Baker Beach, San Francisco, California

Rip Current-Beach Cusp Coupled System: Waves, Currents, Sediments and Tides Self-Organize to form a Self-Maintaining Geometrical Coastal Geomorphology

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I. Introduction

Baker Beach, San Francisco, California is a popular urban beach that attracts a large number of visitors. This beach is located on the south side of the Golden Gate entrance to San Francisco Bay (**Figures 1 and 2**). It has a reputation of being a relatively safe beach, and for most days the surf conditions are mild. However, there are times when Baker Beach is a dangerous beach where people have drowned in the surf. Bing Quan Chung (age 77) drowned on the 20 November 2000 [1]. An unidentified boy (age 13) drowned on the 23 December 2000 [2]. Two U. C. Berkeley engineering students, Jennifer Tsai (age 20) and Kang Cheng Chiu (age 20) drowned in 1995 [3]. Elizabeth Restauro (age 9) and Norma Caguiambaga (age 32) drowned on the 27 November 1972 [4]. The drownings have been blamed on large waves breaking on the beach. However it is likely that a combination of breakers and rip currents were the cause.

This report looks beyond waves as the only hazard, and explores the probability that waves, currents, sediments and tides self-organize into a rip current-beach cusp coupled system to create a beach condition which endangers the lives of beach bathers. The coastal geography of Baker Beach is described, and information given on how, why, and where the greatest dangers occur. This paper is part of the author's Ph. D. thesis.

II Video Filming of Rip Current-Beach Cusp Coupled System

Obtaining data from the field on rip currents during large wave conditions is difficult for a team of researchers, and much more difficult for one person. However, I was fortunate to have observed a well defined rip current-beach cusp coupled system at Baker Beach, California on 16 February 2002. I filmed it on video during the falling of the lower high tide of the day, between 12:30pm and 2:00pm PST (or 20:30 and 22:00 UT; Universal Time, GMT). The rip current-beach cusp coupled system was well formed when I filmed it.

Although I did not observe the formation of the beach cusps I was able to film large waves breaking on the beach and transform into rip currents. It appeared to be a self-maintaining system [5]. Evidence of Dean and Dalrymple [5] is that beach cusps form during a time scale of several hours to several days.

I have been visiting Baker Beach since 1981. Between 1986 and 1989, I worked for the National Park Service as a lifeguard during the summer months (April 15 to October 15). In 1989 I was stationed at China Beach about a mile southwest of Baker Beach and patrolled Baker Beach several times a week. I do not recall seeing or reading about beach cusps and rip currents at Baker Beach such as those I observed and recorded in the video footage on 16 February 2002. Within a week (25 February 2002), the rip currents were gone, and the only evidence of the system was the remnants of the large beach cusp structures on the upper beachface. The impressive rip current-beach cusp condition was relatively short lived, and I have not observed them since. Video recordings were made during 2002 on 25 and 27 February, 6 March, 14 April, 6 October, and 22 December. The remnants of a beach cusp horn-and-embayment chain lasted through out the year and slowly eroded away completely on the lower beachface with only slight evidence of the horns and embayments remaining on the extreme upper beachface by 22 December 2002. This phenomenon has occurred at other times; it can be seen on an aerial photo taken in 1970 (**Figure 3**). When enlarged, the image shows evidence of a fully developed rip current-beach cusp coupled system with horns and embayments. The 1970 aerial photo in **Figure 3** is an enlargement of Baker Beach shown in **Figure 1**.

III Rip Current-Beach Cusp Coupled System

Rip currents and beach cusps during high-energy and shore parallel wave conditions in the surf zone and swash zone at Baker Beach were recorded on videotape on 16 February 2002, at 12:00 noon (20:00 UT, GMT). This rip current-beach cusp system was comprised of 22 horns and

21 embayments in the approximate shape of a 2-dimension cycloidal chain along the entire length of the beachface. A frame from the video that day is shown in **Figure 4** (for approximate scale, note the people on the beach). Baker Beach is about one kilometer in length and the cusps were roughly spaced a little less than 50 meters apart. This system appears to be an infrequent occurrence on Baker Beach. The time I filmed the cusps and rip currents was one week after a ten-day series of spring tidal ranges.

