Entrance to the Hastings River at Port Macquarie, New South Wales

PART II

COASTAL SEDEMENT PROBLEMS

Training Jetties, Narooma, New South Wales

BEACH CUSPS AT POINT REYES AND DRAKES BAY BEACHES, CALIFORNIA

by

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INTRODUCTION

Beach cusps, fairly common and periodic features along many shorelines have been the focus of numerous investigations. The primary efforts have been directed toward (1) determining a causative mechanism for their formation; (2) describing qualitatively the associated water motions and sediment transport; and (3) developing a predictive relationship for their spacing. As in other problems in nearshore dynamics (e.g. rip currents), it may be that there are various valid explanations for different occurrences of beach cusps. In addition to satisfying scientific curiosity, an improved qualitative and quantitative understanding of beach cusp mechanisms would contribute substantially to swash zone dynamics and to nearshore hydrodynamics and sediment transport in general.

This paper describes a series of measurements of beach cusps and associated parameters carried out at Point Reyes and Drakes Bay beaches in northern California during the summers of 1977-1979. An attempt to idealize the beach cusp topography and the resulting swash hydromechanics led to a possible relationship between beach cusp spacing and swash parameters in which the spacing is linearly related to maximum swash excursion.

PREVIOUS INVESTIGATIONS

Early attempts at establishing causative mechanisms for beach cusp initiation and development focused on erosion and/or deposition by swash and backwash processes (Shaler, 1895; Johnson, 1910; Smith and Dolan, 1960; Otvos, 1964; Russell and McIntire, 1965; Gorycki, 1973). Several investigators (Palmer, 1834; Lane, 1888; Johnson, 1910) noted that conditions conducive for cusp formation include parallel wave approach, although others (Evans, 1938; Otvos, 1964) observed cusps forming by oblique wave approach. Branner (1900) and Dalrymple and Lanan (1976) noted that cusps may form by intersecting wave trains. Cusp formation associated with the escape of ponded water from a ridge or other barrier on the berm or backshore has been observed and documented by Jefferson (1899, 1903), Evans (1938), DuBois (1978), and Sallenger (1979). Following Ursell's (1952) popularization of edge waves, recent investigations (Galvin, 1964; Bowen and Inman, 1969; Komar, 1973; Guza and Inman, 1975; Sallenger, 1979) have attributed both the initiation and spacing of cusps to the action of edge waves.

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AREA OF STUDY

The Point Reyes peninsula is located approximately 50 km north of San Francisco, California (Figure 1). The orientations of the two beaches studied and their sediment characteristics result in markedly different beach morphologies.

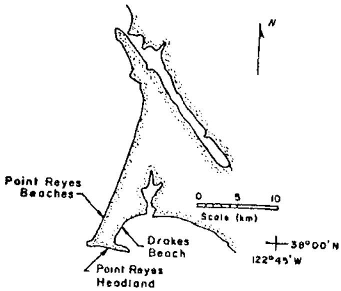

Figure 1. Location Map, Point Reyes and Drakes Bay Beaches, California.

Point Reyes Beach

Point Reyes Beach trends north-northeast and is exposed to the direct action of waves generated in the Pacific Ocean (Figure 2). The

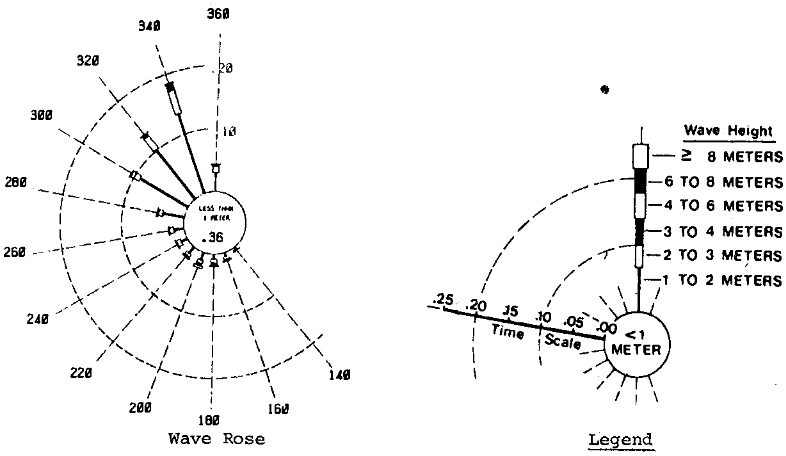

Figure 2. Annual Deep Water Wave Rose, Offshore Point Reyes Area. Combined Sea and Swell, Station 3. (Meteorological International Incorporated, 1977).

beach morphology reflects the highly variable waves through a series of "summer" and "winter" berm terraces, with the uppermost berm approximately 4 m above mean sea level. During the summer of 1977, three terraces each with beach cusps, were present (Figure 3). The beach face is fairly steep with an average slope of 1:10, and beach sediments consist of coarse sand with a mean diameter of approximately 0.8 mm. P. D. Trask and his co-workers (1955a, 1955b, 1956, 1959, 1961) have studied the geological characteristics and cusp formations of the Point Reyes beaches.

