CHAPTER FORTY TWO

LOW FREQUENCY OSCILLATIONS ON THE DUTCH COAST

by

F. Gerritsen[1] and J. van Heteren[2]

1. INTRODUCTION

During several months in 1981 and 1982/1983 two extensive programs of field measurements were carried out at Egmond on the Dutch North Sea coast, one during the spring of 1981 and the other during the winter of 1982/83.

In these programs researchers of the Dutch "Rijkswaterstaat", of The Delft University of Technology and of the Delft Hydraulics Laboratory cooperated in the planning and execution of the measurements and are now involved in data analysis and evaluation of results.

During the year 1983 the senior author spent a sabbatical year with the Rijkswaterstaat in the Netherlands and joined the team effort in analyzing the data.

Reference is made to other papers presented at this conference, highlighting some aspect of this research program: Van Heteren and Stive (1984), Derks and Stive (1984).

The present paper deals with low frequency oscillations in the surfzone and their potential impact on certain aspects of coastal morphology.

The conclusions of this paper have to be considered as tentative and should be followed by further study.

Its main intention is to point to certain possible relationships regarding coastal morphology so that in future measurements the program can be designed in such a way that certain relationships can clearly and unmistakenly be identified.

The programs of measurements carried out in 1981 and 1982/83 were primarily designed to evaluate the usefulness and accuracy of various types of instruments in the surfzone. The measurements were never designed for the use we have made of them and results may therefore not be fully conclusive and thus subject to discussion.

Nevertheless the authors found their tentative findings of sufficient interest to share them with their colleagues.

---

[1] Professor and Chairman, Dept. of Ocean Engineering, Univ. of Hawaii

[2] Staff member, Rijkswaterstaat, Hellevoetsluis, The Netherlands

In the group of low frequency oscillations a distinction has been made between edgewaves and surf beat in this paper.

Edgewaves are characterized as waves propagating parallel to the shoreline and surf beat as waves travelling perpendicular to the shoreline. It is known to the authors that often low frequency oscillations are considered to be in the surfbeat frequency range, without distinction for direction.

For the purpose of studying their effect on coastal morphology a distinction in the two types of waves as discussed above is meaningful.

2. VARIOUS TYPES OF LOW FREQUENCY OSCILLATIONS IN THE SURFZONE

Many phenomena play a role in the generation of low frequency oscillations in the nearshore zone.
In this paper we will limit ourselves to the discussion of some relevant aspects of this subject.

Wave groups and mass transport

In recent years the presence of wave groups in a wave train has been recognized as an important feature, both in the development of coastal processes and in the design of coastal structures, such as breakwaters, In the past the study of the phenomena of wave groupiness has developed along two different lines; one is the correlation aspects of sequential waves in an observed or simulated wave record, the other is the analysis of the modulations in mean energy of a wave record. In this study a third approach is followed: the analysis of low frequency oscillations through spectral analysis.
Two important phenomena may be observed in wave groups:

(1) a lowering of the mean waterlevel associated with high waves in the group and a rising of the mean waterlevel in the group of low waves. This phenomena arises from the concept of energy conservation.
(2) a modulation in mass transport associated with the sequence of groups of high and low waves.

Outside the surfzone the first aspect demonstrates itself as a coupled long wave, which travels shoreward with the groupspeed of the waves, having a 180° phase difference with the center of the group of high waves. This wave is coupled to the wave height modulation of the group. At the breaking point the coherence of wave groups is destroyed; the low frequency wave is released from the group, travelling as a free wave toward the coastline, from which it is reflected in seaward direction. The reflected waves travels through the surfzone to deep water as a free wave.

With respect to the modulation in mass transport the breaking of high waves of a group induces larger onshore directed mass transport than the breaking of low waves. This phenomena again induces a free travelling long wave in the breaking zone, with a phase difference of

180° with respect to the first wave. The two waves cannot be distinguished from one another because they have the same frequency, associated with the group period.

Surf beat

The low period oscillation that is induced by the above described phenomena is here called surf beat. Inside the surfzone the surfbeat demonstrates itself as a standing wave of low period. In this zone both the incoming and reflected wave travel with the speed of a free travelling long wave, $c = \sqrt{gh}$. Outside the surfzone the incoming wave has the speed of the group velocity and the reflected wave that of a free travelling long wave. The seaward propagating free wave is often larger than the incoming forced wave (7).

It has been established that the amplitude of the surfbeat waves is dependent on the wave amplitude of the incoming wave.

According to Munk (11) the ratio of the amplitudes of long period oscillations to wind wave amplitude is about 1:10. This is probably valid for areas outside the surfzone. Inside the surfzone the ratio can be higher depending on depth and location (10).

