Variations of Spacings between Beach Cusps discussed in relation to Edge Wave Theory

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Variations in cusp spacings of beach cusp systems have been examined, and the conclusion is that the apparent regularity of the spacings is not always real. Established edge wave theory predicts equal cusp spacings, and accordingly, the theory needs to be improved or alternative theories accepted. Field measurements of beach cusp formation under reflective morphodynamic conditions confirmed that established edge wave theory was not always capable of explaining beach cusp formation. The beach cusps grew from small irregularly spaced mounds, and the regularity of the cusp spacings seemed to increase during beach cusp development. Correlation between observed average cusp spacing and the average cusp spacing predicted on the basis of edge wave theory might suggest that edge waves were the initiating mechanism causing beach cusp development. However, the observed water circulation pattern and the variations of the individual spacings between the beach cusps were both contradictory to existing edge wave theory.

Keywords: *Beach cusps, cusp spacings, edge waves.*

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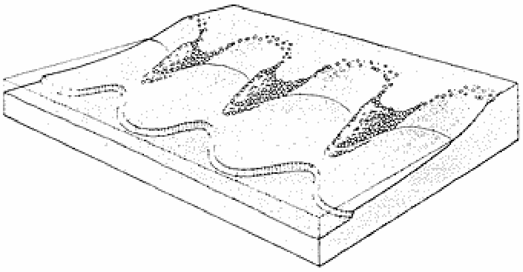

Fig. 1. Beach cusp morphology. The coarser sediment at the horns and the underwater delta-like protuberances are not always represented.

Fig. 2. Beach cusps at Skallingen May 28th 1989. Average cusp spacing is 9.3 m. The standard deviation and variation width of cusp spacings are 1.4 m and 3.3 m, respectively.

Beach cusps are morphological features located on the foreshore. An individual beach cusp consists of two shore normal ridges (horns) separated by a bay (Fig. 1). Underwater, a delta like protuberance may be present seaward of the bay.

Normally beach cusps appear in groups (beach cusp systems) giving the foreshore a sawtooth like appearance. When beach cusps are present, the beach sediment is often sorted according to grain size, with the coarser sediments appearing at the horns (Fig. 2). The wavelength of beach cusp systems (average distance between individual horns) varies from a few centimeters to more than 50 metres depending on locality and wave parameters (Russel & McIntire, 1965; Komar, 1973).

The regularity of spacings between individual beach cusps is considered as a major characteristic of beach cusp systems, and accordingly, beach cusps are classified as rhythmic shoreline features (Komar, 1976, 1983). One of the cornerstones in published theories on beach cusp formation has been the explaintion of how these regular spacings evolve. In the present investigation the variations of cusp spacings will be analyzed on the basis of datasets from the literature, supplemented by datasets from new field measurements. Furthermore, the article contains an analysis of field observations performed while beach cusps developed under reflective conditions on Katholm Strand in Denmark. The results of the analysis are discussed in relation to the established edge wave theory.

The formation of beach cusps has been discussed since Henry Palmer described the phenomenon in 1834. The origin has been related to depositional processes (Johnson, 1910; Smith & Dolan, 1960), erosional processes (Kuenen, 1948; Russel & McIntire, 1965; Schwartz, 1972), or processes including both deposition and erosion (Otvos, 1964; Inman & Guza, 1982). Despite a large number of investigations concerning beach cusp

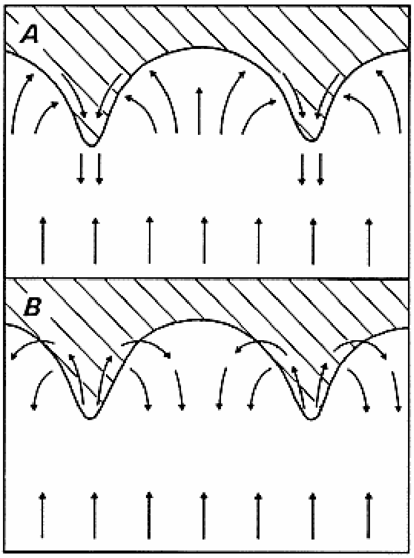

Fig. 3. Beach cusp circulation systems. A: The swash is refracted towards the horns and the backwash occurs near the horns (Kuenen, 1948). B: The swash is concentrated in a region near the horns and the backwash is directed towards the bays where it interferes destructively with the succeeding swash (Russel & McIntire, 1965).