It is suggested that there is a tidal effect associated with the formation of a rip current-beach cusp system, as well as the distribution and sorting of the sediment on the beachface into cusps (horns and embayments) forming a geometric pattern, approximating a cycloidal chain (**Figure 5**). It is interesting to note that Dean and Dalrymple [5] make the following statement, based on a report by Seymour and Aubrey [6]:

> High tide seems to be conducive to the formation of cusps because the water level is stationary for a time sufficient for cusps to be generated; further high-tide cusps are not erased during other tide levels (Seymour and Aubrey 1986).

Longuet-Higgins and Parkin [7] observed that:

> Cusps were observed both near high water and near low water, but near low water they were never well-developed or regular. Accordingly only the cusps near high water have been recorded. In all cases the cusps were formed just after the turn of the tide; they were eliminated practically without trace by the next rising tide. (Longuet-Higgins and Parkin, 1962: 195)

This report explores the possibility that the rip current-beach cusp system on Baker Beach:

• can be visually described as a 3-dimensional series of horns and embayments that has the appearance of a linear cycloidal chain,
• that the height, period, and direction of the principle wave train are the main forcing functions creating this system,
• that spring tidal ranges, and beach sediment characteristics, are two of the contributing factors in the formation of the system.

Rip current-beach cusp systems are an often observed coastal regime. On some ocean beaches such as Drakes Bay, California, a number of large geometric shapes (both horns and embayments) form a sequence along the length of an entire beach, and are associated with rip currents. These observations suggest that the waves, rip currents, beach sediments, and tidal fluxes self-organize into a beach cusp-rip current coupled system on the beachface within the swash zone. Groups of large waves in between groups of small waves break in the surf zone, and run up and run down (sometimes referred to as drawdown) on the beachface (in the swash lens), and with the beach sediment, self-organize to form a geometry of beach cusps (horns and embayments) on the beachface. The 2-dimensional cycloidal geometry is useful in visualizing the 3-dimensional rip current-beach cusp chain along Baker Beach (**Figure 5**).

Three types of water oscillations occur on the beachface at Baker Beach:

1. tidal levels rising and falling twice daily,
2. rise and fall of wave set-up by wave groups,
3. uprush and backrush of the swash of a wave.

These swash oscillations (fluxes) might be a secondary force causing the scouring of the embayments between cusps into what appeared to be a parabolic shape. Thus, the 3-dimensional morphology of the embayments focuses the runoff in the swash zone to stream from the horns into rip currents in the embayments. These three swash oscillations appear to have a direct influence on the kinematics of the rip currents in the embayments. Also, the rip currents appear to be part of the swash circulation and work in harmony within the geometry of the embayment. Dean and Dalrymple [5] make a similar observation in the following:

> When the swash flows are predominately offshore, because the wave and swash periods are equal, the outflow tends to nullify the next uprush at those locations. However, at the location of predominant uprush, the next uprush is impeded, and the sediment-laden water proceeds upslope; in the process, gravity and friction reduce the velocity, causing deposition and contributing to the cusp horns and the lateral flow, which reduces the uprush in the areas of predominant outflow (the embayments) and allows the uprush on the horns to occur with vigor. When the cusps are constructed to their so-called equilibrium geometry, the uprush occurs with substantial force and provides sediment to maintain the cusp elevation. The water flows laterally to join with the lateral flow from the adjacent horn and then returns seaward in the middle of the embayment, some times as a fairly rapidly flowing stream with considerable momentum, contributing to scour of the embayment and to nullification of the next uprush. (Dean and Dalrymple, 2002: 290)

IV Methodology

Data were obtained for this report using two modes of film; digital Hi-8 video, and aerial photographs. With the digital video camera the beach and surf was filmed from an elevated position. Aerial photos were obtained from the collection in the Earth Sciences Library at University of California at Berkeley and were examined with the use of a stereoscopic viewer. Both sets of images were used to obtain information about the beach. The video film allowed me to observe how the rip current-beach cusp system worked over short (minutes and seconds) intervals of time. One of the aerial photos showed a rip current-beach cusp system. Only a few sets of aerial photos were available; there were probably other times that the beach cusp-rip current coupled system existed, of which I am not aware.

A Sony digital video camera recorder (DCR-TR7000) was used to film Baker Beach in real time. The camera had a "steady shot", which enabled the camera to be held steady by hand while recording. A copy of the video is on a CD ROM disk. The camera recorded the date and time on each frame. In terms of real time the camera recorded in hours, minutes, seconds and 10ths of seconds. This allowed frames of individual images to be studied, as a time history of the process. A computer was used to download the video, and this made it possible to study the motion of the beach cusp-rip current interaction at a variety of speeds, both forward and backward. These different views of the images helped in understanding the relationship among the incident waves, beach cusps and rip currents.