Figure 3. Point Reyes Beach, California, August 1977, Showing Three Cusped Berm Terraces.

Drakes Bay Beach

The beach along Drakes Bay is located approximately 6 km southeast of the Point Reyes beach, and is sheltered from the direct attack of high waves from the north and north-northwest. This beach and its southern extension have been studied by Yasso (1965) and identified as a hooked or crenulate bay which is associated with and dependent on sheltering by and diffraction around the Point Reyes headland. As a result of this sheltering, there is only one berm present, with a maximum elevation of approximately 1 m above mean sea level (Figure 4). The average beach face slope is 1:25, and the beach is composed of fine sand having a mean diameter of 0.2 mm.

Figure 4. Drakes Bay Beach, California, July, 1979.

FIELD STUDIES

The observed and measured field data include beach cusp circulation and sediment transport patterns, sediment characteristics, statistics of intercusp spacing, plane table surveys of beach cusps, observations of wave heights and wave periods, and measurements of swash velocities and excursions. Cusp formation on a planar beach was documented during one trip.

Beach Cusp Circulation Patterns

For most of the cases which were observed in the field, beach cusps were already established and thus the observed circulation patterns relate more to the development and maintenance of these features than to their initial formation. In all cases where cusps were present, it was evident that the waves were causing vigorous sediment transport on the beach cusps, with a net circulation landward on the horns (Figure 5a) and seaward in the bays (Figure 5b). This is the same pattern reported by Johnson (1910), Bagnold (1940), O'Brien (1978) and Longuet-Higgins and Parkin (1962), but opposite to that noted by Kuenen (1948). An additional characteristic which to our knowledge has not been reported in the literature (although M. P. O'Brien had recorded this in his field notes on beach cusps in 1930) is that in cases of most effective beach cusp development, the wave and swash period are nearly equal; this equivalence contributes strongly to the net water circulation noted above. This mechanism is illustrated schematically in Figure 6 and described as follows: Waves breaking at the base of the horns cause a strong uprush on these features; however, during the upward excursion, the lateral (longshore) beach gradient causes the trajectories of the water particles to be directed toward the bays. The water accumulates in and flows seaward through the bays. In cases where the swash period is nearly coincident with the wave period, the backrush flow interferes destructively with the succeeding uprush at the embayment positions of the cusps. In some cases, this effect is so complete that following the uprush on the horn, no water will be left on the horn whereas a fairly narrow zone of water (say one-eighth of the cusp spacing in width) will be flowing seaward with a depth on the order of 15-30 cm as shown at Point Reyes Beach in Figure 7. The net result is a dominance of uprush on the horns with the backrush concentrated through the embayments thereby interfering destructively with the next potential uprush. Of substantial relevance to later discussions, is that the swash and wave period do not need to be precisely synchronous since the backrush occurs over a greater time period than the uprush (due to the toll that friction has taken on these velocities) and <u>any</u> dominance of return flow through the embayments will reinforce this net circulation. A "finely tuned" system is thus not required. As discussed in the next paragraphs, this net water circulation pattern is closely related to the maintenance and development of the beach cusp morphology.

(a) Uprush on Cusp Horns.

(b) Backwash in Cusp Bays.

Figure 5. Beach Cusp Circulation Patterns, Drakes Bay Beach, California, July 1978.