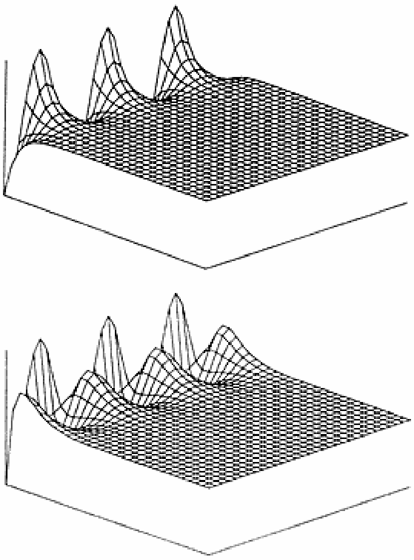

Fig. 4. Three-dimensional mathematical model of the water level fluctuations in association with an edge wave with n = 0 (A) or n = 1 (B).

formation, all aspects of their development are still not fully understood.

Ignoring the initiating mechanism, the water circulation patterns leading to the growth of beach cusps are well-described. Kuenen (1948) proposed a circulation system in which the swash is refracted towards the horns leading to a set-up of water over the horns and a backwash concentrated in a region near the horns (Fig 3.A). This circulation pattern can not account for the development of underwater, delta-like protuberances (Fig. 1) and the concentration of the coarser sediments at the horns.

Contrarily, Russel & McIntire (1965) have described a circulation system in which the swash is concentrated at the horns and the backwash is directed towards the center of the bays, where it interferes destructively with the succeeding swash (Fig 3.B). Both circulation systems will lead to a growth of beach cusps. The circulation systems are self-sustaining, but a triggering mechanism is needed to separate the swash and the backwash, and thereby initiate the circulation systems.

In most of the earlier theories on beach cusp formation, a triggering mechanism was not included (Longuet-Higgins & Parkin, 1962; Russel & McIntire, 1965; Dean & Mauermeyer, 1980) or the initial separation of the swash and the backwash was accounted for by the presence of small and irregularly spaced depressions of the foreshore (Johnson, 1910; Kuenen, 1948; Otvos, 1964). The theories do not explain the formation of the initial depressions, and it has been claimed that neither do they explain the formation of the regular spacings between the individual cusps (Komar, 1976, 1983; Seymour & Aubrey, 1985). In a review on beach cusp formation, Komar (1976, p. 273) concludes that "edge waves remain the only satisfactory explanation for longshore variations in the surf zone properties which can give rise to regularly spaced beach cusps".

EDGE WAVES AND BEACH CUSPS

Edge waves are coast normal periodic gravity waves confined to the nearshore region (Guza & Bowen, 1981). They can be either progressive or standing waves and their period (T_e) varies from the period of incident waves to about 300 seconds.

Edge waves give rise to perturbations of the still water surface in both shore normal and shore parallel directions (Fig. 4). In edge waves the water surface elevation varies sinusoidally in shore parallel direction, and the shore parallel wavelength (L_e) of edge waves is given by the dispersion relation

$$L_c = (g/2\pi)\cdot T_e^{2}\cdot \sin((2n+1)\cdot\beta) \tag{1}$$

(Ursell, 1952), where β is the slope of the foreshore and n is the mode number i.e. number of nodal points in shore normal direction. The edge waves that might cause beach cusp formation have either the same period (synchronous edge waves), or twice the period (subharmonic edge waves), of the incoming waves (Guza & Inman, 1975), and their mode number is expected to be low (0 or 1).

When edge waves are present in the surf zone, the height of the run-up will vary sinusoidally in the shore parallel direction. This motion might be the process that leads to a separation of the swash and the backwash, and thereby initiates the development of regularly spaced beach cusps. Depending on the water circulation pattern, the horns will either arise at the nodes (Guza & Inman, 1975; Guza & Bowen, 1981) or the antinodes (Sallenger, 1979; Inman & Guza, 1982), and depending on whether the edge wave is synchronous or subharmonic, the wavelength of the beach cusp system (L_c) will be either equal to or half the wavelength of the edge wave (Inman & Guza, 1982).

