CHAPTER 71

EDGE WAVES AND THE LITTORAL ENVIRONMENT

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ABSTRACT

Several types of beach features seem to have a rather regular, longshore pattern. This pattern may indeed be sufficiently uniform to be described in terms of a recognisable longshore wavelength. A likely explanation for such features lies in the motion of edge waves, surface waves trapped by refraction to the shoreline. These waves, by themselves or by interaction with the normal, incoming surface waves breaking on the beach, can generate longshore features having a wavelength equal to or half the edge wave wavelength.

If a broad spectrum of edge wave modes were present any longshore variation should appear rather irregular. The existence of regular features therefore suggests that a particular edge wave mode is often dominant, the characteristics of the dominant mode depending on the geometry of the nearshore area and the width of the surf zone.

Any new, artificial structure stretching seawards provides new boundary conditions, almost certainly altering the characteristic of the edge wave spectra. This is particularly obvious in the case of a regularly spaced structure such as a set of groynes. A deeper understanding of the edge wave processes is needed so that the induced changes in the edge wave spectra are the least deleterious or, an intriguing possibility, advantageous.

INTRODUCTION

It would be very convenient if one could take measurements along a line perpendicular to a beach and assume that these were representative of any line normal to the beach. In fact, even on very long, straight beaches, this is never the case. The existence of rip currents, beach cusps, offshore bars of crescentic shape or straight bars with rip channels all provide a longshore perturbation on the system. A large number of different, and in some cases rather extraordinary, theories have been proposed to explain the existence of each of these phenomena, but in the absence of any comprehensive explanation, the engineer has been forced to regard them as annoying noise, making small scale or spot measurements of either sediment or water movement particularly difficult to interpret.

There are indeed situations where the longshore perturbations are not readily apparent, the rip currents are weak and ill defined and regular, longshore features in the sediment are rarely observed, this is the case when small waves approach a coast obliquely - a situation often studied at laboratory scale. One also has situations, perhaps common on the Californian coast where the perturbations in the flow are obvious with very well developed rip currents but the sedimentary features the bars and cusps are rarely well developed. (Shepard & Inman, 1950). Finally the sedimentary features may be so well developed that they appear to completely control the nearshore flow (Sonu, 1972).

At some stage the longshore features cease to be a minor perturbation on the system which can be eliminated by taking a bulk average. More importantly, while the existence of observable longshore features suggests the existence of the edge waves that caused them, the absence of such features does not conversely imply the absence of edge waves. Strong longshore currents will tend to destroy beach cusps, large tidal ranges will discourage the formation of crescentic bars (Bowen & Inman, 1971) but in neither case will be edge wave itself be eliminated. Even in otherwise ideal circumstances the existence of a whole spectra of edge waves could produce a very complex pattern with no obvious longshore wave-length. To examine the basic ideas associated with generation of longshore features in either the water or the sediment it is therefore very necessary to understand the properties of the edge waves which are probably responsible for their existence.

EDGE WAVES

Edge waves are surface waves trapped by refraction to the shore, having an amplitude which is a maximum at the shoreline and generally decreases in the offshore direction. Although the wave elevation decays seawards it may have several maxima and minima. An offshore modal number n gives the number of zero crossings and therefore with increasing n the edge wave becomes more complex and for a given longshore wavenumber decays seawards more slowly. (Bowen & Inman, 1969).

Ursell (1952) considered the motion on a plane beach of slope tan s and derived a dispersion relation between the angular frequency of the edge wave σ and the longshore wavenumber k where

$$\sigma^2 = gk \sin(2n+1)s \qquad (1)$$

and therefore showed that all values of n are not possible as there is a cut-off at

$$\sin(2n+1)s=1 \tag{2}$$

Ursell found experimentally that the edge wave for this particular case, the cut-off mode, could be generated in a wave-tank and might be an important resonance. The cut-off mode may be of practical interest as it represents the longest longshore wavelength that is possible for an edge wave of a given frequency (equation 1).

Ursell's solution applies to the simplest, possible beach topography, a straight coastline with a plane beach of constant slope. Incoming wind waves would have no longshore variation and any longshore perturbations must be derived either from the motion of the edge wave itself or from its interaction with the incoming waves. The orbital motion of both waves, although very complex in the case of an edge wave with a large value of n, is purely oscillatory and leads to no net motion of the water or sediment. However, the amplitude of the edge wave at the shoreline can produce a longshore differential in the maximum run-up on the beach; in consequence, points of equal height above mean water level may be exposed to quite different hydraulic conditions, one point being totally dry for a long period while the other is in the swash zone.

Figure 1 illustrates the two possible cases
a) the edge waves are of the same period as the edge wave
b) the edge waves and the incoming waves are of different period, the edge wave usually being of lower frequency.

