Chapter 1

WAVE PROCESSES IN THE BERKELEY EMBAYMENT

Peter K. Gee

Introduction

Waves are important in almost every physical process that takes place in the sea. A wave, in the form of an undulation moving across the surface of the water, is a conveyor of energy. It may be generated locally or several thousands of miles away in the ocean. Waves expend little energy in travel, and therefore expend most of it at the end of their journey, crashing upon a beach, breakwater, cliff or other landform.

The purpose of this study is to provide information on waves and their possible effects within the embayment between the Berkeley Marina and the Emeryville Marina, henceforth to be referred to as the Berkeley Embayment (FIGURE 1). Our interest in this area lies in recreation as well as in environmental quality, specifically for the shoreline between the Berkeley Marina and Ashby Spit. A beach has been proposed for this stretch by the Berkeley Beach Committee (Manning, 1979). Before any of the landfill took place in the 1950's, a beach existed north from University Avenue to Point Fleming, but much of the sand was sold and used for construction purposes. The proposal is an effort to "repair" environmental damage (the destruction of the beach and the placement of landfill) to West Berkeley. It is hoped to repair the coast with a minimum amount of money spent. However, without proper investigations of the physical processes involved, one cannot fill the shoreline with sand to make a beach, for the sand may not be compatible with the wave action and circulation in the water, and therefore may not stay in place. This study of waves and the following two on water circulation and sediment size analysis, by Linda Goad and Donald Bachman, respectively, are a start in determining whether or not a beach is feasible.

Wave Properties

An ideal wave train is a series of successive waves evenly spaced; each wave is equal, and there is no outside interference. Each wave has four principle characteristics: height, wavelength, period and velocity (Bascom, 1980; Russell and