The only unequivocal field measurements of edge waves resulting in beach cusp formation were made with use of electromagnetic current metres, recording the velocity fields of the incident waves as well as the edge waves (Huntley & Bowen, 1978; Guza & Bowen, 1981). Besides this, the literature contains several examples of correlation between wavelength of beach cusp systems and the period of the incoming waves, using the edge wave dispersion relation (Komar, 1973; Huntley & Bowen, 1975; Sallenger, 1979; Aagaard, 1985; Seymour & Aubrey, 1985; Miller et al. 1989).

DATA AND METHODS

The data for this investigation consists of field measurements of cusp spacings and similar measurements quoted in the literature (Jeffersson, 1899; Johnson, 1910; Evans, 1938; Longuet-Higgins & Parkin, 1962; Flemming, 1964; King, 1965; Guza & Bowen, 1981).

Field observations were collected at four localities in Denmark (Fig. 5). Katholm Strand and Køge Bugt Strandpark are both low energy coasts with almost no tide (⟨⟨ 0.1 m). The coasts of Skallingen and at Liseleje Strand have a moderate wave energy level. At Skallingen the tidal range is about 1.5 m, and at Liseleje Strand it is less than 0.4 m.

The purpose of the field work was to collect datasets of cusp spacings from beach cusp systems with different wavelengths. The spacings were measured with a tape measure between pegs positioned at the outer tip of the horns. The error of measurement is estimated to be less than 0.1 m. Most of the measurements were made on inactive beach cusps, but at Katholm Strand the development of beach cusps was observed. On this occasion the period of the incoming waves was measured with a stop watch as the average period of ten waves. The slope of the foreshore (β) was measured with a clinometer half-way between the tip of the horns and the inner part of the beach cusp bays (Table 1). To estimate the error induced by measuring the slope of the foreshore after beach cusp

Fig. 5. Study localities. 1. Skallingen, 2. Køge Bugt Strandpark, 3. Liseleje Strand, 4. Katholm Strand.

Field measurements					L_c calculated from eq 1			
					Synchronous edgewaves $L_c = L_e$		Subharmonic edgewaves $L_c = \frac{1}{2}\cdot L_e$	
T	β	β_h	β_b	L_c	n=0	n=1	n=0	n=1
2.6 s	8°	11°	6°	7.4 m	1.5 m	4.3 m	3.0 m	8.6 m

Table 1. Comparison between measured and calculated wavelengths (L_c) of the active beach cusp system at Katholm Strand, October 21, 1989. The calculated wavelength for a beach cusp system formed by a subharmonic mode 1 edge wave is only 16 % higher than the observed wavelength of the beach cusp system.

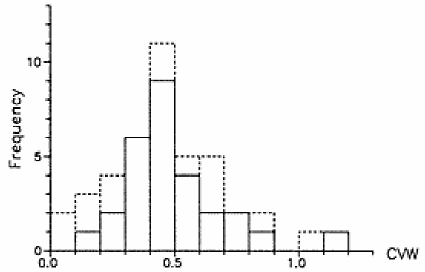

Fig. 6. Distribution of coefficients of variation width (CVW) in 42 different beach cusp systems. The solid line represents CVW-values calculated from cusp spacings with an estimated degree of error of approximately 0.1 m, while the dotted line presents CVW-values calculated from cusp spacings given in whole feet or steps i.e. measurements with a relatively high degree of error.

formation, the slope was also measured at the tip of the horn (β_h) and in the middle of the bay (β_b).

For each series of measurements of spacings between beach cusps ($L_1, L_2, ..., L_k$); the number of cusp spacings (k), the average spacing (L_c), the maximum spacing (L_{max}), the minimum spacing (L_{min}), the standard deviation (SD^+), the coefficient of variance (CV), the variation width (R), and the coefficient of variation width (CVW) defined as

$$CVW = (L_{max} - L_{min})/L_c = R/L_c \qquad (2)$$

have been calculated. Furthermore, for each series of cusp spacings; the test-parameter ρ defined as

$$\begin{aligned} \rho &= \overset{k-1}{\underset{i=1}{MAX}} \left(\frac{MAX\,(L_i,\, L_{i+1})}{MIN\,(L_i,\, L_{i+1})} - 1 \right) \\ &\updownarrow \\ \rho &= MAX \left(\frac{MAX\,(L_1,\, L_2)}{MIN\,(L_1,\, L_2)} - 1,\ \frac{MAX\,(L_2,\, L_3)}{MIN\,(L_2,\, L_3)} - 1, ..., \frac{MAX\,(L_{k-1},\, L_k)}{MIN\,(L_{k-1},\, L_k)} - 1 \right) \end{aligned} \qquad (3)$$

has been calculated. L_i is cusp spacing number i in a given series of cusp spacings. ρ is a relative measure of the most abrupt change between neighbouring cusp spacings in a beach cusp system.