Progressive edge waves

For a long time edge waves were regarded as a subject of pure hydrodynamical interest, with no or little practical significance. In more recent years, however, it has been established that the presence of edge waves can be of fundamental importance in the dynamics and sedimentology of the nearshore zone through their interaction with ocean swell and surfbeat to produce circulation cells and ripcurrent patterns.

Reports of the occurrence of edge waves in the literature indicate that they may come in vastly different dimensions (9).

Observations at Egmond in 1981 and in 1982/83 suggest that edge waves are also present along the Dutch coast.

Where surf beat waves were identified as waves which have their crest parallel to or almost parallel to the shoreline, edge waves have their crests perpendicular to the shoreline. A solution for the edge wave formulation for gently sloping beaches with constant inclination β can be obtained from the linearized shallow water equations (9).

The condition of trapping is reflected in the form of the dispersion relation, which for the shallow water wave approximation is given by

$$\sigma_n^2 = gk\,(2n + 1)\,\tan\beta \qquad (n = 0, 1, 2, \ldots) \qquad (1)$$

where $\tan\beta$ is the beach slope and n the edgewave mode.

The solution for a progressive edge wave is of the form

$$\zeta\,(x, y, t) = F(y)\, e^{\,i(kx-\sigma t)} \qquad (2)$$

in which the x-direction is parallel to the coast and the y-direction perpendicular to the coast positive seaward. k is the longshore wave number and σ the angular freqency. The function F(y) depends on the mode of the edgewave.

Edge waves have velocities in the x and y-direction, respectively parallel and perpendicular to coastline.

Trapping of edgewaves can also occur with different coastal profiles. A profile which is more realistic than the straight beach (from 0 to ~) has the form

$$h = h_0 (1 - e^{-\alpha y}) \qquad 0 < y < \sim \tag{3}$$

The behavior of edge waves for such a profile was studied by Ball (1). It can be shown (Huntley, (6)) that the entrapped modes must obey the condition:

$$\sigma_{cr} = [n (n + 1)]^{\frac{1}{2}} \alpha\sqrt{gh_0} \tag{4}$$

Experiments by Huntley (6) have furthermore shown that the frequencies of spectral peaks in the spectrum can be identified with the frequencies σ_{cr} for the consecutive modes. For a given offshore profile this can be expressed by:

$$f_{cr} = \text{const.} [n (n + 1)]^{\frac{1}{2}} \tag{5}$$

where $f = \sigma/2\pi$. This expression could be verified for the North Sea Coast near Egmond.

Cell circulation

A standing edge wave has surface variations according to:

$$\zeta (x, y, t) = F(y) \cos kx \sin \sigma t \tag{6}$$

Standing edge waves are of particular relevance to coastal morphology.

Both theoretically and experimentally it can be shown that standing edge waves induce a nearshore cell circulation. Kaneko (8) developed a numerical simulation for cell circulation under the influence of standing edge waves on a sloping beach. He considered three conditions:

(a) Cell circulation due to edge waves only.
(b) Cell circulation due to superposition of edge wave and leaky-mode wave (with crest parallel to shoreline) with leaky mode having half the period of the edge wave (subharmonic edge wave). Leaky mode waves are defined as waves, which are not trapped to the coast.
(c) Cell circulation due to superposition of edge wave and leaky-mode wave of the same period (synchronous edge wave).

The leaky mode waves of interest here are the surfbeat waves. The numerical circulations showed that in the cases (a) and (b) the circulation cells which developed, had the same form whereby two circulatory

cells developed each in size equal to one half the wave length of the edge wave. In the second case the velocities were considerably stronger than in the first case. The third case (c) showed a different behavior. Two cells developed along the full length of the edge wave whereby circulatory velocities became fairly strong in case the amplitudes of the two waves had equal value.

3. ANALYSIS OF MEASUREMENTS

Measurements

For a complete description of the measurements reference is made to Derks (2). In 1982/1983 two parallel traverses A and B were erected. Traverse A contained four platforms, traverse B only piles.

In Figure 1 the offshore profile in Traverse A and the measuring stations (A1 - A9) are shown.

