CHAPTER 278

On the systematic offshore decay of breaker bars

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ABSTRACT

Multiple breaker bar systems along the Holland coast exhibit long term cyclic behaviour. Over periods of many years, all bars migrate in a net seaward direction; the outer bar decays offshore, and a new bar is generated near the shoreline. This behaviour is essentially a cross-shore redistribution of sediment; the sediment of the offshore decaying outer bar is transported back onshore.

This paper prcsents a tentative evaluation of a part of the hypothesis formulated by Wijnberg (1995) to explain the cyclic bar system behaviour. The systematic offshore decay of the outer bar is considered to be the key to explaining the cyclicity in this behaviour. The offshore decay is assumed to occur due to a change in the long term balance of bar maintaining conditions (breaking waves) and bar diminishing conditions (very asymmetric waves). This balance will change as a result of offshore migration of the outer bar to deeper water during single storm events.

The calculations presented in this paper support the hypothesis, but field observations of the hydrodynamic conditions during the proces of bar decay are required for a more rigorous verification.

1. INTRODUCTION

Along the Dutch coast, multiple bar systems of nearshore breaker bars exist that exhibit systematic, cyclic behaviour on a time scale of many years (Edelman, 1974; Bakker and De Vroeg, 1988; Ruessink and Kroon, 1994; Wijnberg and Terwindt, 1995). This behaviour consists of a net seaward migration of all bars, with the outer bar decaying offshore and a new bar being generated near the shoreline (Fig. 1). This

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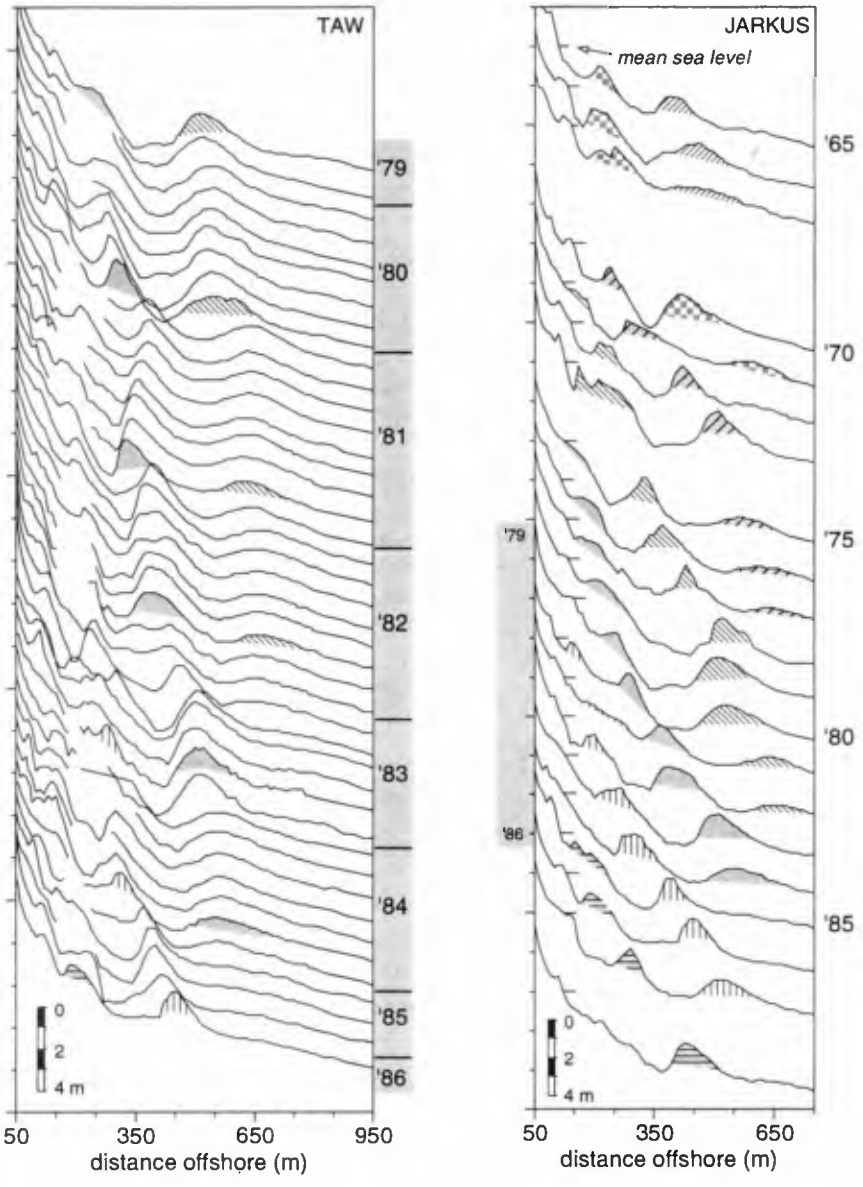

Fig. 1: Illustration of the offshore progression cycle for one profile line (line 8425). Left-hand figure based on TAW data base (several surveys per year, 1979-1986); right-hand figure based on JARKUS data base (one survey per year, 1965-1989). Bars are shaded to emphasise the offshore progression cycle; each bar has its own shading pattern through time.

behaviour implies that every so many years the same general cross-shore bar system configuration re-appears (i.e. when one offshore progression cycle has been completed). The time scale for the offshore progression cycle varies between bar systems, but seems to be quite constant for a given bar system (Wijnberg and Terwindt, 1995; Ruessink and Kroon, 1994).