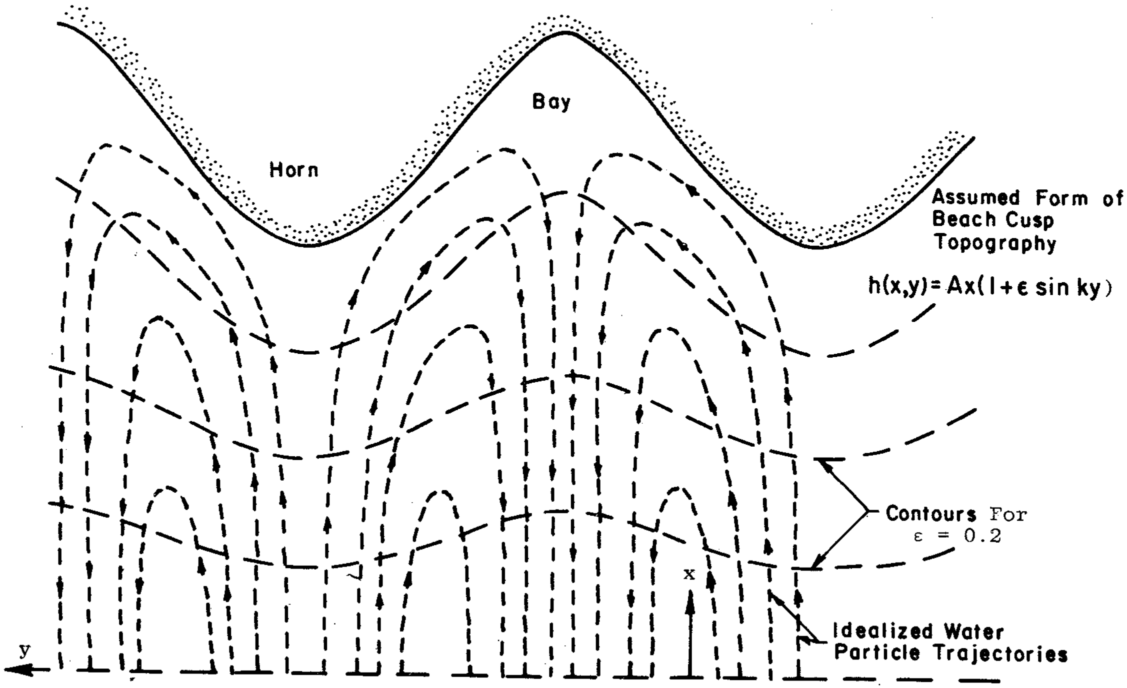

Figure 6. Assumed Beach Cusp Topography and Observed Mean Flow Pattern. Uprush Concentrated on Horns, Seaward Return Flow Concentrated in Bays.

Figure 7. Narrow Zone of Seaward Flow in Cusp Bay, Point Reyes Beach, California, July 1978. Water Depth is on the Order of 15-30 cm.

Sediment Transport Patterns

The sediment transport patterns can be discussed best in the context of the swash characteristics for a planar beach. The swash is two-dimensional with the uprush velocities being higher than the backrush velocities due to friction. Percolation may also play an important role in this inequality on highly permeable beaches. In fact it is these features which result in the positive beach face slope. The uprush transports sediment landward thereby increasing the slope and the backrush transports sediment seaward reducing the beach face slope. The resulting beach face slope is therefore in a state of dynamic equilibrium changing slightly with each uprush and backrush.

As noted previously, the effect of the longshore slopes associated with beach cusps is to concentrate the uprush on the horns and to channel the backrush through the embayments. The result is a steeper slope on the horns since there is little or no destructive backrush to transport sediment seaward. In the embayments, the backrush inequality is greatly augmented by flow from the horns and, as noted, by the reduction of uprush by the local interference with the succeeding wave crest. The results are steeper horn and milder embayment slopes. The equilibrating mechanism that limits the slopes of the horns and bays is the lateral transport of sediment by the water circulation pattern presented in Figure 6. Thus, at equilibrium, the lateral slope from the horns to the embayments and the associated water transport are just sufficient to transport that sediment carried up the horns by the local dominance of uprush. On a smaller scale, the turbulence associated with the uprush plays a role in moderating the "sharpness" of the contours on the horns.

Sediment Characteristics

As noted previously, the mean grain diameter of the sand comprising Point Reyes Beach is approximately 0.8 mm, whereas sand at Drakes Bay

Beach is much finer, with a mean grain size of 0.2 mm. These values are in reasonable accord with those found by Trask and Johnson (1955), Trask, Johnson and Scott (1959) and Trask and Snow (1961). The latter reference found the average diameters at Point Reyes Beach and Drakes Beach to be 0.58 and 0.19 mm, respectively. As shown in Figures 8 and 9, the sand characteristics of cusp horns and bays at each beach did not differ greatly. This is contrary to the findings of several investigators (King, 1972; Komar, 1973; Williams, 1973), who noted that material comprising cusp horns is generally quite coarser than material in the bays. However, in a laboratory study of beach cusps, Flemming (1964) found no significant size sorting between cusp horns and bays. Russell and McIntire (1965) suggest that size variations are most pronounced during the "juvenile" stage but that the contrast diminishes as cusps continue to develop.

Intercusp Spacing

The apparent regularity of spacing between cusps is of particular interest and has been documented by numerous investigators (Shaler, 1895; Kuenen, 1948; King, 1972; and Komar, 1973). Detailed measurements by others (Jefferson, 1903; Evans, 1938) have shown that intercusp spacing often is not so uniform as perceived. Johnson (1919) and Russell and McIntire (1965) suggest that spacing is irregular during the early stages of cusp formation and becomes more uniform as cusps continue to develop.

Intercusp spacings at Point Reyes and Drakes Bay beaches were measured during the summers of 1977 and 1979, and are summarized in Table I. Figures 10 and 11 present sample histograms of spacing between active beach cusps at Point Reyes and Drakes Bay Beaches, respectively.