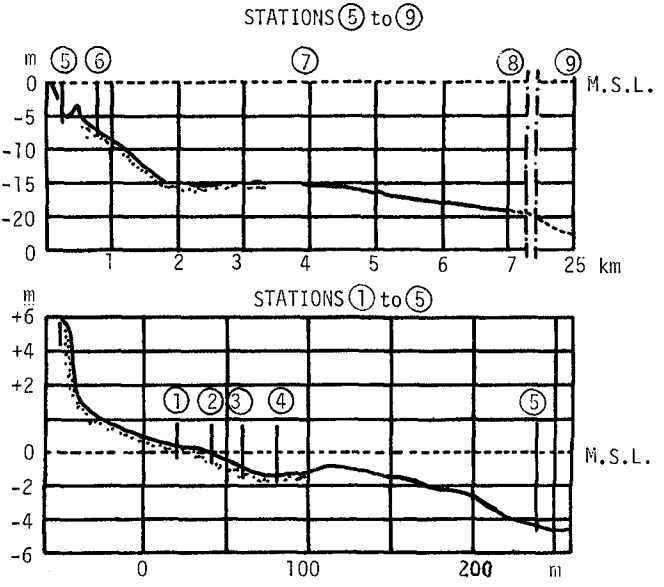

Figure 1: Depth-profile and measuring stations
Traverse A, Stations A1 - A9.

Waves were measured with resistance gages where supporting piles were available and with wave buoys in deeper water. For currents various types of sensors were used.

Digital filtering

A low pass filter has been developed, which suppresses the energy of wind wave frequencies of the spectrum. In order to remove the high frequency oscillations from a waterlevel or velocity record, a moving-average procedure is applied. The length of the record section to which the averaging is applied must be long enough to filter out the high frequency oscillation but short enough to retain the type of oscillations in which we are interested. As a general measure an averaging period of one to two times the peak period of the wave spectrum is an adequate procedure. The application of a moving average system in the time-domain corresponds with a frequency response in the frequency-domain.

If the window function in the time domain has a length 2τ and a height of $1/2\tau$ then the frequency response function is

$$H(f) = \frac{\sin 2\pi f\tau}{2\pi f\tau} \qquad (7)$$

This function has zero crossings for $f\tau = 0.5, 1.0, 1.5, \ldots$. If a number of moving average procedures are applied in series, one finds the impulse response by convolution of the individual weighting functions and the frequency response as the product of the individual frequency response functions.

Based on the above described procedures various low pass filters were designed and applied to selected data. For the 1982/83 observations the original time series was sampled at a frequency of 10 Hz. It was found that a reduction of the number of data points in ratio 1:24 could be applied without loss of relevant information. ($\Delta t = 2.4$ sec).

Characteristics of the selected low pass filter were the following:

(1) Use of the running average procedure 3 times in series with equal block length. This corresponds to a filtering characteristic

$$H(f) = \left(\frac{\sin 2\pi f\tau}{2\pi f\tau}\right)^3 \qquad (8)$$

(2) Selection of block length 2τ in such a manner that

$$H(f) = 0.5 \quad \text{at } f = \frac{1}{4T_p},$$

where T_p is the peak period of the wave or velocity spectrum. This condition gives $2\tau = 1.465\ T_p$.

(3) A further reduction of data points in sequential time series in ration 1:8. The characteristic low pass filter obtained in this way is shown in Figure 2-a.

In addition a high pass filter of the form of Figure 2-b was applied to remove low frequency trends such as the tide. The combined effect is shown in Figure 2-c.

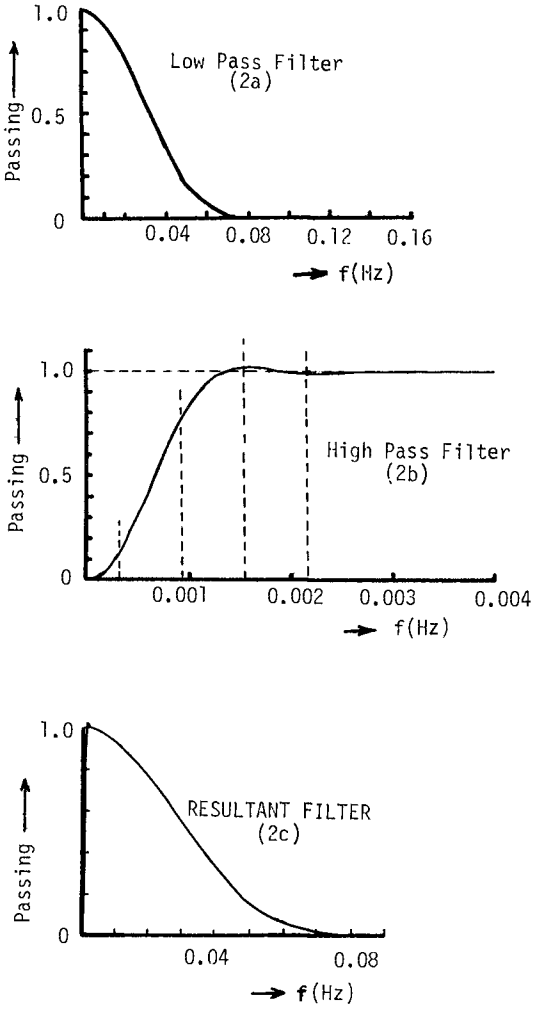

Figure 2. Numerical filter characteristics (T_p = 7.5 sec).

