = Term 8

$3\bar{u}^2u_S$ = Term 9
$3\bar{u}^2u_L$ = Term 10 } will be near zero and will not be significant parameters

*cf Inman and Bagnold (1963)

The three tidal cycles selected (Tides 164PM, 184PM and 234PM) for the groupiness analysis are also used for moment analysis. All current velocity data runs are examined for spikes or glitches which have to be removed before the moment analysis, in addition to the trend and mean prior to filtering. Each of the above ten terms is calculated for all three tidal cycles and averaged into measurements made seaward of the surf zone and measurements obtained within the surf zone.

The schematic representations of the ten terms outside and inside the breakpoint for the three tides examined can be seen in Figures 8 and 9 and indicate that particular velocity moment terms dominate through the nearshore zone. For all three tidal cycles, with varying characteristics, the following velocity moments appear to prevail :

Tide 164PM (Fig. 8a)	Seaward of the Surf Zone	Terms 2, 4 and 8 dominate
Tide 184PM (Fig. 8b)	Seaward of the Surf Zone	Terms 2, 4 and 8 dominate
Tide 234PM (Fig. 8c)	Seaward of the Surf Zone	Terms 2, 4 and 8 dominate

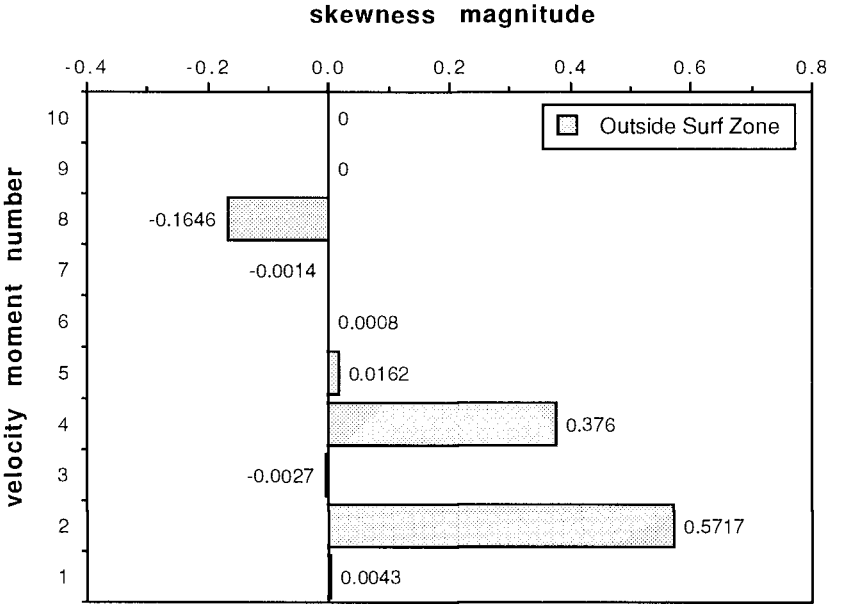

Figure 8(b). Tide 184PM skewness outside the surf zone.

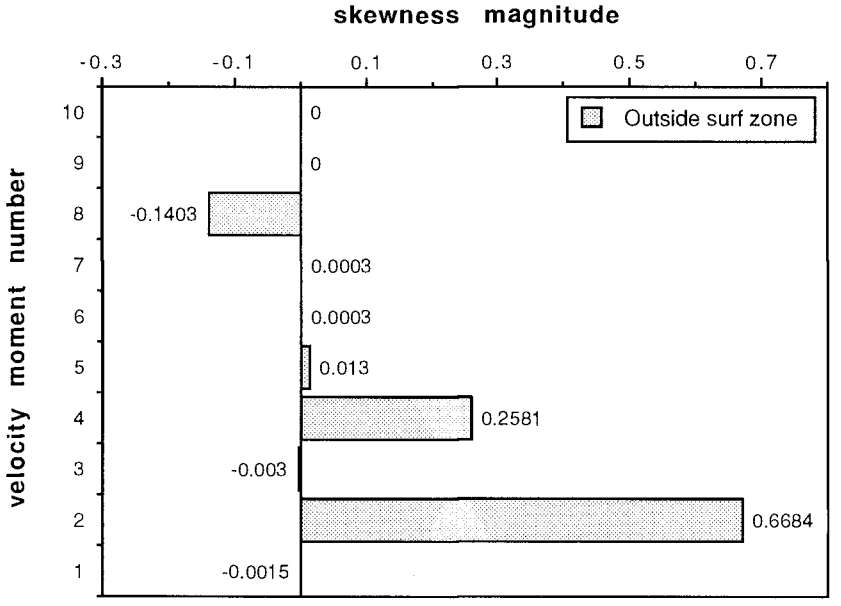

Figure 8(c). Tide 234PM skewness outside the surf zone.