Sediment budget considerations (Wijnberg, 1995; Wijnberg, in prep.) revealed that this cyclic morphologic behaviour is essentially a redistribution of sediment within the nearshore zone. So, although bar shapes are progressing in a net offshore direction, they are not representing a net offshore directed sediment transport. This implies that the sediment of the offshore decaying bar is transported back onshore.

The observed long term cyclic behaviour of multiple breaker bar systems is very intruiging in its own right, but may also have implications for the application and design of shoreface nourishments. For example, what is the best location and timing of a shoreface nourishment on a barred coastal profile? (eg. Hoekstra et al., 1994). Therefore, the identification of the mechanism that drives this systematic behaviour deserves further attention.

Wijnberg (1995) formulated a hypothesis to explain the cyclic bar system behaviour. In this hypothesis, which is briefly summarized in section 3, morphologic feedback in the coastal system is identified as the cause for the cyclicity in the bar behaviour rather than a cyclicity in the external forcing. The key to explaining the cyclic nature of the bar system behaviour is sought in the systematic offshore decay of the outer bar. In this paper, the part of the hypothesis dealing with the systematic offshore decay of the outer bar will be tentatively evaluated by studying the relation between the development stage of the outer bar and a wave climate integrated 'decay parameter'.

2. THE STUDY AREA

The hypothesis on the systematic decay of the outer bar will be evaluated for two multiple bar systems that exhibit similar cyclic behaviour but on a different time scale. The two multiple bar systems are located along the Holland coast (Fig. 2). These two bar systems have very different cycle times, viz. the bar system north of the IJmuiden breakwaters exhibits an approximately 15 year cycle, whereas the bar system south of the breakwaters has a typical cycle time of about 4 years. The alongshore change in the cycle times is rather abrupt, and coincides with the breakwaters (Wijnberg and Terwindt, 1995).

The northern bar system consist of 2 to 3 bars, depending on the phase in the offshore progression cycle (i.e. either 2 well developed bars or, in the case of 3 bars, a gentle outer bar and a small new inner bar, with a well developed middle bar in between). The whole bar system extents about 30 km alongshore.

In the southern bar system the number of bars changes alongshore: in the very south the number varies between 1 and 2, going north this changes into 2 to 3 bars, then 3 to 4 bars, and finally in the very north back to 2 to 3 bars. This bar system has a total length of about 40 km. The alongshore change in the number of bars has no obvious effect on the time span of the offshore progression cycle (Wijnberg and Terwindt, 1995).

Along the Holland coast, the mean wave height (H_{m0}) is about 1.2 m and the mean wave period (T_{m01}) is about 5 s; the mean tidal range is about 1.6 m. The grain size of the sediment in the breaker bar zone is generally in the fine sand range. There seems to be no significant difference in grain size between the two bar systems (Wijnberg, 1995)

Except for the large breakwaters that separate the two studied bar systems, the considered coastal stretch is almost free from engineering structures. In the northern bar system groins are present along about 5 km of beach at the northern end of the region (so still 25 km of beach has no groins). In the southern bar system a small discharging sluice is present (Fig. 2) which discharges some fresh water into the North Sea.