Required resolution of low pass filter

In the beginning of the study measuring series of about 1800 seconds in length were used for analysis. In order to obtain sufficient accuracy (10 subseries) the resolution step could not be smaller than $\Delta f = 0.0029$ Hz. It appeared that this type of resolution would smooth most of the edge wave energies. To overcome this problem a longer length of time series was required. For this five hour records were selected which reduced the resolution step to $\Delta f \simeq 0.0006$ Hz. A five hour time series also has serious drawbacks. It is likely to violate the requirement of stationarity of the low frequency oscillations due to changes in tide and wave conditions over that period. In the future record lengths of 3 hours will be utilized. This period is selected before and after high water to have minimal effect of the tide on the low frequency phenomena.

4. RESULTS OF INVESTIGATIONS

The results of the investigations relate to three different aspects of the problem:

(1) The characteristics of the low frequency spectra (both waterlevel and velocities)
(2) The effect of low frequency oscillations on horizontal circulation (spacing of rip currents)
(3) Relationship of low frequency oscillations to beach profile characteristics

Low frequency spectra

The analyzed data included the measurements of Spring 1981 as well as of Winter 1982.

Space limitations do not allow us to present the results of both measurement series. In this paper only results of 1982 will be presented.

For this paper the measurements of 10 December 1982 were selected. This series is characterized by significant wave heights ($H_s = 4\sqrt{m_0}$) and peak periods as follows:

Sta A9 :	$H_s = 2.56$ m	$T_p = 7.5$ sec
Sta A8 :	$H_s = 2.18$ m	$T_p = 6.95$ sec
Sta A6 :	$H_s = 2.14$ m	$T_p = 7.5$ sec
Sta A5 :	$H_s = 1.64$ m	$T_p = 6.75$ sec

The low pass filter, described in section 3 is based on a peak period for the offshore waves of 7.5 sec.

The wave spectrum in Sta A5 is presented in Figure 3.

The results of the low frequency spectra obtained by applying the low and high pass filters are presented in Figures 4 through 7.

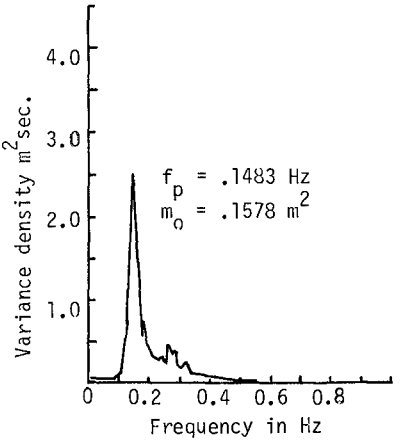

Figure 3. Wave spectrum in Station A5

In figure 4 the low frequency wave spectra are shown for stations A2, A3, A4, and A5 (stations 2 - 5 in traverse A).

The type of oscillations present in these spectra include the surfbeat types (waves travelling perpendicular to the shoreline) and the edgewave types (waves travelling parallel to the shoreline).

Without further information the distinction between these two types of oscillations is difficult to assess.

To assist in the distinction of these types the following additional information was utilized.

(a) Directional information obtained from horizontal velocity components;
(b) Phase spectra (phase of wave in one station compared to the next station).
(c) Coherence spectra, giving correlation between one oscillation and another.
(d) Horizontal circulation patterns.

By considering the above information in addition to the low frequency spectra the following picture emerges:

In almost all low frequency spectra a dominant peak occurs at a frequency between 0.0012 and 0.0033 Hz (This peak is clearly dominant in Figure 6[a] and 7[a].). This peak is attributed to the zero mode edge wave. The sharp peaks visible e.g. in Figure 4 are contributed to edge wave peaks of higher modes. The peaks in Stations A2, A3, and A4 are superimposed on three broad bands of low frequency energy. The middle one, between frequencies 0.012 Hz and 0.024 Hz contains the largest amount of energy and is believed to represent the major surfbeat mode.