The statistical parameters from the field observations are given in Table 2, and the same parameters calculated from the data collected from earlier publications are given in Table 3 and Table 4. The data on which Table 3 is based were given in feet or steps and the error of measurement is therefore considered here to be relatively high (> 1 unit). The data on which Table 4 is based were given in decimal metres, decimal feet, or feet and inches. These data have been converted into decimal metres before calculating the statistical parameters, and the error of the spacings is considered here to be approximately 0.1 metres.

Observations of beach cusp formation

The beach cusps that evolved on Katholm Strand, October 21st 1989, had an average cusp spacing of 7.4 m (SD^+ = 1.7 m, CVW = 0.59, ρ = 0.31). The spacings between the individual cusps were 10.1, 7.7, 7.0, 5.7 and 6.3 m respectively, and the beach cusp system did not appear rhythmic. The beach cusps grew from small irregularly spaced mounds, and the regularity of the cusp spacings seemed to increase during beach cusp development.

The beach cusps formed in calm weather. The crests of the incident waves were almost parallel to the beach, and the breakers were surging at the foreshore indicating reflective conditions. The circulation pattern described by Russel & McIntire (1965) was observed in connection with only a few of the incoming waves. For most incoming waves no separation of the swash and the backwash occurred. Similar circulation patterns have often been observed by the authors on Danish coasts. Most Danish coasts are characterized by; restricted fetches, absence of swell, and normally a wave spectrum consisting of a wide

Locality	k	L_{max} (m)	L_{min} (m)	L_c (m)	SD^+ (m)	CV	R (m)	CVW	ρ
Skallingen 23/5-1989	4	14.5	12.0	13.6	1.2	0.09	2.5	0.18	0.21
	5	13.8	10.1	12.3	1.7	0.13	3.7	0.30	0.37
	4	1.6	1.2	1.4	0.2	0.15	0.4	0.29	0.33
	11	14.6	9.1	12.7	1.6	0.13	5.5	0.43	0.38
Skallingen 28/5-1989	5	9.3	6.0	8.1	1.4	0.17	3.3	0.41	0.55
Køge Bugt Strandpark 19/9-1989	7	13.1	9.6	11.1	1.4	0.13	3.5	0.32	0.36
	5	19.4	12.7	15.6	2.8	0.18	6.7	0.43	0.53
	9	19.3	8.6	13.8	3.0	0.22	5.5	0.40	1.24
Køge Bugt Strandpark 3/10-1989	9	11.9	7.0	9.7	1.8	0.19	4.9	0.51	0.39
	4	15.0	8.7	11.0	2.8	0.26	6.3	0.57	0.60
	19	15.7	7.9	10.4	1.9	0.18	7.9	0.76	0.59
	9	12.6	9.9	11.7	0.8	0.07	2.7	0.23	0.18
	13	11.6	7.1	10.3	1.4	0.14	4.5	0.44	0.64
	5	16.0	12.0	13.3	1.8	0.13	4.0	0.30	0.32
Liseleje Strand 17/10-1989	9	11.9	8.6	10.2	1.1	0.11	3.3	0.32	0.19
Katholm Strand 21/10-1989	5	10.1	5.7	7.4	1.7	0.23	4.4	0.59	0.31
Average						0.16		0.41	0.45

Table 2. Statistical parameters calculated on the basis of cusp spacing data collected on Danish coasts (k = number of cusp spacings, L_{max} = longest cusp spacing, L_{min} = shortest cusp spacing, L_c = average beach cusp wavelength, SD^+ = standard deviation of spacings, CV = SD^+/L_c, R = $L_{max} - L_{min}$, CVW = R/L_c, ρ (definition in text)).