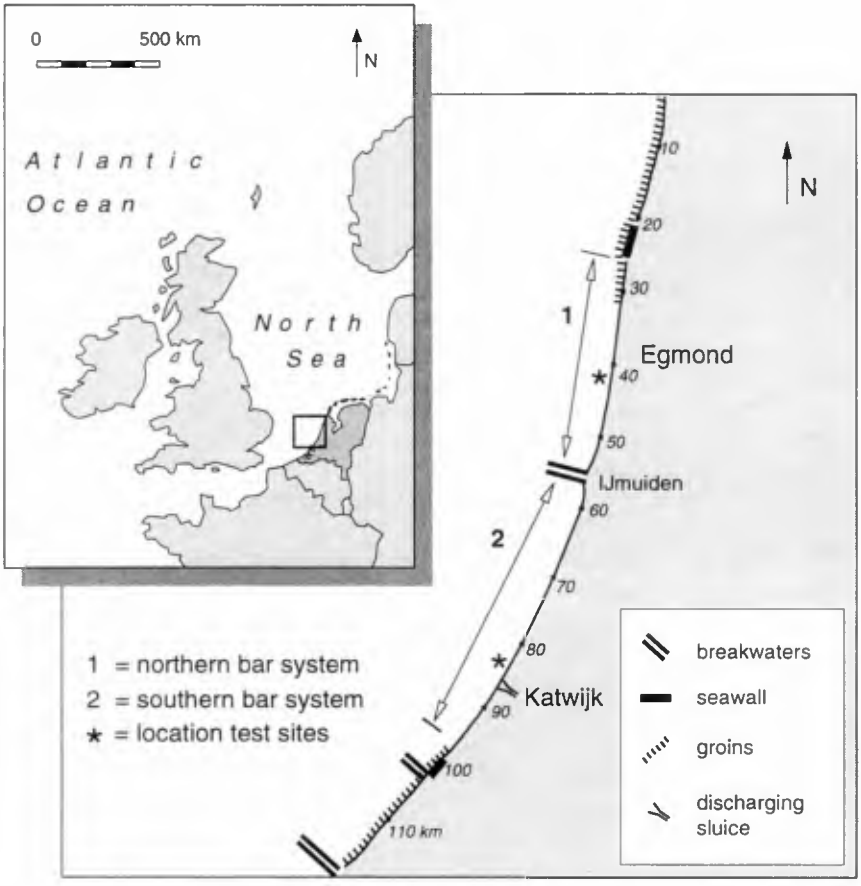

Fig. 2: Location of the study area

3. A CONCEPTUAL MORPHODYNAMIC MODEL

The multi-year cyclic behaviour of breaker bar systems can not readily be explained by existing theories on bar behaviour. These theories focus on the formation and maintenance of bar topography and pay little attention to the degeneration of bars. Our lack of understanding of the decay of bar features is illustrated by one of the findings of Roelvink et al. (1995) who mimicked long term cyclic bar behaviour with a cross-shore profile model. Roelvink ct al. had to prescribe a reduced angle of repose for the sediment in the outer nearshore zone to force the outer bar to decay offshore.

According to Wijnberg (1995; in prep.), the cyclicity in the long term bar behaviour is most likely explained by morphologic feedback in the breaker bar system rather than by cyclicity in the external forcing. To explain the observed cyclic bar system behaviour, a central role was attributed to the behaviour of the outer bar. As long as the outer bar remains well developed at a certain position, the inner bar(s) do not move net offshore and will only move to and fro within a limited cross-shore range. Only as the outer bar disappears can the inner bar migrate net offshore (cf. Lippmann et al., 1993). This key role of the outer bar is plausible because the outer bar will obviously affect the hydrodynamic conditions in a down-wave direction, and therefore systematically affects the wave and current climate in the inner nearshore zone. Therefore, attention is further focused on mechanisms that may explain the systematic decay of the outer bar.

It was hypothesized by Wijnberg (1995; in prep.) that the systematic decay of the outer bar occurs due to a changing balance in the occurrence of conditions that favour decay of the outer bar topography (%DCAY) and the occurrence of conditions that favour maintenance of the bar topography (%MAIN). The bar-maintaining conditions were identified as those with breaking waves across the bar, favouring the occurrence of break-point or long-wave mechanisms for the formation and maintenance of bar features. The bar-diminishing conditions were identified as those with very asymmetric waves across the bar (so the highest waves in the wave field will just start to break), allowing for an onshore directed sediment transport. A more complete justification for the choice of these two process 'regimes' can be found in Wijnberg (1995) or Wijnberg (in prep.)

The change in balance between the two types of conditions is induced by the offshore migration of the outer bar on a seaward sloping bed. The latter happens when the bar is migrating into deeper water during individual storm events, i.e. when waves are breaking on the outer bar. The deeper the bar gets, the less likely that bar-maintaining conditions occur. Consequently, the relative dominance of bar-diminishing conditions will increase. The rate of increase will depend on the characteristics of the wave climate.

4. METHODS

To evaluate the proposed mechanism for the systematic offshore decay of the nearshore bars, the balance of %DCAY and %MAIN will be calculated for various development stages of the outer bar (Fig. 3). The balance is expressed in terms of the decay parameter I_{decay}:

$$I_{decay} = \frac{\%DCAY}{\%DCAY + \%MAIN} = \frac{\%DCAY}{\%ACT} \quad (1)$$

%DCAY = mean annual percentage of occurrence of bar-diminishing conditions on the outer bar

%MAIN = mean annual percentage of occurrence of bar-maintaining conditions on the outer bar.

%ACT = mean annual percentage of occurrence of morphologically active conditions on the outer bar.