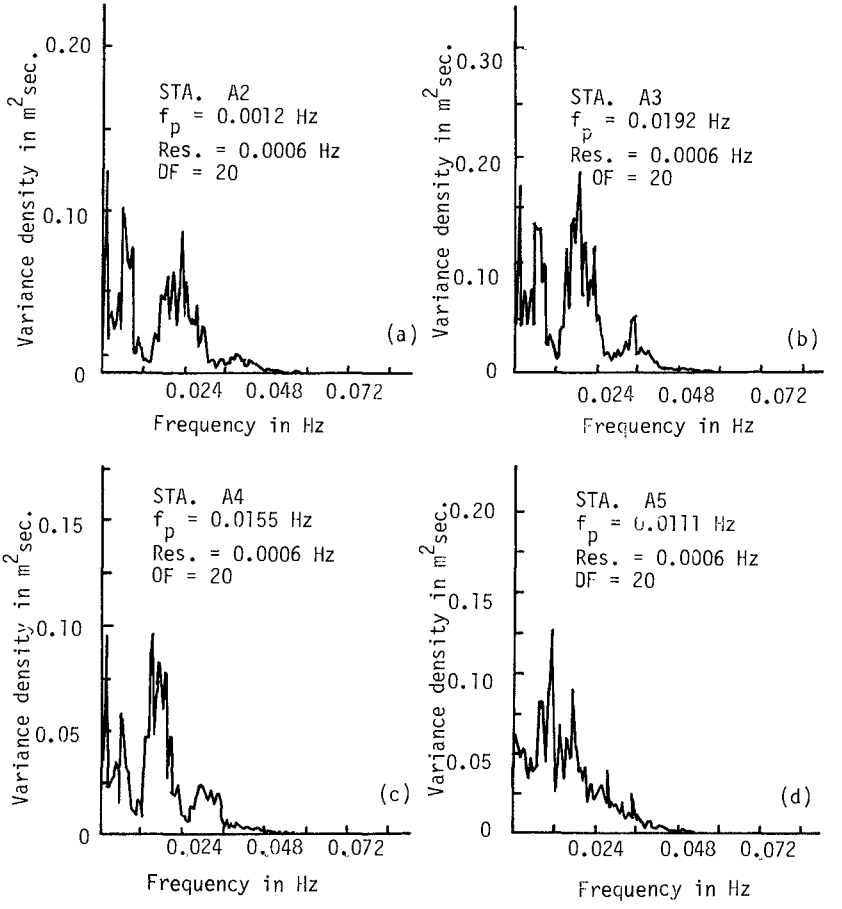

Figure 4: Low frequency wave spectra for stations A2 - A5

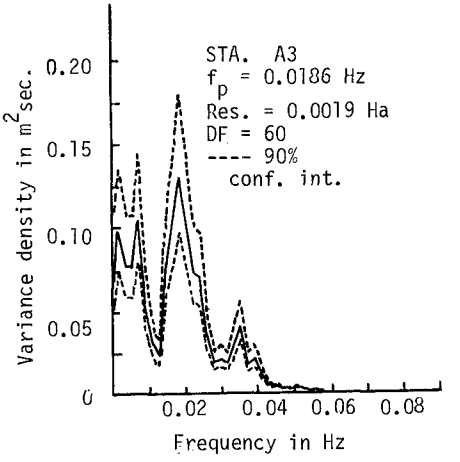

Figure 5. Low frequency wave spectrum for Sta. A3 for different resolution and degrees of freedom

The bands on either side also contain surfbeat energy. It is of interest to consider the frequency at which the major surfbeat energy has its maximum density and to relate this to the peak frequency of the offshore waves:

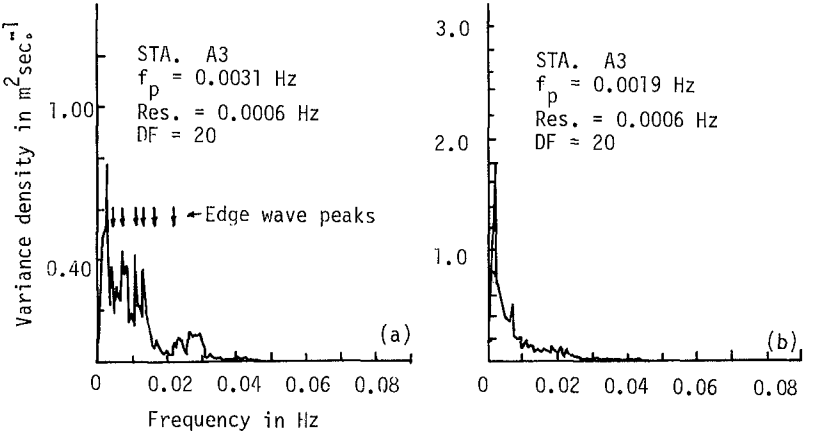

Figure 6. Low frequency spectra for velocity components (a) Perpendicular to coast; (b) parallel to coast