Publication	k	L_{max}	L_{min}	L_c	SD^+	CV	R	CVW	ρ
Jefferson (1899)	9	22	6	16	6.1	0.37	16	1.00	1.14
Johnson (1910)	5	35	31	34	1.7	0.05	4	0.12	0.13
	16	15	8	11	1.7	0.15	7	0.64	0.63
	23	10	4	7	1.7	0.24	6	0.86	0.50
	4	28	27	28	0.5	0.02	1	0.04	0.04
	4	11	5	10	3.0	0.32	6	0.60	1.20
	6	17	9	15	3.0	0.21	8	0.53	0.89
	9	19	12	15	2.6	0.17	7	0.47	0.38
	3	30	27	28	1.7	0.06	3	0.11	0.11
	3	19	13	15	3.5	0.23	6	0.40	0.46
	5	8	6	7	0.8	0.12	2	0.29	0.33
Flemming (1964)	9	19	9	16	3.7	0.23	10	0.63	1.00
King (1965)	5	89	83	85	2.5	0.03	6	0.07	0.07
	5	108	83	98	10.1	0.10	25	0.26	0.13
Average						0.16		0.43	0.50

Table 3. Statistical parameters calculated on the basis of cusp spacing data collected from different publications. The cusp spacings are given in steps (Jefferson, 1899; Johnson, 1910) or feet (Flemming, 1964; King, 1965). Notations have been defined in Table 2.

Publication	k	L_{max} (m)	L_{min} (m)	L_s (m)	SD* (m)	CV	R (m)	CVW	ρ
Longuet-Higgins & Parkin (1962)	15	0.94	0.31	0.55	0.17	0.30	0.63	1.15	1.20
Evans (1938)	9	0.6	0.3	0.5	0.08	0.17	0.3	0.60	0.40
	8	0.5	0.3	0.4	0.09	0.23	0.3	0.50	0.55
	12	2.2	1.4	1.9	0.27	0.15	0.8	0.44	0.45
	6	10.8	5.7	7.6	1.90	0.27	5.2	0.68	0.94
	5	5.0	3.3	4.2	0.64	0.17	1.7	0.40	0.36
	8	5.1	3.4	4.2	0.60	0.15	1.7	0.40	0.49
	17	5.1	3.6	4.3	0.44	0.11	1.5	0.35	0.25
	6	5.1	3.6	4.3	0.45	0.11	1.5	0.35	0.23
	17	6.4	2.6	4.3	1.08	0.26	3.8	0.58	0.67
	12	5.3	2.3	3.8	0.95	0.26	3.0	0.79	0.31
Guza & Bowen (1981)	17	16.0	10.0	12.6	1.56	0.12	6.0	0.48	0.45
Average						0.18		0.58	0.53

Table 4. Statistical parameters calculated on the basis of cusp spacing data collected from different publications. The cusp spacings given by Longuet-Higgins & Parkin (1962) and by Evans (1938) were respectively given in feet and inches and in decimal feet. The spacings have been transformed into decimal metres before calculating the statistical parametres. Notations have been defined in Table 2.

Variation	Spacings between individual beach cusps	Unit	CVW	ρ	Publication/Locality
High	21-20-18-16-22-17-6-7-22	Paces	1.00	1.14	Jefferson (1899)
	0.58-0.56-0.56-0.48-0.46-0.46-0.38-0.51-0.30-0.66-0.84-0.91-0.48-0.51-0.43	Meters	1.15	1.20	Longuet-Higgins & Parkin (1962)
	11.2-11.7-10.7-8.7-9.7-11.5-9.7-9.7-9.4-9.5-9.8-10.9-12.4-12.9-15.7-9.9-9.2-7.9-8.4	Meters	0.76	0.59	Køge Bugt Strandpark 3/10-1989
Intermediate	17-17-15-9-17-15	Feet	0.53	0.89	Johnson (1910)
Low	31-35-35-35-34-33	Feet	0.12	0.13	Johnson (1910)
	83-89-86-86-83	Feet	0.07	0.07	King (1965)
	12.0-14.5-14.5-13.5	Meters	0.18	0.21	Skallingen 23/5-1989

Table 5. Examples of cusp spacings in beach cusp systems with relatively low (CVW ⟨ 0.2), intermediate (0.2 ⟨ CVW ⟨ 0.7) or high (CVW ⟩ 0.7) coefficients of variation width.

range of periods. The maintenance of the circulation pattern described by Russel & McIntire (1965) does not require a very fine tuning between the swash and the backwash (Dean & Mauermeyer, 1980). Nevertheless, if the interval between the arrival of two succeeding waves becomes too long, the destructive interference between the backwash and the swash will cease, and the circulation pattern will come to an end.