Two further subdivisions are useful
i) incoming wave larger amplitude than the edge wave
ii) edge wave larger than incoming wave.

If Figure 1 is regarded as a view looking down on the shoreline, given by the mean water line (MWL), the incoming wave will just move up and down the beach. The combination with a standing edge wave of the same period will produce a longshore perturbation in the water line on the beach either a(i) of the edge wave wavelength or a(ii) complex system primarily of the edge wave wavelength but with a system of smaller amplitude in between the major crests depending on the relative size of the waves.

If the edge wave is progressive the perturbation is of the same wavelength as the edge wave case a(i) independent of the relative size of the waves.

When the edge wave and the incoming wave are of different periods which have no harmonic relation, at any given time they will be of random phase. The maximum run up of the incoming waves will be within the shaded areas occasionally reaching the maximum excursion when the waves are temporarily in phase. A longshore perturbation will result only if the edge waves are standing waves and will have a wavelength half that of the edge wave.

The shaded areas are the perturbation of the run-up of the incoming wave by the edge waves. As in b(ii) the edge wave motion is dominant, the darker shading has been used to indicate the perturbation of the maximum edge wave incursion due to the incoming waves.

It is necessary to consider the relative size of the waves as at the shoreline the amplitude of the incoming wave is a minimum while that of the edge waves is a maximum, case (ii) may therefore be reasonably common.

The important interactions are those that produce steady drift velocities in the nearshore zone. The self-interaction of the incoming wave is obviously important producing drift velocities and longshore currents. However, although these may be large, they are uniform in the longshore direction.

If the edge wave is of significantly different frequency from the incoming waves, cross interactions will generate oscillations at the sum and difference frequencies rather than steady currents. However if they are of the same frequency, their interaction produces steady currents, the nearshore circulation patterns (Bowen & Inman, 1969). These, in turn, may lead to the formation of sedimentary features (Bowen & Inman, 1969; Komar, 1971). This type of interaction produces features, rip currents or beach cusps, which theoretically have exactly the same longshore wavelength as the edge waves. The interaction is independent of whether the edge wave is progressive or standing, the mechanism is the same as that shown in a(i) of Figure 1.

Steady drift velocities also arise from the second-order solution for the edge wave motion. These velocities are probably small but until accurate measurements are made of edge wave amplitudes they cannot be entirely dismissed as insignificant as the motion due to a standing edge wave provides a satisfactory explanation for the formation of crescentic bars and particularly for crescentic bars with matching cusps

(Bowen & Inman, 1971). These features have a theoretical wavelength of half that of the edge wave. The drift velocities associated with a progressive edge wave have no longshore variation although they change in magnitude and longshore direction as a function of the distance from the shore.

On an infinitely long beach a very large number of edge wave modes are possible; for each frequency there are a set of wavelengths, a different wavelength for each possible value of n. The measurement and identification of edge waves is therefore a formidable task. Fortunately one mode is often dominant giving the rather regular longshore variations which are often observed but irregular, or apparently irregular features, will be generated if more than one edge wave mode present is of significant amplitude.

In reality, the local geometry may be very important in determining the possible dominant mode. A situation of practical interest occurs when a beach is bounded by two headlands, or groynes, perpendicular to the shoreline a distance b apart. The possible wavelengths of the standing edge wave between the boundaries are given by

$$L = \frac{2b}{m} \qquad m = 1, 2, 3 \qquad (3)$$

so that m is a longshore model number. The resonant periods T of the bay are, from (1) and (3)

$$T^2 = \frac{4\pi}{g} \qquad \frac{b}{m\sin(2n+1)s} \qquad (4)$$

If the width of the bay, or the groyne spacing, is about 400m, then small values of m and n give resonant periods of the order of a minute, essentially in the surf beat range. For small m the cut-off mode has a period of 10 - 20 secs. With a slope of 0.030, a reasonable value for an exposed coast, there are 26 possible values of n in addition to the cut-off mode (Table 1). All values of m are possible but the very short wavelength associated with large values of m are probably not of any practical interest.

CONCLUSIONS

It is clear that the introduction of artificial boundaries on a beach can profoundly influence the spectrum of edge wave energy. This could be particularly important if the new geometry has resonances close to the predominant frequency of incoming waves.

There is some indication that the bottom drift velocity due to the edge wave is offshore close to the shore, of order (Bowen & Inman, 1971)

$$\frac{a^2}{4_g} \left[\frac{\sigma}{\tan s}\right]^3 \tag{5}$$

where a is the amplitude of the edge wave at the shoreline.

Large edge waves of short period might therefore have a significant erosional capacity. Measurements of edge wave amplitude are required urgently so that the significance of this type of estimate can be established.