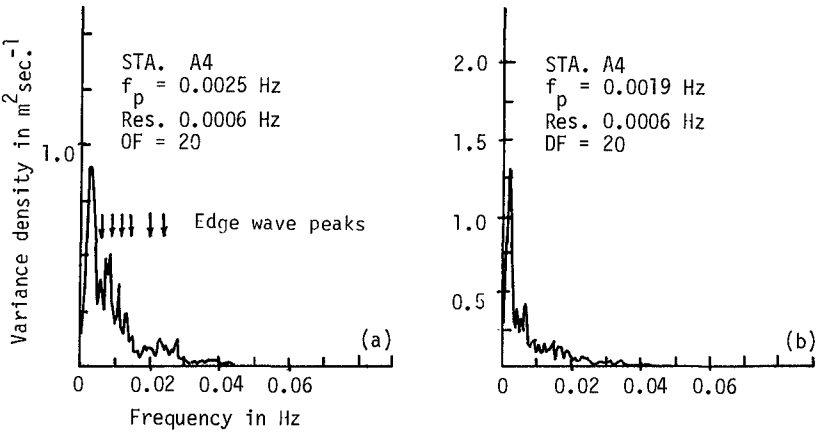

Figure 7. Low frequency spectra for velocity components
(a) perpendicular to coast;
(b) parallel to coast

In station A5, f_p = .1483 Hz.

For stations 2-4 we have (f_{ps} denoting the peak of the surfbeat energy):

Sta A2: f_{ps} = 0.024; fp/fps = 6.2

Sta A3: f_{ps} = 0.019; fp/fps = 7.8

Sta A4: f_{ps} = 0.015; fp/fps = 9.9

with an average value (for stations 2 to 4) of 8.0.

In order to compare total energy values for the three different surfbeat modes it must be realized that due to the application of the filter, energies in the higher frequencies are undervalued compared to the values corresponding to the lower frequencies. Since the filter characteristics are known this can be compensated for. However, this is not necessary where spectra are used to identify where peaks occur. In this study this compensation was not applied.

Keeping this in mind and going from Station A4 to Station A2 there is a shift of energies to lower frequencies in a relative perspective. The highest variance density (0.18 m^2sec) is present in Station A3; this value however includes some edge wave energy as well. The sharp peaks in the spectra for stations A2 and A4 are also considered to represent edge wave energy. The grouping of surfbeat energy is less distinct at Station A5 (Figure 4d). The individual peaks are also considered edge wave peaks.

One method to filter edge wave energy is to use a larger resolution frequency step (0.0019 Hz) and obtain a higher degree of accuracy (Oegrees of freedom = 60). See Figure 5, showing an example of this approach for Station A3.

Figure 6 and 7 present the low frequency spectra for onshore and alongshore velocity components for Stations A3 and A4.

It is to be noted (Figure 6[a]) that where surfbeat energy is high (f~ 0.02 Hz) onshore velocities are low. This corresponds with the situation at standing waves, at a location close to the nodal point.

An example of the calculated phase spectrum between surface elevations of Stations A2 and A3, is presented in Figure 8. Both edge wave peaks of low frequency and surfbeat peaks have phase = 0, as expected (standing waves). The coherence function for the same quantities is shown in Figure 9, showing high coherence for the very low frequency oscillation as well as the surf beat modes.

The resolution of 0.0019 Hz used for the analysis in Fig. 8 and 9 smoothes the edge wave energy and therefore does not allow identification of edge wave peaks.

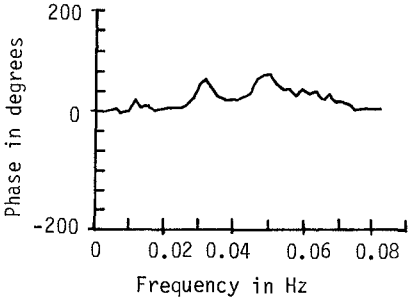

Figure 8. Phase spectrum (waterlevel) for Stations A2 and A3

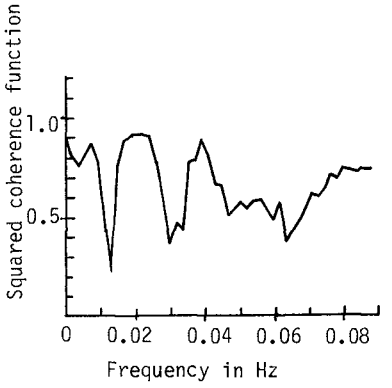

Figure 9. Squared coherence function (waterlevel) for Stations A2 and A3

Figure 6[a] and 7[a] have been used to plot the (assumed) edgewave frequency peaks as a function of the mode number. The results are plotted in Figure 10 and validate the relationship given in equation (5), with the value of the constant equal to 0.0031.