TABLE I

SPACING CHARACTERISTICS OF BEACH CUSPS AT POINT REYES AND DRAKES BAY BEACHES

Location	Berm Level	Year	No. of Cusps	Average Spacing (m)	Standard Deviation of Spacing (m)
Point Reyes South Beach	Upper	1977	11	62.0	8.8
	Upper	1979	10	61.6	9.5
	Mid	1977	15	41.4	7.2
	Mid (Active)	1979	21	42.8	7.9
	Lower (Active)	1977	30	27.9	2.5
Drakes Beach	Only One Berm Present	1977	31	29.8	5.2
		1979	26	23.2	4.5

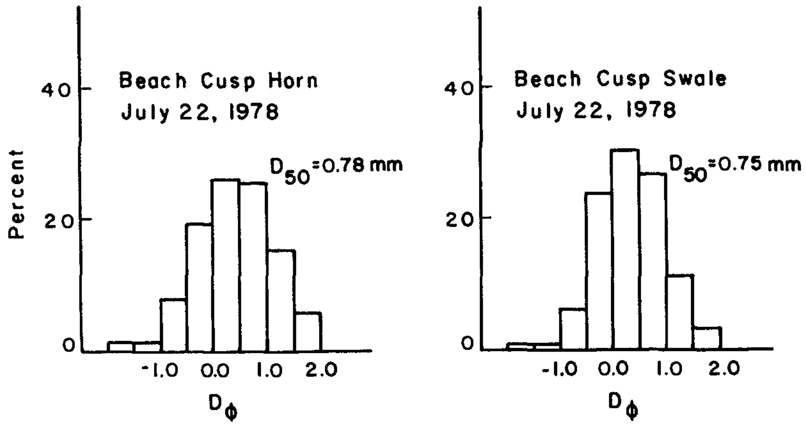

Figure 8. Representative Sediment Size Characteristics on Beach Cusps at Point Reyes Beach, California.

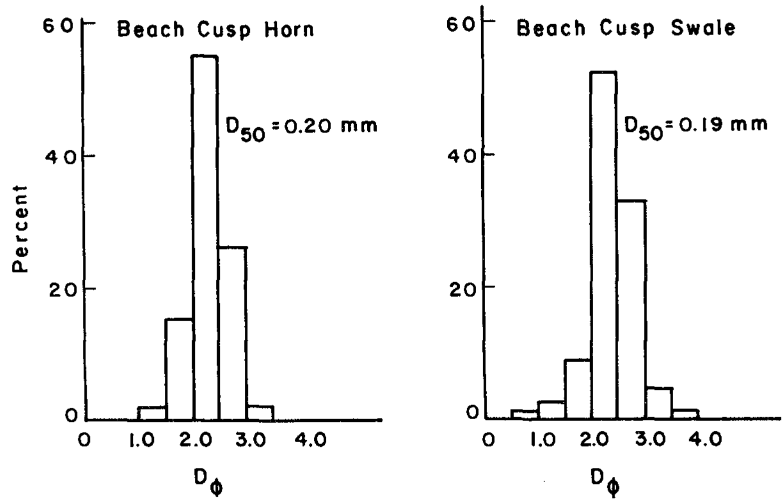

Figure 9. Representative Sediment Size Characteristics on Beach Cusps at Drakes Beach, California.

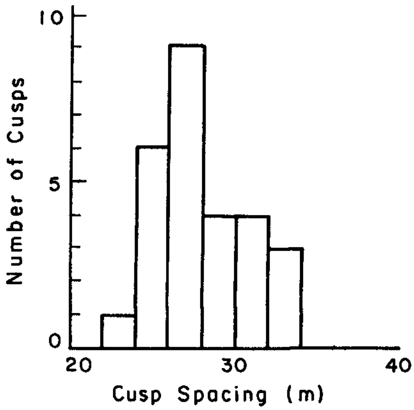

Figure 10. Histogram of Spacing of 30 Beach Cusps. Active Lower Berm, Point Reyes Beach South, California, August 23, 1977.

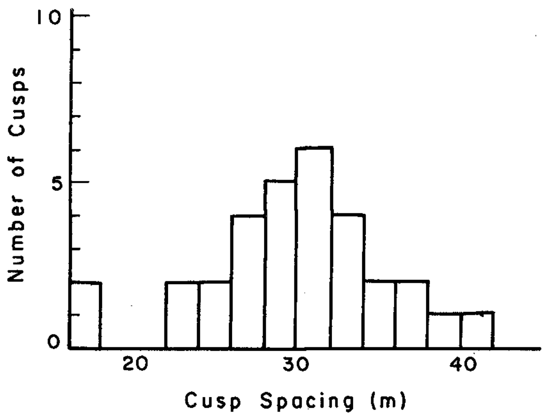

Figure 11. Histogram of Spacing of 31 Active Beach Cusps, Drakes Bay Beach, California, August 23, 1977.

During the 1977 field trip, there were three levels of cusps at Point Reyes beach, with only the lower level active. It is of interest to note that there is a consistent increase in cusp spacing with increasing berm elevation. Also of interest is the consistency of mean cusp spacing in 1977 and 1979. It is possible but unlikely that the beach cusps at the upper berm were not active during the intervening winters. The mean spacings at this level differed for the two summers by only 0.4 m of 61.8 m (0.6%). At the mid-level, which was active during the 1979 trip, the means differ by 1.4 m of 42.1 m (3.3%). At the Drakes Bay beaches, the difference is greater--6.6 m of 25.5 m (25.9%). The ratio of standard deviation of beach cusp spacing to mean varies over a fairly narrow range. For the Point Reyes and Drakes Bay beaches, these ranges are 9.0 to 18.5% and 17.4 to 19.4%, respectively.