The interaction between the waves and rip current-beach cusp system was filmed from the following four elevated positions.

1. On the bluff above Lands End, to the west of Baker Beach, just north of the Palace of Fine Arts.
2. On the visitor's lookout at Eagle's Point (Golden Gate National Recreation Area) to the west of Baker Beach above China Beach Lifeguard Station
3. On the Bluff directly above the northern end of Baker Beach along the entrance path to the beach.
4. On the bluff above the beach to the north next to the Cosby Battery, a WWII US Army barracks.

Of these four vantage points, the fourth provided the best angle to observe the rip current beach-cusp system. This position allowed filming the action from above the beach, at an angle that permitted observation of the interface between the ocean and the beach. However, the camera was not in the ideal position, which would have been vertically above the beach. The observations given herein are visual descriptions, resulting from viewing the film many times.

During the early fall of 2002 when the surf conditions were calm, simple beach profiles were taken along two transects. A modified version of the low-tech "Emery board" designed by K.O. Emery in 1961 as given in Komar [8] was used. Sediment samples were obtained along these two transects, and examined for grain size and shape. The sediments were photographed with a digital camera mounted on a microscope and visually enlarged by 1000 times. The equipment in Pollen Laboratory were used under the direction of Professor Byrne in the Department of Geography, University of California, Berkeley. The sediments were mechanically analyzed for size distribution using a set of 8 sieves and a sieve shaker. For this lab work I used the equipment in the Geotechnical Engineering Laboratory under the direction of Professor Riemer in the Department of Civil and Environmental Engineering, University of California, Berkeley. This was done using the type of equipment and the methods described by Das [9]. The sieves used were the following U.S. standard sizes: 10 (2mm), 16 (1.190mm), 20 (0.850mm), 30 (0.590mm), 40 (0.417mm), 60 (0.250mm), 100 (0.149mm), and 140 (0.105mm.) The sieves were stacked with the largest openings on top and shook for 15 minutes on a sieve shaker.

V. Wave Observations

The waves observed on 16 February 2002 had six distinct characteristics. One, they were large, the maximum breaker height being about 3 meters. Two, they were parallel to the shoreline as they broke (the direction of approach was normal to the shore). Three, they were long period swell. Four, they were of the plunging type and broke on the edge of the beachface in very shallow water. Five, they approached the beach in sub groups of small waves and large waves. Six, the period and height of the waves breaking on the beach were variable. Visual observation indicated that the waves (height, direction, and period) are the primary force driving this rip current-beach cusp coupled system.

The swell observed approached the beach from the west northwest (open ocean direction, ~290°) through the passage defined by geological features on the north (Point Bonita) and south (Lands End) side of the entrance to San Francisco Bay. Wave data were obtained from the Point Reyes Buoy, CDIP station 02901 (operated by The Scripps Institution of Oceanography, UCSD, http://cdip.ucsd.edu). The buoy is about 40 miles northwest of Baker Beach. This buoy is located at 37 deg. 56.8' North, 123 deg. 28.2' West, which is approximately 21 miles west of Point Reyes, California. Point Reyes is about 32 miles northwest of Baker Beach (**Figure 2**). At the time the video was taken the swell appeared to be refracted only a little by bottom bathymetry and currents at the Golden Gate. The wave crests were nearly parallel to shore as they broke on Baker Beach. The beachface was relatively steep, and many of the waves were of the "shorebreak" type. These are waves that break as a plunging type breaker in very shallow water, on the beachface. "Shorebreak" is a common term used by lifeguards, defined as being caused by heavy surf conditions on a steep beach where plunging waves break in very shallow water and can be dangerous to bathers [6].

At 12:00 PST (20:00 UT), the significant wave height at the buoy was about 3 meters, (**Figure 6A**). The spectral peak wave period was 16 seconds, (**Figure 6B**). The mean direction from which the waves were coming was approximately 300° true, (**Figure 7C**). The energy spectrum was relatively narrow, and the spectral peak wave period was relatively long as can be seen in **Figure 8**. It is interesting and probably important that the wave periods for a few days prior to my observations were relatively long, as much as 18 to 20 seconds, and the direction from which they came was approximately 290°true. Also note that no data were recorded for the Point Reyes buoy on 17

February 2002 for 00:00 to 15:44 UT, owing to equipment malfunction.