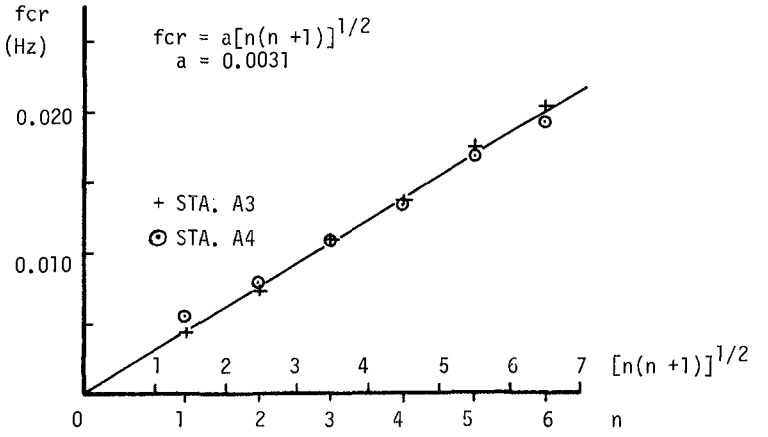

Figure 10. Edge wave frequency peaks as function of mode number for velocities perpendicular to coast. (reference Figure 6(a) and 7(a)).

Massel and Musielak (10) found for the Baltic Coast at Lubiatowe for the constant value 0.0041, which is somewhat higher but of the same order of magnitude.

An offshore profile of exponential shape is given by relation (3):

$$h/h_o = 1 - e^{-\alpha y}$$

If h_o = 16m and α = 0.001315 (obtained form equation(5)) a reasonable approximation for the offshore profile at Egmond is obtained.

The effect of low frequency oscillations on horizontal circulation

In section 2 a description is given of possible circulation patterns induced by edgewaves or by edge waves and surfbeat waves combined.

With respect to ripcurrent distances along the Dutch Coast reference is made to Ten Hoopen and Van Driel (5). They found that along the Dutch coast ripcurrent distances varied from 150 to 1850m with an average distance of 785m. Aerial photographs of the Egmond coastline in 1981 show an average distance of rips of about 1300-1400m whereas the 1983 photographs showed shorter distances, 600-700m. Unfortunately there is no extensive information available for the circulation patterns and rip current distances at the date of the measurements except some local observations near the measuring site showing ripcurrent distances of 500-700m.

In view of the characteristics of the low frequency spectra, discussed above, it is feasible that a zero mode edge wave occurs by itself or simultaneously with a surf beat wave of double frequency, a situation corresponding with respectively the conditions (a) or (b) of the combi-

nation listed in section 2. The length of the complete circulation cell is than half of the wave length of the edge wave. Taking 700m as the distance between ripcurrents the zero mode edge wave length is then 1400m and the corresponding frequency for the zero mode edge wave (equation (1) for n = 0) is: $\sigma = 1.92 \times 10^{-2}$rad/sec and $f = \sigma/2\pi = 0.0031$ Hz. The corresponding first mode is $f(1) = f(0)\sqrt{3} = 0.0053$Hz.

The value f(0) = 0.0031 Hz corresponds with the major low frequency peak in Figure 6a (Station A3). In this figure the next peak is either at f = 0.004Hz or 0.005Hz. The assumption of a zero mode edge-wave peak at f~0.003 corresponding to a wavelength of 1400m therefore appears to be in general agreement with observed rip current patterns.

Relationship between low frequency spectra and beach profile characteristics

It is beyond the scope of this paper to discuss the various mechanisms that contribute to the formation of longshore bars and troughs. In this study we will only investigate if the dimension of troughs between offshore bars has any relationships with the major surfbeat wave. It is suggested that the following mechanism may play a part in the bar and trough formation. During high wave conditions (storms), waves break on the second bar. During this process due to variable mass transport a surfbeat type standing wave is induced with its nodal points at the first and second bar (see Figure 11).

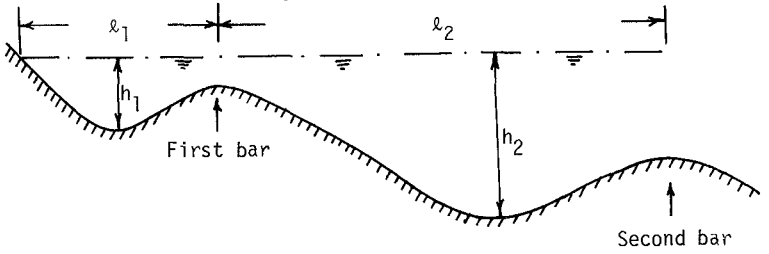

Figure 11. Schematic offshore profile

If such a concept would be correct the following relationship should be valid:

$$T = 2\ell_2 \left\{ \frac{1}{\sqrt{gh_2}} \right\} \qquad (9)$$

whereby T is the dominant surfbeat period and ℓ_2 the distance between first and second bar.