Variations of cusp spacings

The coefficient of variation width (CVW) is used as a first approach in the examination of the regularity of spacings between the individual cusps in beach cusp systems. The distribution of CVW is shown in Figure 6. When all data are included, the average value of CVW is 0.47. If only the data with small estimated errors are included, the average value of CVW is 0.45. In descriptive terms, a coefficient of variation width close to 0.5 means that the variation of the distances between the individual cusps in a beach cusp system is generally half the wavelength of the beach cusp system. Figure 6 shows that, in some cases, the variation of the distances between the individual cusps even exceeds the wavelength of the beach cusp system (CVW ⟩ 1). Examples of individual spacings between cusps in beach cusp systems with relatively low (CVW ⟨ 0.2), intermediate (0.2 ⟨ CVW ⟨ 0.7) and high (CVW ⟩ 0.7) CVW-values are given in Table 5.

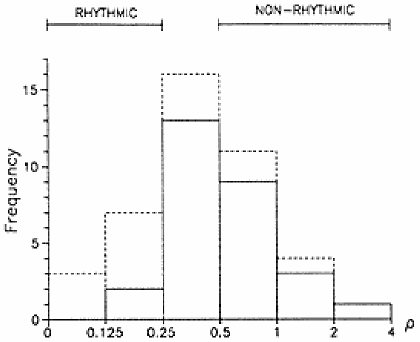

Fig. 7. Distribution of the test parameter ρ in 42 different beach cusp systems. The solid line represents ρ-values calculated from cusp spacings with an estimated degree of error of approximately 0.1 m, while the dotted line represents ρ-values calculated from cusp spacings given in whole feet or steps i.e. measurements with a relatively high degree of error. Beach cusp systems with a ρ-value larger than 0.5 are classified as non-rhythmic, while beach cusp systems with a ρ-value smaller than 0.25 are classified as rhythmic.

The test parameter ρ is a relative measure of the most abrupt change between neighbouring cusp spacings in a beach cusp system. The distribution of ρ is given in Figure 7. If one cusp spacing in a beach cusp system is more than 50 % higher than the succeeding cusp spacing, ρ will be larger than 0.5. It is difficult to explain such a change in cusp spacing using established edge wave theory, and beach cusp systems with a ρ-value larger than 0.5 are classified as non-rhythmic beach cusp systems. Likewise, if ρ is less than 0.25, the beach cusp system is classified as rhythmic. Using these criteria, 16 out of the 42 investigated beach cusp systems are classified as non-rhythmic, while 10 are classified as rhythmic.

DISCUSSION AND CONCLUSIONS

On the basis of field observations of cusp spacings collected by Shepard (1963) on a curved beach, and the relation between the beach slope and the wavelength of beach cusp systems given by the edge wave dispersion relation (eq 1), Komar (1983) claims that systematic variations of the cusp spacings could be the result of systematic longshore variations of the beach slope. Systematic longshore variations of the beach slope are expected on almost any natural coast as a result of; either 1. longshore variations of beach sediment grain size (Bascom, 1951; Wiegel, 1964) or sorting (McLean & Kirk, 1969), or 2. longshore variations in wave height associated with the overall curvature of the coast (Bascom, 1951) or with the presence of megacusp systems (Wright & Short, 1983). If the beach cusp system has a large longshore extent, the resulting systematic variations of cusp spacings might lead to high CVW-values. Conversly variations of cusp spacings over shorter distances would be expected to be rather small and systematic. This is not the case in beach cusp systems with high ρ-values.

The conclusion is: 1. that not all beach cusp systems are rhythmic, and 2. that improvements of the existing edge wave theory, or the acceptance of alternative morphogenetic theories are needed to explain the formation of non-rhythmic beach cusp systems.