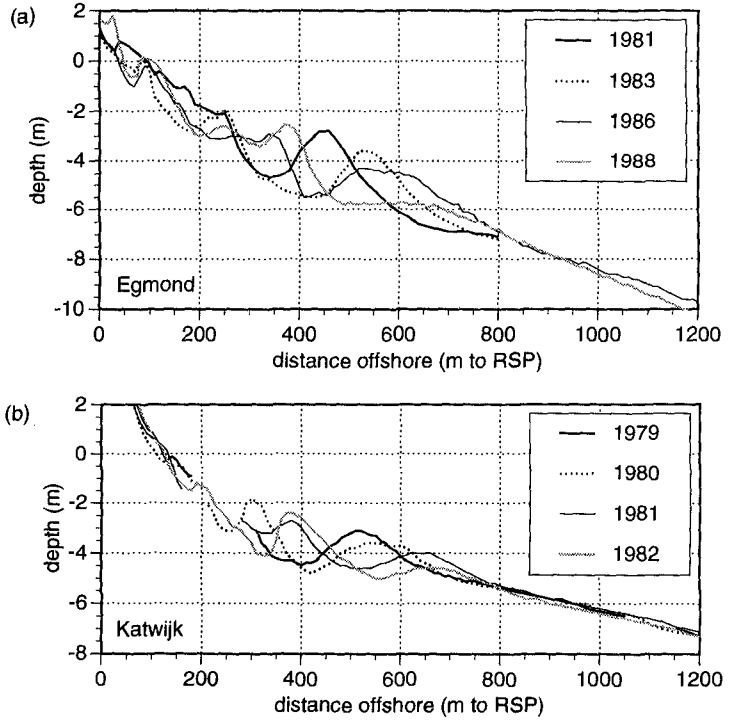

Fig. 3: Nearshore profiles used in the model computations at (a) the Egmond site, and (b) the Katwijk site. (All profiles extend down to about 20 m water depth.)

'Morphologically active conditions' (%ACT) are those conditions during which the outer bar is changing its morphology. This does not necessarily imply that during morphologically *in*active conditions the sediment is completely immobile; it is just so that any sediment transport under those conditions does not result in noticeable morphological change. The outer bar has been observed to be morphologically inactive during the calm summer months (Wijnberg, 1995).

Bar-maintaining conditions are defined (Wijnberg, 1995; Wijnberg, in prep.a) as those conditions that produce more than 5% of breaking waves on the bar. Bar-diminishing conditions are defined as those which produce only 0.1% to 5% of breaking waves on the bar. %DCAY and %MAIN are estimated from the mean annual offshore wave climate.

The data on the offshore hydrodynamic climate along the Holland coast are of the following type: a mean annual percentage of occurrence, $P(H_{m0},\alpha)$, and a mean water level elevation, $h(H_{m0},\alpha)$, arc available, with wave height bands of 0.5 m and wave direction bands of 15 degrees. The mean water level represents the average set-up or set-down that occurs during given wave conditions. H_{m0} and α are the central values of the wave height class respectively wave directional class that they represent.

To estimate %DCAY and %MAIN one needs to know the percentage of breaking waves occurring on the outer bar for each of the wave climate 'cells' (H_{m0}, α). Adding all $P(H_{m0},\alpha)$ for all (H_{m0}, α) cells that produce more than 5% of breaking waves gives %MAIN; adding all $P(H_{m0},\alpha)$ for all (H_{m0}, α) cells that produce between 0.1% and 5% of breaking waves gives %DCAY. The WAVIS model (Van Rijn and Wijnberg, 1996) was used to calculate the percentages of breaking waves for each (H_{m0}, α) cell.

Since WAVIS is a probabilistic type of wave model, a representative wave field (H_i,T_i, p_i, α_i) was generated for each (H_{m0},α)-cell, where: H_i is the central value of the i^{th} (0.25 m wide) wave height class; T_i is an empirically determined wave period that goes on average with H_i ($T_i = 6*H_i^{0.333}$ (Wijnberg, 1995)); p_i is the probablility of occurrence of the i^{th} wave height class assuming the wave heights are Rayleigh distributed; α_i was chosen constant for all wave height classes, viz. equalling α.

The values of %DCAY and %MAIN are calculated for the outer bars at two locations, viz. near Katwijk and near Egmond. The Katwijk site is located in the southern bar system, and the Egmond site in the northern bar system (Fig. 2).

5. RESULTS

5.1 The decay parameter and the development stage of the outer bar

The values of %ACT, %DCAY, %MAIN, and I_{decay} in relation to the depth of the outer bar crest are shown in Fig. 4, for both the Katwijk site and the Egmond site. The depth of the outer bar crest represents the development stage of the outer bar (Fig. 3). The depth of the bar crest is given relative to the Dutch ordnance datum NAP which approximates mean sea level.