Plane Table Surveys

Plane table surveys of beach cusps were conducted at various locations along Point Reyes and Drakes Bay beaches. Each survey included three horns and the two intervening bays. The mapping consisted of lines located approximately along the horns and bays and lines at each quarter point, which provided reasonable definition of cusp topography. Three example surveys are presented in Figures 12 to 14. The characteristics of these beach cusps will be discussed in a later section.

Swash and Wave Observations

During the 1979 field trip, limited observations of swash velocity and excursion were measured. Stakes were driven in the beach at 5 m intervals along lines extending upward along the horns and embayments. Maximum swash excursions were readily estimated to an accuracy of 1 m, and using an electronic stopwatch, swash velocities were calculated based on the time required for a floating object to advance (retreat) from stake to stake on the uprush (backrush). On July 28, 1979, uprush distance and associated beach cusp spacings were measured at both Point Reyes and Drakes Bay beaches. The parameters of interest including the ratio of cusp spacing, λ, to uprush distance, $(\xi_x)_{max}$, are presented in Table II.

TABLE II

SUMMARY OF UPRUSH EXCURSION AND BEACH CUSP SPACING MEASUREMENTS
JULY 28, 1979

Location	Uprush Excursions		Beach Cusp Spacings		$\lambda/(\xi_x)_{max}$
	No. Observed	Average Value, $(\xi_x)_{max}$, (m)	No. Observed	Average Value, λ (m)	
Drakes Bay*	46	12.5	26	23.2	1.9
Point Reyes	11	14.6	4	46.0	3.2

*Cusps in process of formation.

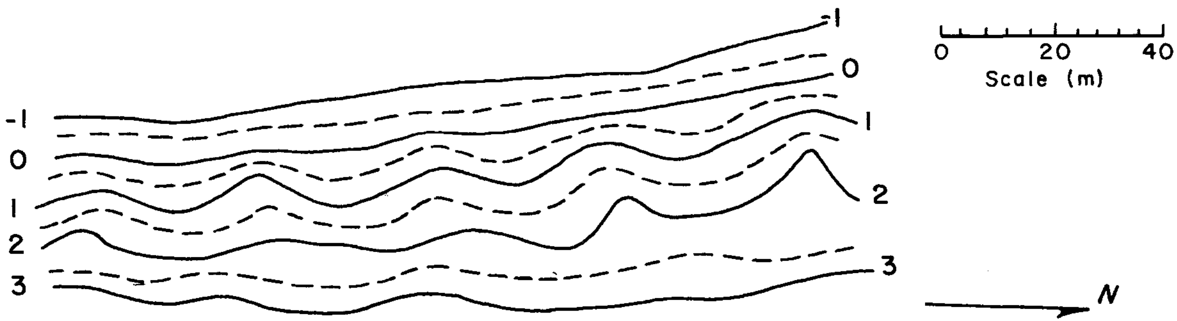

Figure 12. Beach Cusps at Point Reyes Beach North, California, July 22, 1978. Contours are in Meters Relative to an Arbitrary Datum.

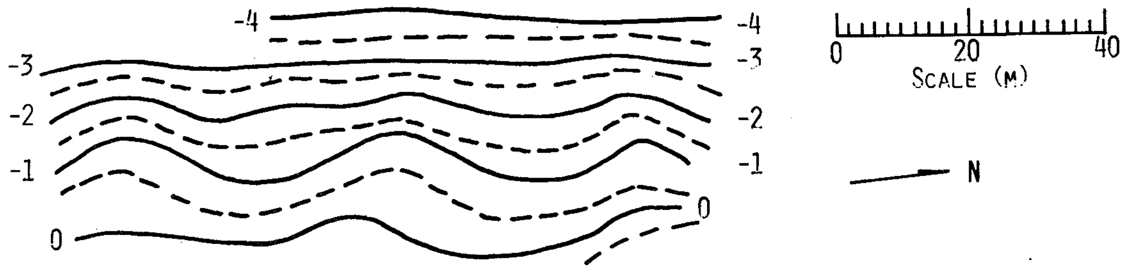

Figure 13. Beach Cusps at Point Reyes Beach South, California, July 23, 1978. Contours are in Meters Relative to an Arbitrary Datum.