Nearly all theoretical studies of the size and spacing of rip currents and beach cusps assume that waves breaking on the beach can be treated as being of approximately uniform height and period. Field observations however show the waves have irregular heights and periods (**Figure 8**, parts 1 and 2). The waves broke on the beach in groups, with sub-groups of smaller waves breaking between sub-groups of larger waves. The wave period also varied, ranging from 12.75 seconds (**Figure 8**, part 2, frames I-K) to 21.02 seconds (**Figure 8**, part 1, frames A-C) in a group. A group of waves is defined for this report to be from the time of the largest wave in the first group of waves to the time of the largest wave in the following group of waves [11]. Observations of the time between these large wave groups ranged from 5 minutes to 25 minutes, although this varied. On Baker Beach the length of time between wave groups appeared to be an additional factor which defined the geomorphology of the spacing and size of the cusp (video footage show that smaller wave groups break and swash lower down the beachface than larger waves). This is related to the wave set-up and set-down [5]. These observations point to the possibility that wave groups are part of the self-organization of the beach sediment, which forms the spacing and size of the cusps on Baker Beach.

VI Rip Current Kinematics at Beach Cusps

The characteristics of the rip currents observed on Baker Beach were not only a result of the waves, but also of the 3-dimensional shape of the beach cusp. The video film shows the following. As a wave breaks it runs up into the beach cusp embayment and onto the cusp horn or apex ; similar to the description by Bascom, [12]. The shape of the cusp, and gravity, channel the seawater swash, which is focused to flow first directly toward a low point in the cusp embayment, then stream seaward as a relatively narrow rip current (**Figure 9**). This streaming rip current is visually well-defined by a slightly elevated cylindrical shape, which forms as the focused seawater flowing from the right and left horns of the embayment and join together.

The above is a similar to the description of wave motion and beach cusps made by Longuet-Higgins and Parkin [7] — who discussed their observations and conclusions with Brigadier R.A. Bagnold. Their observations were made of small cusps forming on a steep shingle beach (small smooth flat pebbles) on the south coast of England.

> …During periods of cusp development, the shingle in the swash zone is clearly in a state of flux, being carried forwards up the beach by the incoming waves and back again, to a greater or less extent, by the returning backwash. Therefore the question whether the beach is built up or eroded at any particular point reduces to whether the constructive power of the upwash is on the whole greater or less than the destructive power of the backwash.
>
> Now the relative strength of the upwash and backwash is determined partly by the permeability of the beach: if the beach is permeable, part of the upwash penetrates downwards and returns by sub-surface percolation, emerging at the surface only much lower in the swash zone. Accordingly, it was reasoned, the greater the permeability, the greater the chances of constructive action of the waves (cf. Bagnold, 1940). (Longuet-Higgins and Parkin, 1962: 195- 196).

The rip currents appear in the video film to flow the strongest before the last larger wave of the larger wave sub-group (**Figure 9,** frames A through E). The wave groups set up a rhythmic motion in the swash zone of the beach cusp horn and embayment. This rhythmic motion draws-down as a wave begins to break in the surf zone, and then runs up the swash zone after the wave breaks. Just before this wave breaks, the seawater in the beach cusp embayment is focused and radiated directly inward to form a rip current, that runs down its center. Thus, as the larger waves break in deeper water than the smaller waves, the rip current travels further down the slope of the embayments (the sand is saturated in these embayments) and into the surf zone. This allows more seawater to be channeled along the rip current by the increase in size of the area of embayments. This also increases the length of the rip current and its strength, which is variable as a result of the lower water level. This is caused by the largest wave of the large wave sub-group as it breaks farther seaward that the smaller waves.

VII Beach Morphology

The beach sediment is composed mainly of coarse sand grains (based on the Wentworth classification). Large beach cusps in a cycloidal chain shape were observed well formed on the beachface on 16 February 2002. Remnants of these large cusps appeared to remain throughout the summer and fall as a morphological feature on the upper beach face, as observed on 6 October 2002.