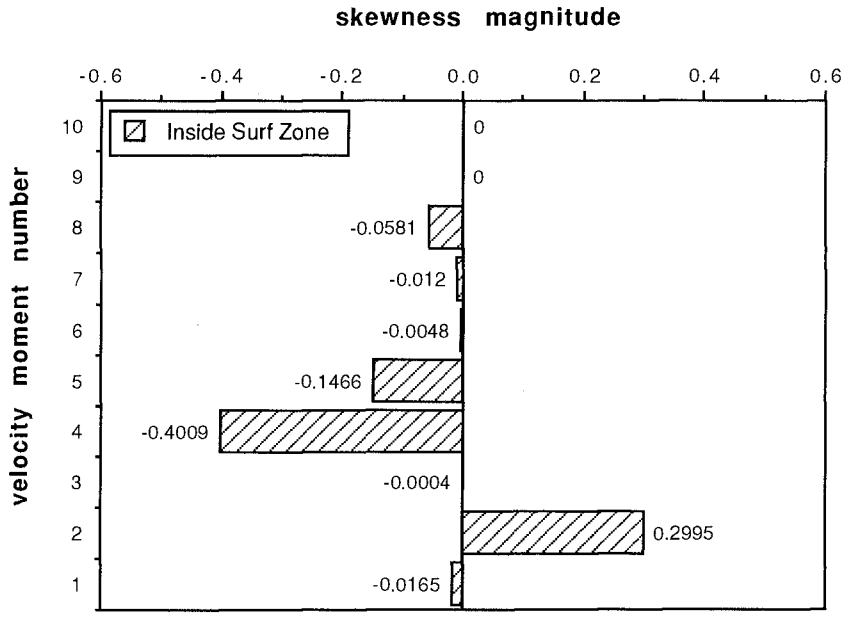

Figure 9(a). Tide 184PM skewness inside the surf zone.

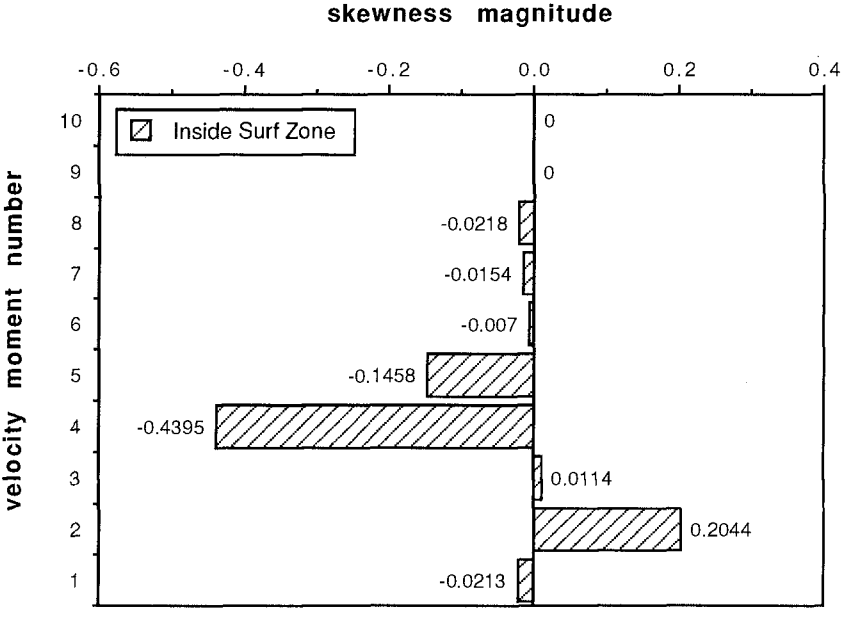

Figure 9(b). Tide 234PM skewness inside the surf zone.

Tide 164PM	Within the Surf Zone	No data collected*
Tide 184PM (Fig. 9a)	Within the Surf Zone	Terms 2, 4 and 5 dominate
Tide 234PM (Fig. 9b)	Within the Surf Zone	Terms 2, 4 and 5 dominate

* Storm too violent so data logging stopped.

Seaward of the surf zone, the terms which dominate are, therefore, Term 2 (the skewness of the short wave velocity), Term 4 (the Inman/Bagnold-type term where short waves mobilise the sediment which is then moved by a mean flow) and Term 8 (the term describing the correlation between the short incident wave groups and the long wave motion). Inside the breakpoint, those terms which appear to dominate the very nearshore wave field are Terms 2 and 4 (described previously) and Term 5 (the Inman/Bagnold-type term which represents the mobilisation of sediment by long waves and the subsequent movement by a mean flow). The similarity of these terms for each of the tides, not only in direction but also in percentage contribution to the total skewness implies a remarkable degree of consistency, independent of incident wave conditions. It is also interesting to note the variation of Term 8 through the nearshore system since this reflects the earlier wave groupiness analysis; Term 8 describes the correlation between the incident wave envelope and the long wave motion and its behaviour supports the cross-correlation work which shows a large negative value occurs outside the breakpoint in the deeper water and a trend towards zero and then positive values as the shoreline is approached (Figure 8).

4. CONCLUSIONS

The following conclusions can be drawn :

(i) Outside the surf zone the cross-correlation between the long wave motion and the wave envelope has a constant negative value and is relatively insensitive to depth. At the breakpoint the correlation decreases towards zero, whilst within the inner surf zone positive correlation values occur. The interaction between long waves and short waves varies systematically through the surf zone.
(ii) Wave groupiness does not decay immediately at the breakpoint. Instead there is a persistence of the groupiness through the surf zone. It is suggested that this might have important implications for modelling sediment response.
(iii) The terms dominating skewness inside the surf zone are : the skewness of the incident waves, the correlation between the incident wave energy and a mean flow, and the correlation between the long wave energy and a mean flow.
(iv) Outside the surf zone, the terms for the skewness of the short incident waves and the correlation between incident waves and a mean flow are dominant, in addition to the correlation between the wave envelope and the long wave motion.
(v) It would appear that the relative importance of these skewness terms is almost insensitive to the incident wave conditions measured on this beach.

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