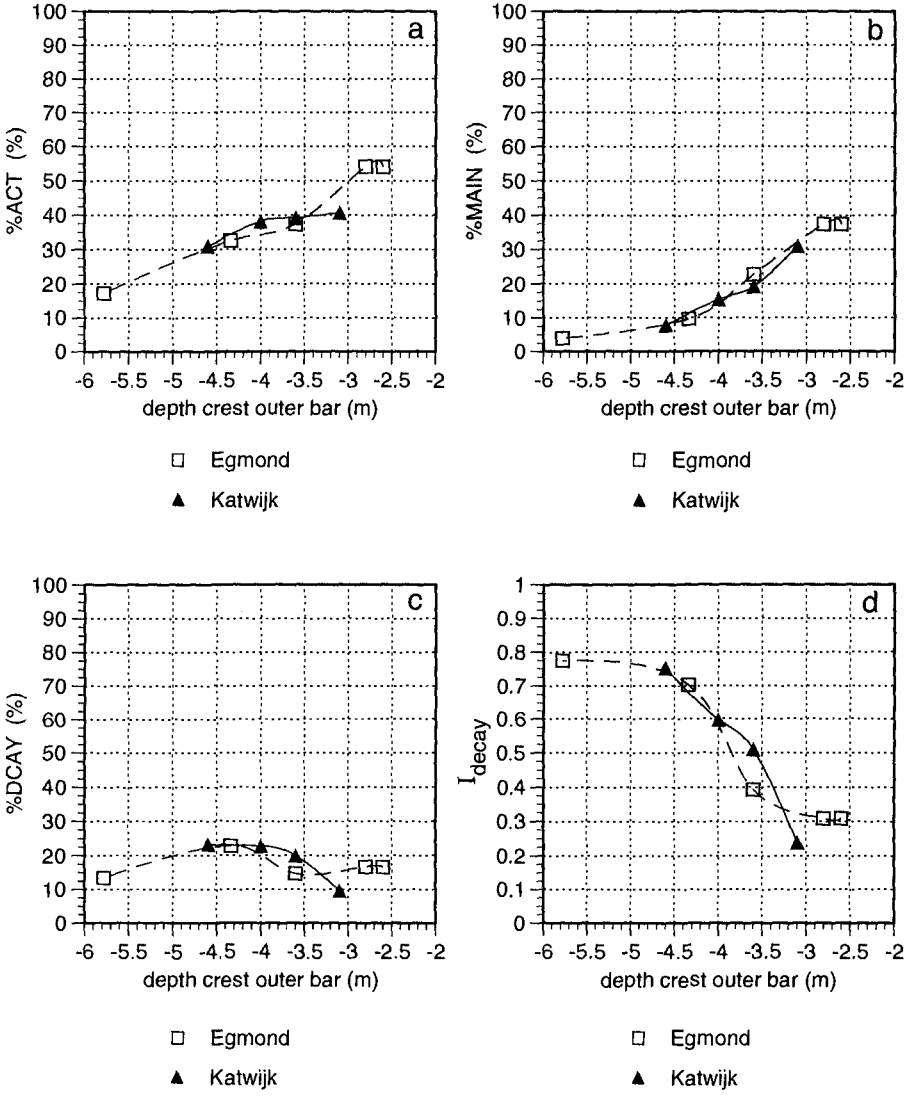

Fig. 4: Nearshore wave climate parameters as a function of the development stage of the outer bar. (a) %ACT, (b) %MAIN, (c) %DCAY, and (d) I_{decay}.

As expected, the percentage of time that morphologically active conditions occur on the outer bar decreases with the increase of depth of the bar crest (Fig. 4a). The percentage of time that bar-maintaining conditions occur on the outer bar decreases steadily with the increase of depth of the bar crest as well (Fig. 4b). The percentage of time that conditions occur that favour decay of the outer bar appears to vary between about 15% and 25% (Fig. 4c). %DCAY seems to reach a maximum around 4 to 4.5 m water depth. The balance between bar-diminishing conditions and bar-maintaining conditions, expressed by I_{decay}, changes with the depth of the crest of the outer bar. The deeper the bar crest, the larger the relative importance of conditions that favour bar decay (Fig. 4d).

The explanation for the fact that %DCAY does not steadily decrease with depth like %ACT and %MAIN, is the following. As the outer bar gets to deeper water, wave conditions that previously (i.e. when the bar was located shallower) produced just over 0.1% of breaking waves, will now produce less than 0.1% of breaking waves. Those wave climate classes will no longer add to the value of %DCAY. However, some of the wave climate classes that previously produced more than 5% of breaking waves on the outer bar will now produce between 0.1% and 5% of breaking waves, and consequently will add to the value of %DCAY.