The wave periods associated with crescentic bars (Bowen & lnman, 1971) are relatively long, of the order of 30 secs, yet the drift velocities associated with these edge waves seem to explain the observed formation of large sedimentary features. This certainly suggests, as the frequency cubed enters the drift velocity relation, that edge waves of higher frequency could play a significant role in determining the equilibrium slope of the beach.

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TABLE I

Resonant periods for various (m, n) in seconds.

b = 400 m, = 0·030 (1°43')

n \ m	1	2	3	4	5	6	7	8	9	10	11
0	130·5	92·2	75·3	65·3	58·4	53·2	49·4	46·2	43·5	41·3	39·3
1	75·5	53·4	43·6	37·8	33·8	-	-	-	25·2	-	-
2	58·6	41·5	33·8	29·3	26·6	23·9	23·2	20·7	-	18·6	-
3	49·6	35·1	28·6	34·8	-	-	-	-	16·5	-	-
4	43·8	31·0	25·3	21·9	19·6	-	-	-	-	-	-
5	39·8	28·2	23·0	19·9	-	-	-	-	13·3	12·6	12·0
6	36·8	26·0	21·2	18·4	16·5	15·0	13·9	-	12·3	11·7	11·1
7	34·3	24·3	19·7	17·2	-	-	-	12·1	11·4	10·9	-
8	32·4	22·9	18·7	-	14·5	13·2	12·3	11·5	10·8	-	-
9	30·8	21·8	17·8	15·4	-	-	11·7	10·9	10·3	-	-
10	29·5	20·9	17·0	-	13·2	12·1	11·2	-	9·8	-	-
11	28·4	20·1	16·4	14·8	-	11·6	10·8	-	-	-	-
12	27·4	19·4	15·8	-	-	11·2	-	-	-	-	-
13	26·6	18·7	15·3	13·3	11·9	10·9	-	-	8·9	-	-
14	25·9	18·3	14·9	-	11·6	-	-	-	-	-	-
15	25·4	17·9	14·6	12·7	11·4	-	-	-	-	-	-
16	24·8	17·5	-	-	11·1	-	-	-	-	-	-
17	24·3	17·2	14·0	12·2	10·9	9·9	9·2	8·6	8·1		
18	23·9	16·9	-	12·0	-	-	-	-	-	-	-
19	23·6	16·7	13·6	11·8	10·5	-	-	-	-	-	-
22	32·9	16·2	13·2	11·5	10·2	9·4	8·7	8·1	7·6	-	-
25	22·6	16·0	13·0	11·3	10·1	-	-	-	-	-	-
Cut-off	22·6	16·0	13·0	11·3	10·1	9·3	8·6	8·0	7·5	-	-
L	500	400		200				100			

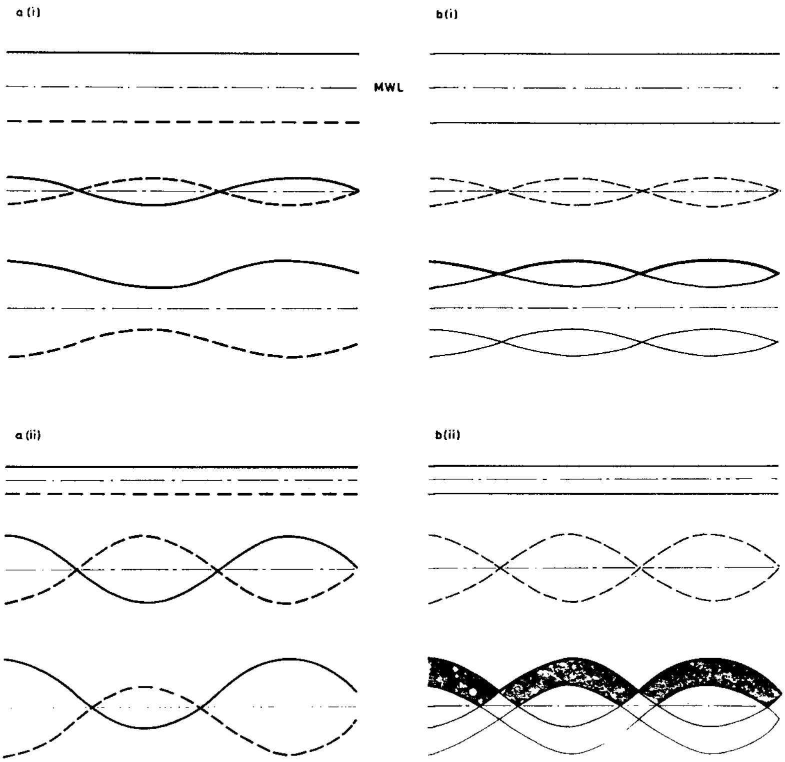

FIGURE 1.

Incoming wave/edge wave interaction a) with waves of the same frequency b) waves of different frequency. Case (i) incoming waves larger than edge waves; case (ii) edge waves dominant.