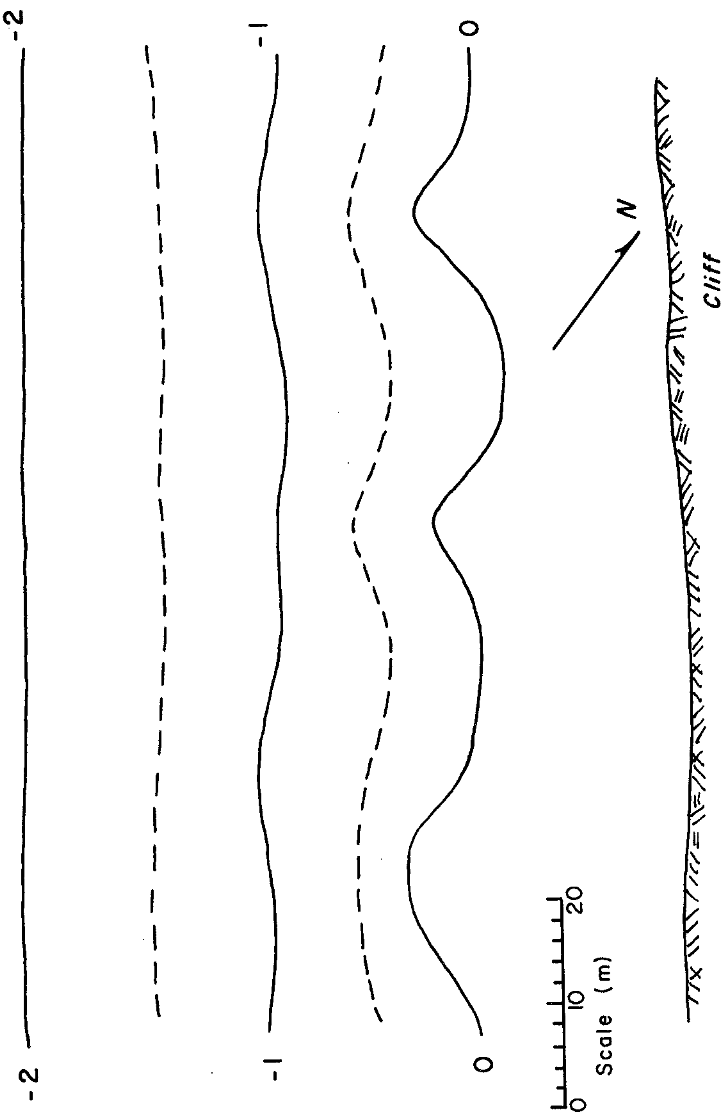

Figure 14. Beach Cusps at Drakes Beach, California, August 25, 1977. Contours are in Meters Relative to an Arbitrary Datum.

The ratio of $\lambda/(\xi_x)_{max}$ of 1.9 and 3.2 are of interest as will be discussed later.

Observations of Beach Cusp Initiation

During the 1979 field trip, storm waves caused the cusps at Drakes Beach to be essentially eradicated leaving a planar beach. The following day (July 28, 1979), the cusps started to reform and the periods of 100 consecutive waves were measured and the associated breaking heights estimated visually. The range in breaking heights (10 to 70 cm) resulted in breaking at varying locations offshore and caused the observed wave periods at the breaking point to differ from those that would occur at a fixed location; the periods were corrected to a common breaking location considering linear shallow water wave theory for the celerity and a uniform slope of 1:25. The resulting histogram of wave periods is presented in Figure 15; the mean and standard deviation of the wave periods are 15.4 sec. and 5.1 sec., respectively. In addition a series of 46 wave heights and associated uprush excursions were observed. The mean and standard deviation of 46 wave heights (visually observed) were 33.5 cm and 17.0 cm, respectively and those of the 46 uprush excursions were 12.5 m and 4.0 m, respectively. It is interesting that the ratio of standard deviation to mean was determined to be less for the uprush excursions than for the wave heights--0.32 vs. 0.51. The correlation coefficient, r, was calculated between the breaking wave heights, H_b, and the associated uprush excursions, $|\xi_{x_i}|$

$$r = \frac{\sum(H_{b_i} - \bar{H}_b)(|\xi_{x_i}| - \overline{|\xi_x|})}{\sqrt{\sum(H_{b_i} - \bar{H}_b)^2 \sum(|\xi_{x_i}| - \overline{|\xi_x|})}} \qquad (1)$$

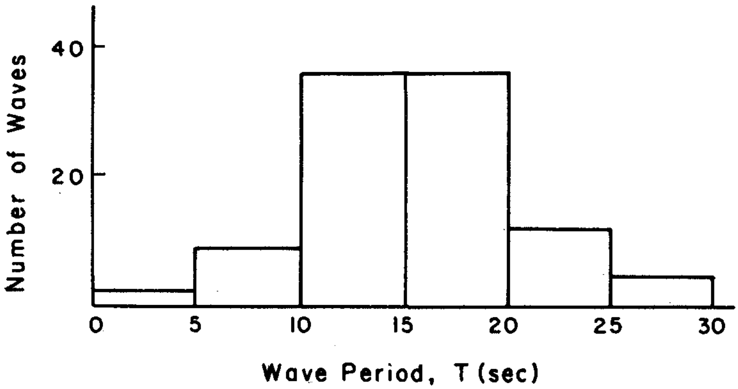

Figure 15. Histogram of the Periods of 100 Consecutive Waves, Measured During Formation of Beach Cusps, Drakes Beach, July 28, 1979.

and a very small negative value ($r = -0.15$) was found. The explanation may be that the mild slope causes the larger waves to break further offshore and in the vicinity of the beach face, the amount of wave energy available for the uprush is nearly independent of the breaking wave height.