5.2 Sensitivity of the decay parameter to the definition of %DCAY and %MAIN

The decay parameter I_{decay} reflects the relative importance of %DCAY vs. %MAIN and therefore depends on the definition of the two process regimes in terms of the fraction of breaking waves on the outer bar (Q_b). In this section, the extent to which the results shown in Fig. 4 are sensitive to the choice of the boundaries will be evaluated.

The sensitivity of the values of %DCAY and %MAIN, and consequently %ACT and I_{decay}, to the definition of the process regimes is analysed by plotting the cumulative percentage of occurrence of wave conditions with increasingly higher fractions of breaking (Q_b) waves on the outer bar (Fig. 5). These plots will reveal whether the values of %DCAY and %MAIN are sensitive to the choice of the boundaries between the process regimes in a reasonably close range around the previously defined values of Q_b=0.001 and Q_b=0.05. For the boundary between %DCAY and %MAIN a value of Q_b between 0.04 and 0.06 is considered, and for the lower boundary of %DCAY a value of Q_b between 0.001 and 0.01

The cumulation in the plots in Fig. 5 starts at a fraction of breaking waves of 0.001. Therefore, the cumulative percentage in Fig. 4 only refers to wave conditions that produce at least 0.1% of breaking waves on the outer bar. For example, on the bar crest at 3.1 m -NAP (Fig. 5a) about 22.5% of the mean annual wave conditions will produce between 0.1% and 8.3% of breaking waves on the outer bar (near Katwijk).

It appears that for the bar crest at 3.1 m -NAP, the variables %DCAY and %MAIN will be quite sensitive to the location of the boundary at Q_b=0.05. For the bar crest at 3.1 m -NAP about 11 % of the wave climate is enclosed in the discretely defined wave climate cells that produce a fraction of breaking waves of 0.055 on the outer bar (Fig. 5a). The value of %ACT will be hardly affected at this position of the bar crest.

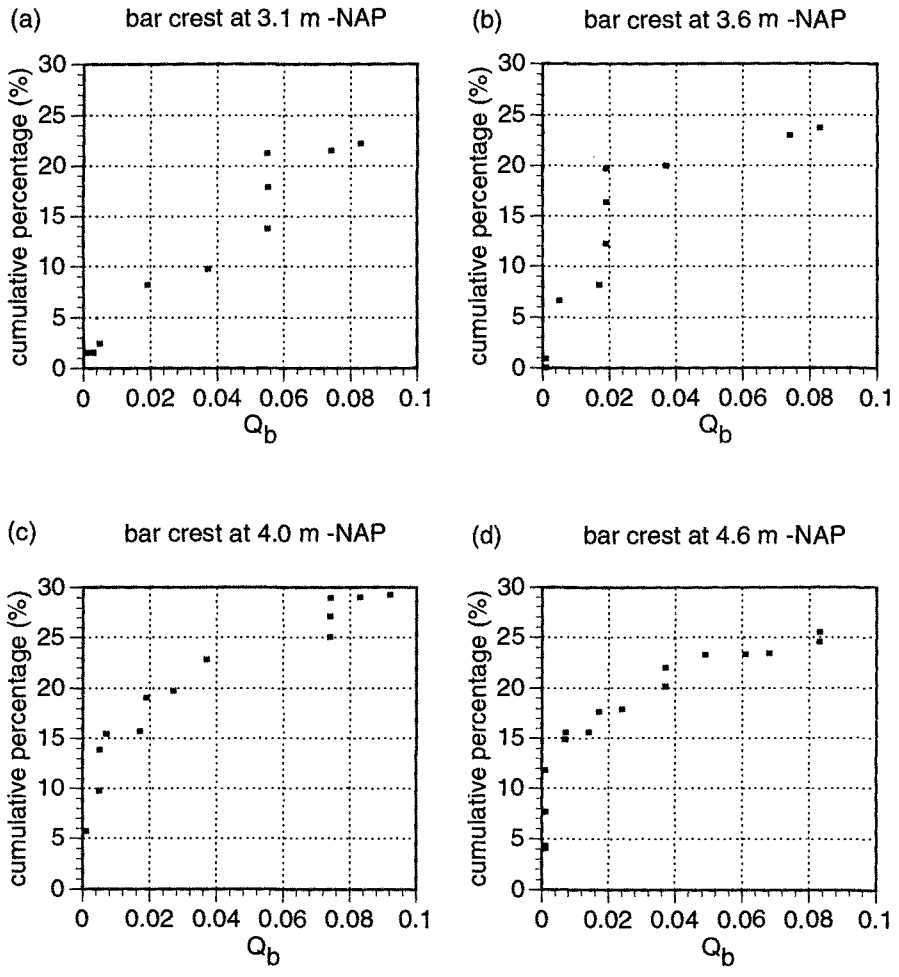

Fig. 5: Cumulative percentage of occurrence of wave conditions with increasingly higher fraction of breaking waves on the outer bar, for Qb≥0.001 (Katwijk site). (a) Bar crest at 3.1 m -NAP, (b) bar crest at 3.6 m -NAP, (c) bar crest at 4.0 m -NAP, (d) bar crest at 4.6 m -NAP

A comparable sensitivity to the Q_b=0.05 boundary exists at the Egmond site for the bar crests at 2.6 m depth and 2.8 m depth (not shown).