San Francisco Bay (as with all tidal bays) has an ebb-tide bar, known as the San Francisco Bar. The size of the bar is a function of the tidal prism of San Francisco Bay and the amount of sediment available. This bar is composed of sediment from several sources, which circulate around San Francisco Bay and its entrance due to currents and waves (waves appear to have a greater influence than the tidal currents). The sources of sediment are from the cliffs of the inner and outer coast and the tributaries around the bay; creeks, streams, rivers [13]. A paper by Battalio and Trivedi [14] and report by Moffatt & Nichol Engineers [15] gives a schematic diagram of sediment transport in the Golden Gate region (**Figure 10**). Baker Beach is influenced by this sediment transport. Other direct sources of sediment are from Lobos Creek near the south end of the beach and steep cliffs at the north end of the beach. The bar has been substantially modified by dredging of the deep navigation channel through it and the relocation of the dredged sediment, deposited on the outside of the bar [14].

The shoreline of the beach is a 3-dimensional feature at the interface of a liquid, a gas and a solid (ocean, air, and sediment). The three states mix as particles (with sediment and water being the most dominant) and are forced directly and indirectly by gravity. On Baker Beach there are three mixing regions near the surface, where observations were made and sediment samples collected.

One mixing region is where the waves break. On this beach (while I was filming the event on video) plunging waves entrained air as bubbles into the water. As the wave plunged down to the surface underwater of the beach, sediment was forced upward into suspension. Then as the wave transformed into a current, the sediment was transported by the water. The three states mixed in a cylindrical shape nearly parallel to the beach, with the dimensions of this region directly related to the energy of the oncoming wave.

A second region is the upper limit where the swash reaches the maximum shoreward limit and starts to then flow back down under the action of gravity. Here, water and sediment mix with little influence from the atmosphere. The sediment in this region has more structure because of the properties of water and air (surface tension), which bind individual sediment grains.

The third region is the upper part of the beach where sediment is transported by the most extreme runup of the water at high tide, and by winds. There is a boundary within the sediment where the water and the air do not mix. On the shoreward side of the boundary the sediment is mixed only with air. The sediment in the region has less structure as result of being mixed with the air. This allows the sediment to move and shift with less resistance.

A. Sand Grain Size

Sediment samples were collected from these three regions along two beach profiles transects:

1. at the top of the beach,
2. at the top of the swash zone,
3. at the breaker point.

The two samples at the breaker point were taken a little seaward of the end of the beach profile surveys. Six samples were mechanically analyzed for size distribution; one set is shown in **Figure 11, a-c**. The small squares on the graphs represent cumulative percent and a solid line connects the squares. The largest median diameter of sediments was at the break point, with the high tide waterline next with smaller sediments, and the upper part of the beach with the finest sediments (**Figure 11, a-c**). The largest individual sediments (size of pebbles) were collected at the top of the swash zone. It is important to note that these sediments are large enough to significantly affect the distribution curves. [Note: I recently became aware of the sieve analyses of six beach sediment samples taken many years ago, three along two transects [15]. The samples were taken at the foreshore, slope and backshore along Range Lines (transects) 18 and 19.

B. Beach profiles

I made a survey of beach profiles along two transects on 6 October 2002 (**Figure 12**). The two profile transects were at about a third of a kilometer from each end of the beach (the profile transects divided the beach into approximately three equal parts). The surveys started from the top of the beach at the vegetation line, and ended to as far as I could safely get at the seaward extreme of the swash for the smallest wave of a wave group. Beach profile number 1 is located at the south end of the beach, at an emergency solar powered call box, near the outfall of Lobos Creek. Beach profile number 2 is located at the north end of the beach near the northern edge of the Chamberlain Battery. The two profiles extended from the landward edge of the berm to the lowest possible seaward edge of the swash zone. Beach profile number 1 has a slope of 1:21 over a horizontal distance along the transect of 48 meters. Beach profile number 2 has a slope of 1:23 over a horizontal distance along the transect of 36 meters. [I recently became aware of two beach profiles that extend from shore into water about 40 feet deep below MLLW. (from U.S. Army Corps of Engineers, San Francisco district [15]. In comparing these earlier beach profiles, it is emphasized here that profiles change with varying water levels and wave conditions [16[and [17].

VIII. Surf Similarity Parameter

Owing to the combination of the relatively steep beach face and long wave period (swell), Baker Beach was a relatively reflective beach on 16 February 2002.