THEORY

Introduction

In this section, the interpretation of field observations will form the basis for an attempt to develop a theory representing the swash dynamics on a cusped beach. In addition to the goal of clarifying the mechanisms, a successful theory should yield reliable predictions of beach cusp spacing. The theory presented here commences with an idealization of the beach cusp topography, then proceeds to develop the swash characteristics and finally an equation for the beach cusp spacing is presented in terms of the swash mechanics and the topographic relief of the cusp.

Idealization of Beach Cusp Topography

Based on examination of a number of beach cusps, a reasonable, simple and idealized representation was selected as

$$h(x,y) = Ax(1 + \varepsilon \sin ky) \tag{2}$$

in which x and y represent horizontal distances in the shore normal and shore parallel directions, respectively, h represents the elevation of the sand surface above some datum, k is the longshore wave number of the beach cusps, A is the average slope, and ε is a small parameter. Figure 6 presents example calculated contours for $\varepsilon = 0.2$. The parameter, ε, can be shown to be

$$\varepsilon = \frac{h_H - h_B}{2Ax} \tag{3}$$

or

$$\varepsilon = \frac{h_H - h_B}{(h_H + h_B)} \tag{4}$$

where the subscripts "H" and "B" denote horn and bay respectively and h_H and h_B are measured at the same x value.

Water Particle Kinematics

The approach will be to consider the water particle motion as that of a discrete particle subject to an initial velocity and gravitational force. The effects of friction will be neglected.

The governing equations for the water particle are

$$\frac{dV_x}{dt} = -g \sin \alpha_x = -g \frac{\partial h}{\partial x} = -gA(1 + \varepsilon \sin ky) \tag{5}$$

$$\frac{dV_y}{dt} = -g \sin \alpha_y = -g \frac{\partial h}{\partial y} = -gAx\ k(\varepsilon \cos ky) \tag{6}$$

and the solutions for the water particle excursions can be shown to be

$$\xi_x(t) = V_{x_o} t - \frac{gAt^2}{2} \tag{7}$$

$$\xi_y(t) = -\frac{1}{2} gAxk\ \varepsilon \cos ky\ t^2 \tag{8}$$

Equations (7) and (8) are approximate since these solutions do not account for variations in slope as the particle moves across the cusp. In utilizing these equations below, the mid-position of the excursion in the x and y directions will be used to approximate this effect.

One use of these equations is in calculating the swash period, i.e. to a first approximation the water particle will return to the initial position in a time T_s, i.e. $\xi_x(T_s) = 0$, or

$$0 = V_{x_o} T_s - \frac{gAT_s^2}{2} \tag{9}$$

or

$$T_s = \frac{2V_{x_o}}{gA} \cong \frac{2V_{x_o}}{g \sin \alpha_x} \tag{10}$$

The maximum uprush occurs at $t = \frac{T_s}{2}$, i.e.

$$(\xi_x)_{max} = \frac{V_{x_o}^2}{2gA} \tag{11}$$

which simply represents a conversion of the initial kinetic energy of the water particle to potential energy.

The maximum displacement of a water particle in the y-direction should be more-or-less equal to one-half the cusp spacing, λ, and should occur at $t = T_s$. In addition, as noted above, taking values of x and cos ky in Eq. (8) as

$$x \approx \bar{x} = \frac{(\xi_x)_{max}}{2} \tag{12}$$

$$\cos ky \approx \cos \overline{ky} \approx 0.6 \tag{13}$$

and noting that $k = \frac{2\pi}{\lambda}$, $(\xi_y)_{max} = \frac{\lambda}{2}$, and $A \approx \sin \alpha_x$, yields for the cusp spacing, λ

$$\lambda \cong \sqrt{1.2\ \pi\varepsilon\ \frac{V_{x_o}^2}{gA}} \tag{14}$$

and using Eq. (11), the cusp spacing can be expressed in terms of the maximum swash as

$$\lambda \cong 3.9\sqrt{\varepsilon}\ (\xi_x)_{max} \tag{15}$$

Six of the sets of observed cusp systems provided enough information to determine ε. Three of these systems are presented in Figures 12, 13, and 14. The average ε values are presented in Table III and range from 0.07 to 0.29 with the values at Drakes Bay generally smaller than those at Point Reyes Beaches.

TABLE III

SUMMARY OF BEACH CUSP ε PARAMETERS

Date and Location of Survey	ε
Drakes Bay Beach August 25, 1977	0.13
Point Reyes Beach, North July 22, 1978	0.15
Point Reyes Beach, South July 23, 1978	0.10
Drakes Bay Beach July 23, 1978	0.07
Drakes Bay Beach July 23, 1979	0.09
Point Reyes Beach, South July 24, 1979	0.16
Point Reyes Beach, South July 27, 1979	0.20
Point Reyes Beach, South July 29, 1979	0.29