The values of %DCAY and %MAIN on the bar crest located at 3.6 m -NAP will be insensitive to a shift between Q_b=0.04 and Q_b=0.06 (Fig. 5b). However, %DCAY will be somewhat affected by a raise of the lower boundary to Q_b=0.01.

For the positions of the bar crest at 4 m -NAP and 4.6 m -NAP, about 15% of the wave climate appears to be enclosed in wave climate cells that produce a fraction of breaking waves between 0.001 and 0.01 (Fig. 5c,d). Consequently, for these deeper bars the choice of the boundary between morphologically inactive conditions and morphologically active conditions is quite important for the values of %ACT and %DCAY.

The sensitivity of %DCAY and %MAIN - and consequently of %ACT and I_{decay} - to the choice of the boundaries is related to the stepwise increase of cumulative "curves" shown in Fig. 4. This shape is probably related to the discrete description of the wave climate and the the discrete description of the input wave fields in the WAVIS model. Only a limited set of combinations of wave heights and wave directions is used for the wave climate description. Each single wave height represents an interval of wave heights and each single wave direction represents a sector of wave directions. In addition, the discrete description of the wave field input in the WAVIS model allows the value of Qb to change in discrete steps only.

The effect of the discrete description of the wave climate and wave field on Fig.4 can be smoothed by averaging over a set of calculations where the lower boundary of %DCAY was varied between Q_b=0.01 and Q_b=0.001, and the boundary between %DCAY and %MAIN was varied between Q_b=0.04 and Q_b=0.06. The result of the averaging is shown in Fig. 6. This figure appears to be very similar to Fig. 4. The smoothed figures, however, reveal more clearly the simmilarities and differences between the Egmond site and the Katwijk site.

5.3 Differences between the Katwijk and Egmond site

To discuss differences between the Katwijk and Egmond site the smoothed results are analysed (Fig. 6), because these are less affected by the discrete representation of the wave information (see section 5.2).

A difference between the Egmond site and the Katwijk site in the occurrence of morphologically active conditions (Fig. 6a) only occurs for the shallower positions of the outer bar (bar crests shallower than 3.5 m -NAP). At both sites, those shallower outer bars are still in the non-decaying stage of their development. In that non-decaying stage, the percentage of time that morphologically active conditions occur on the outer bar seems to be slightly larger at the Egmond site than at the Katwijk site.

The bar-maintaining conditions occur about equally often at both sites for the deeper positons of the outer bar (Fig. 6b). However, for bar crest positions shallower than 4 m -NAP the bar-maintaining conditions occur somewhat more often near Egmond than near Katwijk.

Regarding the bar-diminishing conditions (Fig. 6c), an obvious difference only occurs for the bar crest position at 3.6 m -NAP, where the bar-diminishing conditions occur more frequently near Katwijk than near Egmond.