It is interesting to compare this with the empirical relationship between the surf similarity parameter (ratio of beach slope, tan , to the square root of deep water wave steepness) and whether the combination of wave and beach condition is reflective or dissipative (e.g., Battjes, [18]; Dean and Dalrymple, [5])

TABLE I
Relationship between the Surf Similarity Parameter and the breaker type. Source: Battjes (1974)

ζ	**≈0.1**	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**
Breaker Type:	**Spilling**	**Plunging**	**Collapsing/Surging**				

The surf similarity parameter is

$$\frac{\tan}{\sqrt{Ho/Lo}} \qquad \frac{0.046}{\sqrt{Ho/Lo}} \tag{8.1}$$

where tan = 0.046 was the average slope of the two profiles I measured. The length of a 16 second period wave in deep water according to linear theory is (g is the acceleration of gravity, which is 9.8 m/sec^2)

$$L_o \quad \frac{g}{2}T^2 \quad \frac{g}{2} 16^{2} \quad 400\,\text{meters}. \qquad (8.2)$$

For a deep water wave height of 2 meters

$$\sqrt{Ho/Lo} \quad \sqrt{2/400} \quad 0.071 \qquad (8.3)$$

and

$$\frac{0.046}{0.071} \quad 0.65. \qquad (8.4)$$

On the day I recorded the waves, beach cusps, and rip currents using video at Baker Beach the swash zone and the surf zone were close together. The width of the surf zone was about the same as the width of the swash zone. The width of the surf zone estimated from the video tapes indicated that it was roughly about the length at the shore of a single breaking wave (recall that wave lengths decrease as they move into shallow waters). Owing to the irregularity of the waves, the width of the surf zone changed with each wave; the larger the wave, the wider the surf zone. Many of the waves broke almost at the shore as a "shorebreak", and ran up and down the 3-dimensional beach face (with cusps). It appeared to be more of a "reflective" beach/wave condition than a "dissipative" beach/wave condition.

IV. Self-Maintaining Beach Cusp-Rip Current System

The largest wave of a group approached the beach, then broke on the shore, where due to gravity much of the sea water of the previous wave had flowed seaward, as a rip current, clear of the beach cusp embayment in the swash zone. Each of the first smaller waves of a wave group swept through a given portion of the bay of the cusp, but not in a uniform manner, channeling into the rip current. Then the last few waves of the same wave group swept more uniformly through the entire cusp channeling a rip current through the middle of the beach cusp embayment in a more focused stream. The geomorphology of beach cusps at Baker Beach appeared to be somewhat symmetrical in terms of visual geometry.

In one observation, nine frames from a section of video footage were taken with a second of time in between each frame (**Figure 13**). This demonstrates that the runup of seawater does not fill in the beach cusp embayment in a geometrically symmetrical motion, but rather fills in from the one side and swashes toward the opposite side (in a clock-wise motion) before running seaward as rip current. The rip current in this observation discharges seaward from the west horn of the cusp. However, in another section the runup of a wave the runup had a geometrically symmetrical motion, and channels a rip current through the center of the beach cusp bay (similar to Bagnold, [19]).

The rip current-beach cusp system at that time was well developed and self-maintaining. It is possible that the tidal range or oscillation from the high tide mark to the low tide mark, during extreme spring tide stages, influenced the dimension of the cusp formation on the entire beachface (both upper and lower). Also, it is possible that there is a relationship between the length and width of the beach cusp that is directly related to the overall height of the beach cusp; from the high tide level to the low tide level (Dean and Maurmeyer, [20], and Werner and Fink, [21]). This height is influenced by three oscillations; one is the wave swashing, and the second is wave group setup and setdown, and the third is the tidal range. When I returned to the beach in December after a large storm the beachface was "leveled" to almost a sloping plane. That is, except for the extreme upper beach face, which had slight cusp formations — which appeared to be a memory of the embayment and horn spacing of the large beach cusp morphology.

X. Edge Waves

There are two basic questions here.