Selecting a value of 0.15 as reasonably representative and employing Eq. (15),

$$\lambda \doteq 1.5 \ (\xi_x)_{max} \tag{16}$$

i.e. cusp spacing is linearly related to swash excursion. It is relevant to note that Longuet-Higgins and Parkin (1962) found that their beach cusp data demonstrated a linear relationship between spacing and excursion. Their approximate empirical relationship is

$$\lambda(m) = 2.8 + 0.54 \ (\xi_x)_{max} \tag{17}$$

where $(\xi_x)_{max}$ is in meters. If the empirical relationship to their data is constrained to pass through the origin, the fit is not nearly as good as with the constant in Eq. (17); however, it would be

$$\lambda(m) \approx 1.2 \ (\xi_x)_m \tag{18}$$

DISCUSSION

"Active" beach cusps as discussed herein refers to a system in which the swash is sufficiently vigorous to transport significant quantities of sediment and which strongly reinforces the beach cusp topography, i.e. a tendency for deposition on the horns and erosion in the bays. In all cases observed "active" beach cusps were characterized by strong and predominant runup on the horns with a seaward flow concentrated through the embayments. This motion was enhanced by a near equality of the wave and swash periods which tended to maintain the cusp topography. The measured ratios $\lambda/(\xi_x)_{max}$ (1.9 and 3.2) presented in Table III are in order of magnitude agreement with the value (1.5) predicted in Eq. (16). Based on a plane table survey of August 22, 1977, the three berm elevations mapped are approximately 2 m, 3 m and 4 m above mean sea level. Although we did not establish elevations relative to a known datum, (e.g. MSL) these elevations are believed to be accurate to within 0.5 m. Considering the beach face slope, A, to be the same (1:10) during periods when all berms were formed, the approximate maximum swash excursion would be

$$(\xi_x)_{max} \doteq \frac{B}{A} = 10 \ B$$

in which B is the berm elevation. For the cusp spacings presented in Table I, the ratios of cusp spacing to maximum swash excursions, $(\lambda/(\xi_x)_{max})$, are 1.6, 1.4 and 1.4 for the upper, mid and lower sets. These ratios are in remarkably good agreement with the value (1.5) predicted by Eq. (16).

The relationship developed herein between cusp spacing and maximum swash excursion is in qualitative agreement with the effect of sediment size and cusp spacing, other factors being the same. Based on Eq. (11), the swash increases with decreasing beach slope. It is well-known that the beach face slope increases with grain size (Bascom, 1951), thus the swash excursion and cusp spacing would decrease with increasing sediment size. Trask, Johnson and Scott (1956) have documented for the Point

Reyes Beach area, a trend of decreasing cusp spacing with increasing sediment size.

Edge waves provide a possible alternate explanation of beach cusp formation; the associated predicted spacing, λ, is

$$\lambda = \frac{gT^2}{2\pi} \sin(2n+1)\beta \tag{19}$$

in which T is the wave period, β is the beach slope and n is the modal number. For a beach slope of 1:25 and the data presented in Figure 15 (associated with observed formation of cusps), the average wave period of 15.4 seconds yields spacings of 14.8, 44.3 and 29.6 m respectively for the three classes of edge waves noted above. The average observed spacing was 23.2 m which is closest to but differs by approximately 30% from the zeroth mode subharmonic case. Moreover, these subharmonic oscillations entail alternating uprush and backwash in adjacent cusp swales; this was clearly not occurring in any of the cusps observed. A more serious concern in accepting the edge wave explanation is the rather wide range of wave periods presented in Figure 15, and the uncertainty of the use of a single value for the effective beach slope. Additionally, the edge wave theory is linear and thus strictly applies only for small displacements. The swash excursions observed during cusp formation were on the order of 12 m thus raising questions as to the validity of a linear wave theory. Finally it is noted that edge waves would predict an increasing spacing with increasing slope which is contrary to the field observations of Trask, Johnson and Scott (1956) in which beach slope was inferred herein from sediment size.

CONCLUSIONS

There are several results from this study that support the conclusion that swash mechanisms govern beach cusp formation and spacing.

(1) The water circulation patterns resulting from the swash are such that they cause sediment transport upward and deposition on the horns and a seaward flow and scour in the embayments;

(2) The simple theory developed herein predicts a linear relationship between cusp spacing, λ, and maximum swash excursion, $(\xi_x)_{max}$, i.e.

$$\lambda \approx 3.9\sqrt{\varepsilon}\ (\xi_x)_{max}$$

in which ε is a parameter describing the cusp geometry (Eq. (4)). This relationship is in general accord with field results obtained in this study and that of Longuet-Higgins and Parkin (1962).

(3) The correspondence of large cusp spacing with high berm elevations at Point Reyes (Table I) and inferred maximum swash excursions provide very good quantitative agreement with the simple relationship developed herein.

(4) Wave periods were measured during beach cusp formation from an approximately planar beach. These periods were quite variable, suggesting that edge waves are probably not the causative mechanism. Additional difficulties in accepting edge waves as the cause are the characteristic non-planar beach geometry and a different trend than inferred from the field data of Trask, Johnson and Scott (1956).

Although swash mechanisms appear to control cusp formation and maintenance at the beaches studied, edge waves or other mechanisms may dominate for cusp features on other beaches and/or under different wave conditions.

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