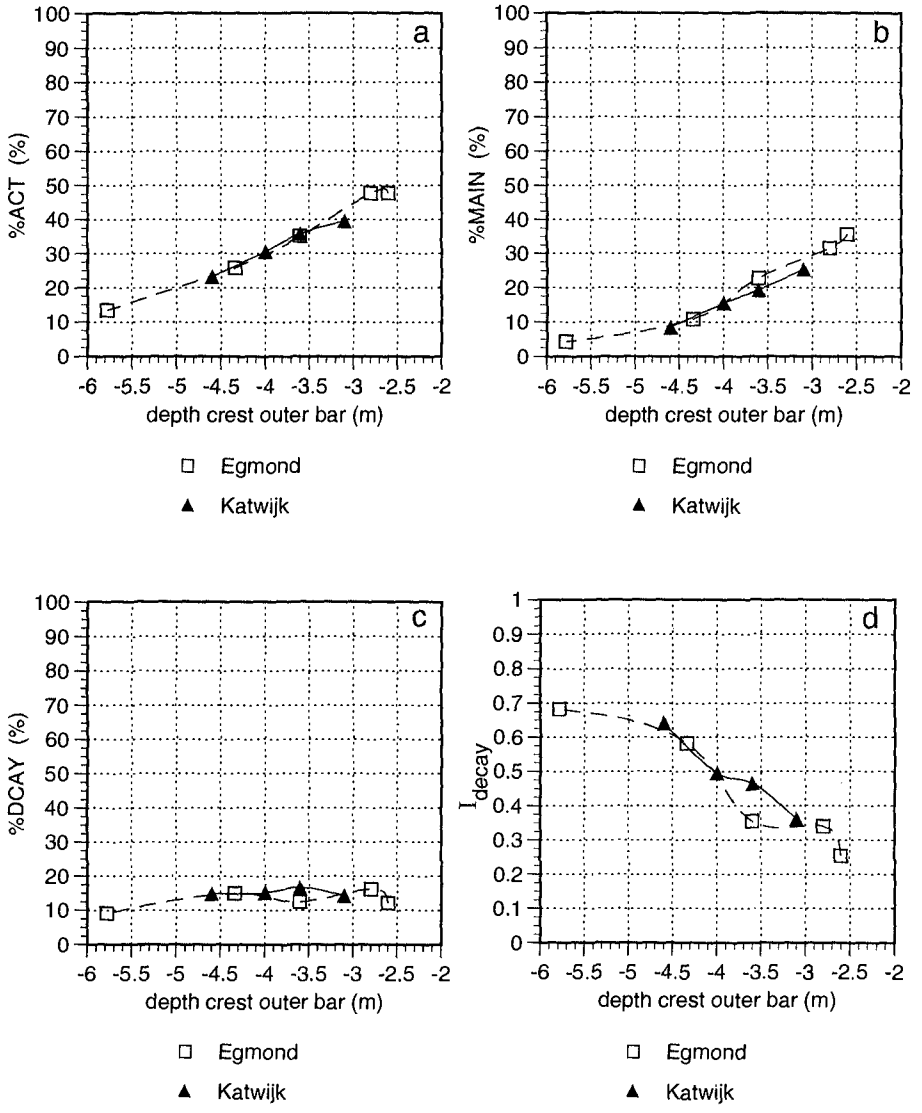

Fig. 6: Smoothed values of the nearshore wave climate parameters as a function of the development stage of the outer bar.
(a) %ACT, (b) %MAIN, (c) %DCAY, and (d) I_{decay}.

The slight differences between the %MAIN and %DCAY 'curves' for Egmond and Katwijk result in I_{decay} 'curves' for Egmond and Katwijk that clearly deviate for the bar crest position at 3.6 m -NAP. This discrepancy was consistently present irrespective ofthe exact definitions of the boundaries between the process regimes in terms of Q_b (Wijnberg, 1995). The relatively frequent occurrence of bar-diminishing conditions near Katwijk around 3.6 m -NAP coincides with the onset of bar decay at this location. Near Egmond, an outer bar with its crest at 3.6m -NAP is still in a non-decaying stage.

6. DISCUSSION AND CONCLUSIONS

The relationship found between the decay parameter and the development stage of the outer bar, as shown in Fig. 4d and 6d, supports the concept that the balance between bar-diminishing conditions (very asymmetric waves) and bar-maintaining conditions (breaking waves) is important for the fate of the outer bar. These results support the bar-decay hypothesis for two reasons. Firstly, the value of the decay parameter increases with the depth of the outer bar crest. This indicates an increase in the relative importance of the bar-diminishing conditions with depth, as was expected from the formulated hypothesis. Secondly, the difference between the Egmond and Katwijk site in the depth of onset of bar decay is well indicated by the decay parameter.

The results presented in Section 5 further indicate that the chosen definitions of the two process regimes in terms of the fraction of breaking waves (Q_b) enclose the relevant processes for respectively maintaining bar topography and diminishing bar topography. It is emphasized that no choice is made here for a particular mechanism that maintains the bar topography other than that this mechanism is directly or indirectly related to the occurrence of wave breaking. Long-wave mechanisms are therefore not excluded here (eg. bound long waves can be released in the surfzone by the breaking of the short waves).

The suggested mechanism for the systematic decay of the outer bar could not directly be verified with field observations. The currently existing bathymetric surveys in the studied area are to widely spaced in time to pinpoint the hydrodynamic conditions responsible for the observed (net) changes in the outer bar topography. The relatively wide spacing of the surveys is due to the fact that ships can only survey the nearshore bathymetry during relatively calm conditions, and consequently cannot survey during the conditions that are hypothesized to be important for the behaviour of the outer bar. Remote-sensing systems like the video-monitoring system introduced by Lippmann and Holman (1989) might be a valuable tool for obtaining the required high resolution morphologic information during the more severe wave conditions.

To conclude, the presented conceptual model for the systematic offshore decay of breaker bars seems viable. However, the results presented in this paper are considered to be supporting evidence for the hypothesis rather than a real proof of it. For a more rigourous verification of the conceptual model field observations are needed of the process of bar decay itself.

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