- *One, why and how did the surface sediments form a geometric shape resembling cycloidal chain?*
- *And two, were there edge waves, or did the beach cusp-rip current coupled system self-organize?*

Recall that the average alongshore length of the beach cusps (or spacing) was about 50 meters. The alongshore length of edge waves, $\mathbf{L_e}$, for a beach slope (tan) of 0.046 (=2.64 degrees) calculated using the equation of Ursell [22] (also see Longuet-Higgins and Parker, [7]; Dean and Maurmeyer, [20]; Bowen and Inman[23]; Inman and Guza,[24])

$$L_e \quad \frac{gT^2}{2}\sin(2n \quad 1) \quad . \qquad (9.1)$$

For the case of the edge wave being synchronous with the incident wave period, T_e=T, for n=0, for a plane sloping beach, and simple periodic incident waves of constant period and uniform height:

$$L_e \quad \frac{9.8T^2}{2}(\sim 0.046) \qquad (9.2)$$

(recall that for relatively small beach slope angles, , sin ≈ tan ;in this case, ≈0.046, for = 2.64 degrees.)

≈10.3 meters for T =12 sec.
≈18 meters for T = 16 sec.
≈ 23 meter for T = 18 sec.

Or, if the edge waves have a period that is the first subharmonic of the incident wave period, as some investigators suggest (with what justification?), the alongshore length of the edge waves would be twice as long as shown above. Compare these values with the average value of the beach cusp length of a little less than 50 meters.

The theory of Ursell [22] (pp. 84) is an exact theory. An approximate long wave theory was developed by Eckart [25] (pp. 51, Eq. 61) is sometimes used in the technical literature. It is:

$$L_e \quad \frac{gT^2}{2}(2n \quad 1)\tan \quad . \tag{9.3}$$

Note the difference: (2n+1) tan rather than sin(2n+1) . For n=0, and small values of , the numerical values are nearly the same. As mentioned above, for the beach angle of Baker Beach, at the time of the survey, the average of two beach profile transects was about ≈ 2.64 degrees, and sin ≈ tan ≈ 0.046.

In order to see how the edge wave lengths calculated for Baker Beach fit into the context of other beach slopes and incident wave periods, the following Table 2 is given.

TABLE 2

Alongshore L_e, meters, for n=0 (edge wave period synchronous with incident wave period.

Beach Face Slope	Wave Period Seconds: 8	10	12	14	16	18
1:10	10.0	15.6	22.5	30.6	39.9	50.5
1:20	5.0	7.8	11.2	15.3	20.0	25.3
1:30	3.3	5.1	7.4	10.1	13.2	16.7

It is not evident how simple periodic standing edge waves are formed by irregular swell. The above can be compared to the study by Dean and Maurmeyer [20] on beach cusps on the Great Beach at Point Reyes National Seashore in Marin County, California. This straight beach, about ten miles long, is to the north of the headland. Baker Beach is 32 miles to the southeast but owing to its location within the Golden Gate, the surf is not as high, and owing to the configuration of the coastline the waves are filtered in regard to the open ocean direction of wave travel. Also of note is that Dean and Maurmeyer [20] did not have measurements of wave conditions, but they made some visual observations.

XI. Discussion

1. It is difficult, almost impossible, for one person working alone to obtain quantitative data on rip currents at times of high surf. The author was fortunate that by chance he visited Baker Beach when there was a beach cusp-rip current coupled system that was being self-maintained, and filmed it by video. Observations from the video have been described herein, and have been discussed in comparison with observations of other researchers.

2. The rip current-cusp coupled system at Baker Beach has an intriguing geometry that can visually be described as a cycloidal chain. It was not evident to the author, either from his own observations, or reading papers by other researchers why this shape should have evolved. Perhaps it is explained by the "self-organization" theory. However, this theory although very complex, is still a simplification of reality (e.g. Werner and Fink, [21]; Coco, Huntly and O'Hare, [26]).

3. The swell was long period and parallel to the beach (i. e. the incident swell approached the beach in a normal direction). The beachface was relatively steep. The combination resulted in a relatively reflective beach/wave system. It appears from a review of the technical literature on the subject of beach cusp-rip current coupled systems that a "reflective beach " is the type most likely to have them develop, and to be self-maintaining (Longuet-Higgins and Parker [7]; Dean and Maurmeyer [20]; Short [11]; Coco, O'Hare and Huntly [27]).

4. Two types of beach cusp swash patterns were recorded on video. One pattern was similar to that described by Bagnold in 1940; "the horn divergent type" of Masselink and Pattiaratchi [27], where the wave breaks and swashes up over the two horns of the cusp and channels through the center of the cusp embayment. A second pattern, one not described in the literature to my knowledge, is where the wave breaks and flows as a current from one horn of a cusp through the embayment in a clockwise motion toward the second horn, then streams seaward as a rip current (**Figure 13**). The cause of this pattern was not apparent even after reviewing the video tape many times.