Several genetic hypotheses explaining the formation of non-rhythmic beach morphology are given in the literature (Johnson, 1910; Kuenen, 1948; Otvos, 1964; Komar, 1983; Holman & Bowen, 1982). Among these, two hypotheses accept the existence of edge waves. On a theoretical basis, Komar (1983) has shown that the summation of several rhythmic beach morphologies with different shore parallel wavelengths might produce an irregular shoreline. Likewise, Holman & Bowen (1982) used a mathematical model to show that a complex beach morphology might be the result of interaction between edge waves with different mode numbers. In a field experiment, Seymour & Aubrey (1985) observed a transition (over five days) from a rhythmic beach cusp system with a wavelength of approximately 19 m on a non-rhythmic beach cusp system with spacings ranging from 16 to 48 m to a rhythmic beach cusp system with a wavelength averaging about 40 m. Their results suggest that superposition of rhythmic beach cusp systems can produce a transient non-rhythmic beach cusp system. However, this theory cannot account for the formation of beach cusps on the initially planar beach at Katholm Strand.

The hypothesis concerning interaction between edge waves with different mode numbers (Holman & Bowen, 1982) has still not been confirmed by field evidence. Unfortunately, with the instrumentation used at Katholm Strand it was not possible to study the actual wave motions involved in the beach cusp formation. However, the beach cusp system at Katholm Strand might have been produced by interacting edge waves.

In earlier investigations several authors confirm edge wave theory after having obtained good correlations between observed and calculated wavelengths of beach cusp systems (Komar, 1973; Huntley & Bowen, 1975; Sallenger, 1979; Aagaard, 1985; Seymour & Aubrey, 1985; Miller et al. 1989). As an example, Miller et al. (1989) used the range of periods (10 - 12 sec.) and beach slope (4° - 6°) when beach cusps were formed to calculate the possible range of cusp wavelengths (22 - 47 m). The observed mean wavelength of the resulting beach cusp system (36 m) was within the predicted range and Miller et al. (1989, p. 758) claimed that their data "suggest that the initial perturbations of the beach surface were associated with edge waves".

At Katholm Strand, the calculated wavelength for a beach cusp system formed by a subharmonic mode 1 edge wave was only 16 % higher than the observed wavelength and belonged to the 95 % confidence interval of the observed wavelength (Table 1). This result might suggest that a subharmonic mode 1 edge wave was involved in the formation of the beach cusps. However, presence of a subharmonic edge wave would be accompanied by a systematic circulation pattern and would lead to the formation of a rhythmic beach cusp system. At Katholm Strand, no systematic circulation pattern was observed, and the developed beach cusp system did not seem rhythmic. The investigation suggested that exsisting edge wave theory is not always capable of explaining beach cusp formation, and that the edge wave dispersion relation should be used with caution as a tool for testing edge wave theory. A good correlation between observed and calculated wavelengths does not prove that the formation of beach cusps is associated with edge waves. For each measured period of the incoming waves, the dispersion relation predicts at least four possible beach cusp system wavelengths. If some deviation between observed and calculated wavelength is accepted, the probability of confirming the edge wave theory is good.

Besides this, a major problem in using the dispersion relation (eq 1) for testing edge wave theory is the difficulty in properly measuring the slope of the foreshore, β. According to edge wave theory, the value of β in the dispersion relation is the slope of the foreshore prior to beach cusp formation. In practice, the slope of the foreshore will not be measured until after the beach cusp system has developed and no methods for transferring these slope measurements into a proper β-value are available. Using a mathematical model of beach cusp morphology suggested by Guza & Bowen (1981) it can be shown that the error induced by measuring the slope of the foreshore after beach cusp formation will be minimized if the slope is measured half-way between the tip of the horn and the middle of the bay. However, the mathematical model of beach cusp morphology has not been confirmed by field investigations, and though the error will be minimized, the method does not make it possible to estimate the size of the error. The slope used for calculating the possible wavelengths of the active beach cusp system at Katholm

Strand was measured half-way between the tip of the horn and the middle of the bay. To estimate the possible error in using this technique the slope of the fore shore was also measured at the tip of the horn (β_h) and in the middle of the bay (β_b). If the beach cusp system developed without net accumulation/erosion, the slope of the foreshore prior to beach cusp formation, β, would be expected to be within this range. By inserting the β-values in the dispersion relation (eq 1) the wavelength of a beach cusp system formed by a subharmonic mode 1 edge wave was calculated as 6.5 m (12 % lower than the observed wavelength) and 11.5 m (55 % higher than the observed wavelength), respectively. These calculations show: 1. that the possible range of calculated beach cusp wavelengths is wide, and 2. that a standard method for slope measurements is needed to allow comparison between future investigations.

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