The overbar signifies the average value over the trough of $\left\{ \frac{1}{\sqrt{gh_2}} \right\}$. In first approximation the above expression for T can be written as:

$$T = \frac{2\ell_2}{\sqrt{gh_2}} \qquad (10)$$

Expression (10) was tested for a significant number of profiles during different times of their development. See also Nanninga (12). It was found that for most of the observations the value of T ranged from 75 to 85 sec.

Observations during storms on December 21 and December 27, 1982 showed a peak period of waves offshore of 9.0 sec.

The conditions during storm are selected because it is assumed that under those conditions bedforming activities occur. The ratio of the values of T found above and the peak period during storms then ranges between 8.3 and 9.5, which is similar to the ratio found in section 4 for station A3 and A4 (respectively 7.8 and 9.9).

In station A5 which is located in the trough between first and second bar, an (assumed) surfbeat peak occurs around f=0.011 Hz corresponding to a period of 90 seconds. The above suggests a fairly good correlation between the period T, defined above and the period at which surfbeat energy peaks. It is suggested that further investigations are in order to validate this relationship.

For the channel between first bar and coastline two possibilities are open:

(1) The width of this channel could correspond to 1/4 wave length with an anti-node located at the coastline. In that case, T would range from 110 - 130 sec. and does not correspond to the same surfbeat peak period. However there is a possibility that a correlation with the surfbeat mode at lower frequencies may be found.

(2) The width of this channel could correspond to 1/2 of the local wave length with an offshore bar starting to develop near the shoreline. In that case T would range from 55-65 sec. which is 6.1 to 7.2 times the peak period. This is close to the observed values listed in 4 for Station A2 and A3 (respectively 6.8 and 7.8).

5. CONCLUSIONS

(1) It is concluded that low frequency oscillations in the surfzone may contribute in different ways to bedforming conditions of the Dutch North Sea coast.

(2) Evidence is found of the following specific influences of low frequency oscillations on the Dutch coastline:

   (a) Edge waves in possible combination with surfbeat are likely to influence horizontal circulating patterns and the spacing of rip currents.

   (b) Surfbeat oscillations seem to have a bedforming influence on the offshore profile.

6. ACKNOWLEDGEMENTS

The authors wish to thank A.P. Roskam for assistance in computer programming and data analysis.

The senior author wishes to express his appreciation to the Dutch Rijkswaterstaat for the opportunity to participate in their studies.

7. REFERENCES

1. Ball, F.K. (1967) "Edge waves in an ocean of finite depth", Deep Sea Research, 14, 179-88.

2. Derks, H. (1982, 1983) "Measurements in the surfzone near Egmond", Reports Delft Hydraulics Laboratory, R 1597, parts I - VI.

3. Derks, H. and M.J.F. Stive (1984) "Field investigation in the T.O.W. study program", Proceedings 19th ICCE, Houston.

4. Heteren, J. van and M.J.F. Stive (1984) "Wave kinematics and directionality in the surf zone", Proceedings 19th ICCE, Houston.

5. Hoopen, H.G.H. ten and G.B. van Driel, "Report aerial photographs, rip currents - investigations , nota WWKZ-79G.013., Rijkswaterstaat, The Netherlands.

6. Huntley, D.A. (1976) "Long period waves on a natural beach", J. Geophys. Res., 81, 6441-6449.

7. Huntley, D.A., T. Guza and E.B. Thornton (1981) "Field observations of surf beat, 1. Progressive edge waves", J. Geophys. Res., vol. 86, no. C7, pp. 6451-6466, July 20.

8. Kaneko, Arata (1983) "A numerical experiment on nearshore circulation in standing waves", Coastal Engineering, 7, 271-284.

9. Le Blond, Paul H. and Lawrence A. Mysak (1978) "Waves in the ocean", Elsevier Oceanographic Series 20, Elsevier Scientific Publishing Co., Amsterdam Oxford, New York.

10. Massel, Stanislaw, and Stanislaw Musielak (1980) "Long-period oscillations in surf zone", Polish Academy of Sciences, Institute of Hydroengineering - Gdansk, Hydrotechnical Transaction, vol. 41.

11. Munk, W. (1949) "Surf beats", Eos Trans., AUG 30, 849-854.

12. Nanninga, H. (1983) "Morphological behavior of the surfzone near Egmond, from local field measurements", Final Project Report, Delft University of Technology.