5. The rip current-beach cusp phenomenon is a coupled system. It appeared to be self-maintaining, at least until a major change in wave conditions occurred. Observations were made of a well-developed system, not an "evolving" system. There is almost nothing in the technical literature of observations during the formation of beach cusps. Observation and measurements of an evolving system are needed; e.g. Coco, O'Hare and Huntly[27](pp.747).

6. The two mechanisms for the formation of a beach cusp/rip current system most commonly cited in the recent technical literature are "self-organization" and the other forced by a combination of edge waves and breakers. Coco, O'Hare and Huntly [27]say:

> We believe that our analysis shows it is simply not possible to find beach cusps in the field or generate them in the laboratory and make simple measurements which provide support for one theory above the other. (Coco, O'Hare and Huntly, 1999: 747)

Coco, Huntly and O'Hare [26] made a numerical investigation of the formation and development of beach cusps. They conclude:

> Results obtained confirm the validity of the self-organization approach and its capacity to predict beach cusp spacing, with values in fair agreement with the available field measurements… However, changes in the random seed and runs for large numbers of swash cycles reveal a dynamical systems with significant unpredictable behavior. (Coco, Huntly and O'Hare, 2000: 991)

7. Edge waves are cited in the technical literature as being a mechanism in the formation of beach cusp. It appears that they may be in some cases, if the beach is steep. However, the evidence for the presence of standing edge waves is not obvious on ocean beaches. It was not possible for the author to determine from the video tape whether or not they were present at Baker Beach. It is possible they were present in the initial formation of the beach cusps, acting as a "trigger".

8. After looking at the data on the beach sediment at Baker Beach, there is no evidence for or against the size of the sand grains being a factor in the formation of the geometric patterns. Also, I was unable to determine if the dimensions of the individual beach cusps and their overall spacing were related to the grain size and shape.

9. It would have been desirable to survey the beach profile through the surf zone, but it was not possible for one person to do so. The two beach profiles along two transects surveyed about thirty years ago [15] are helpful, but it must be recalled that profiles change with changing wave and current conditions (e.g., Wiegel 1964[16], [17]).

XII. Conclusions and Recommendations

• A fully-developed rip current-beach cusp coupled system was observed and recorded on video tape at Baker Beach, San Francisco, California on 16 February, 2002. This is a popular urban beach.

• The video tape allowed for the repeated study of a real time observation, at different speeds, both forward and backward. This is a useful research tool: and it would be beneficial for a shared-collection of videos to be developed.

• Open ocean wave data were available from the directional wave buoy located about 40 miles northwest of Baker Beach, the Point Reyes Buoy.

• The long period swell approached the beach, shore normal (i.e., waves parallel to the beach). The combination of the long wave period and relatively steep beach face were such that this was a reflective beach/wave system on 16 February 2002. The waves broke as plunging type breakers and many were of the type described as "shorebreak" by lifeguards.

• It was observed that individual waves of the wave groups swashed upward onto the beach, and circulated the sand grains in the confines of a cusp. The large waves of the groups (called a "set" by surfers) swashing up on Baker Beach were the primary source of energy forming rip currents and maintaining beach cusps. It appears from the video that this phenomenon is self-organizing, and self-maintaining for a limited time (several days). Each wave of a group influenced the pattern and distribution of the cusps, which is a result of the entire series of waves in a group. The fluid dynamics of water play a role in the shape of the cusps. However, another mechanism acting on the beach is the astronomical tides. Although I did not obtain data on the relationship between tides and rip currents, it has been reported by others (e.g. Brander and Short, [30], pp. 36) that rip current maximum flow speeds occur near low tide and minimum speeds around high tide. This is very important from the standpoint of a lifeguard, and should be investigated further.

• The rip current-beach cusp coupled system evolved as part of the geomorphology of the beach. The beach sand and the waves produced a morphology coupled with rip currents at each cusp, which presents a hazard to the beach visitor.

• The author, a professional lifeguard, believes each cell of the cycloidaal chain can pose a danger. Thus, along the length of Baker Beach there can be over 20 potential locations for dangerous rip current at one time. From a lifeguard's point of view this combination of large shorebreaking waves and rip currents can result in life threatening situations for the unaware beach visitor.

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