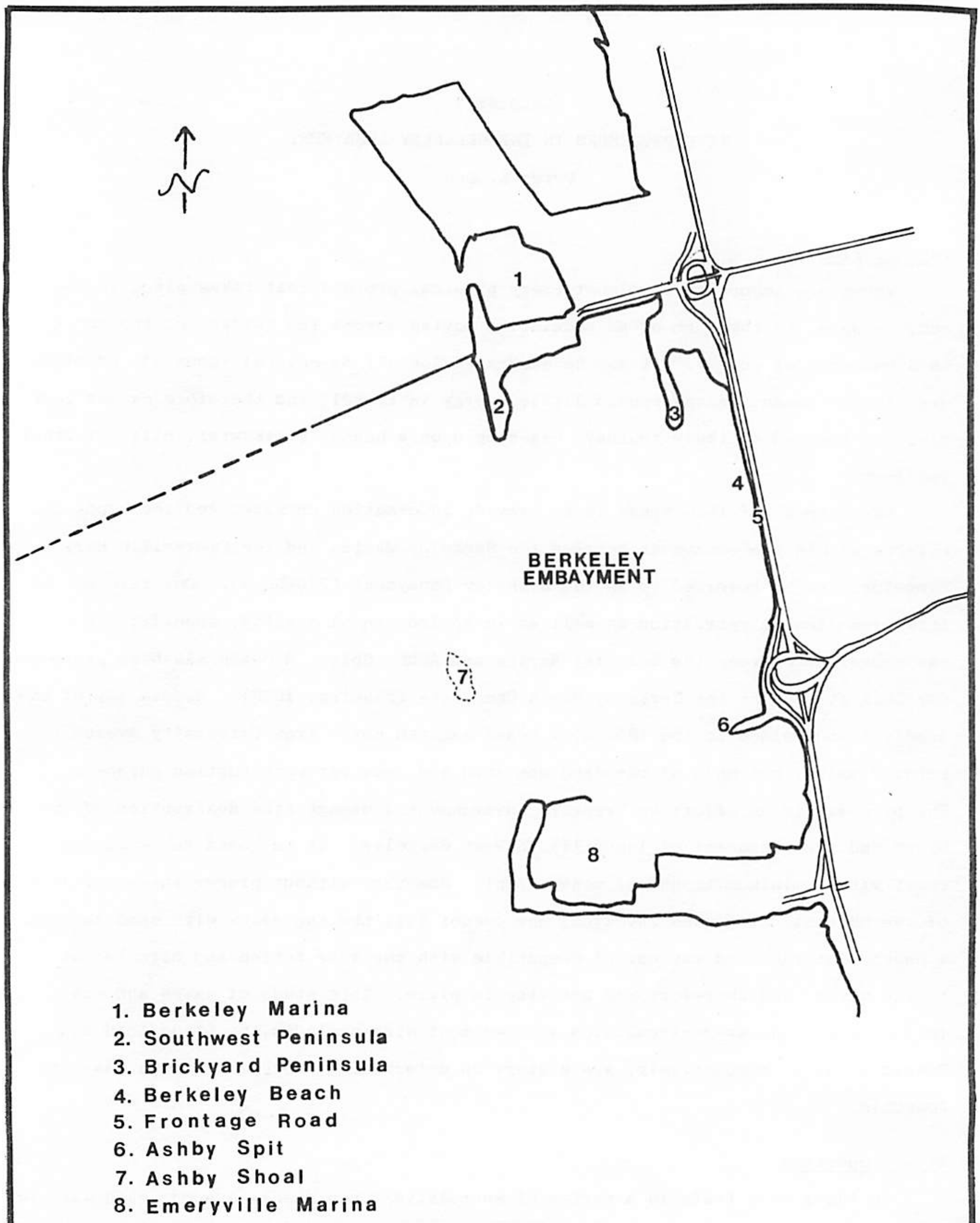

FIGURE 1. BERKELEY EMBAYMENT.
[Source: U.S. Dept. of Commerce, 1981]

FIGURE 1. Berkeley Embayment.

Macmillan, 1952). Height (H) is the vertical distance between the crest and the trough of the wave, and wavelength (L) is the horizontal distance between adjacent crests or troughs. These are usually measured in feet. Ideally, these two characteristics are independent of each other, but in actual situations this rule does not hold true, as we shall soon see. The period (T) of a wave is the time in seconds between two successive crests past a fixed point; this is inversely related to the frequency (f), or the number of waves that pass a stationary point per unit time. Wave velocity (v) is the speed (and direction) which waves travel past a fixed point.

Under ideal conditions, velocity is equal to the wavelength divided by the period. However, the Berkeley Embayment, like any other marine body, is far from ideal. In actual conditions, velocity is given by the relation (Bascom, 1980)

$$v = \sqrt{gL/2\pi} \quad \text{or} \quad \sqrt{5.12L}$$

where g is the acceleration of gravity (32 ft/sec^2) and wavelength is given by the relation

$$L = (g/2\pi)T^2 \quad \text{or} \quad 5.12T^2.$$

The greater the wavelength, the greater the velocity. Furthermore, wave height is independent of wavelength only if it is not greater than one-seventh of the wavelength (Bascom, 1980); that is, the wave begins to break when wave steepness (H/L) exceeds 1:7.

Waves can be generated naturally by wind, seismic activity, or the gravitational pull of the moon and sun. Our study of the Berkeley Embayment is concerned with the most familiar kind, those generated by wind. Waves are created as the frictional drag of air moving across the water surface produces ripples. A higher surface tension increases the frictional drag with the air, and therfore enhances the response to the wind. Generally, the minimum wind speed to cause this response is 3.6 feet per second (Russell and Macmillan, 1952). Waves grow rapidly as the wind bears directly on the steep side of the ripples, which inturn allows for a more effective transferral of energy from air to water.

Factors that influence the size of wind waves are wind velocity, duration of the time the wind blows, and the distance over water in which the wind blows (the fetch). In the open ocean, waves grow to become stable swells, obtaining the maximum dimensions possible for the wind generating them; this result is known as a fully developed sea (Bascon, 1980). Within the Berkeley Embayment, however, limits such as shallowness and nearness to the shore can counter the effects of the above factors. The shallowness reduces wave velocity, which brings about a proportionate decrease in wavelength, which in turn tends to increase the wave height (Russell and Macmillan, 1952). Even if the water were deeper, the short distance to shore would prohibit the full development of waves.

In addition to the surface motion of waves there exists an internal motion. Individual particles are said to be moving in circular orbits at a relatively constant rate and in one rotational direction (Wiegel, 1964). FIGURE 2 is an illustration of the orbital motion. When a crest is approaching, the particles are rising (a); when the crest is overhead, they are moving in the same direction as the wave (b); when the crest is leaving, the particles are falling (c); and when the trough is overhead, they are moving in the opposite direction to the waves (d).

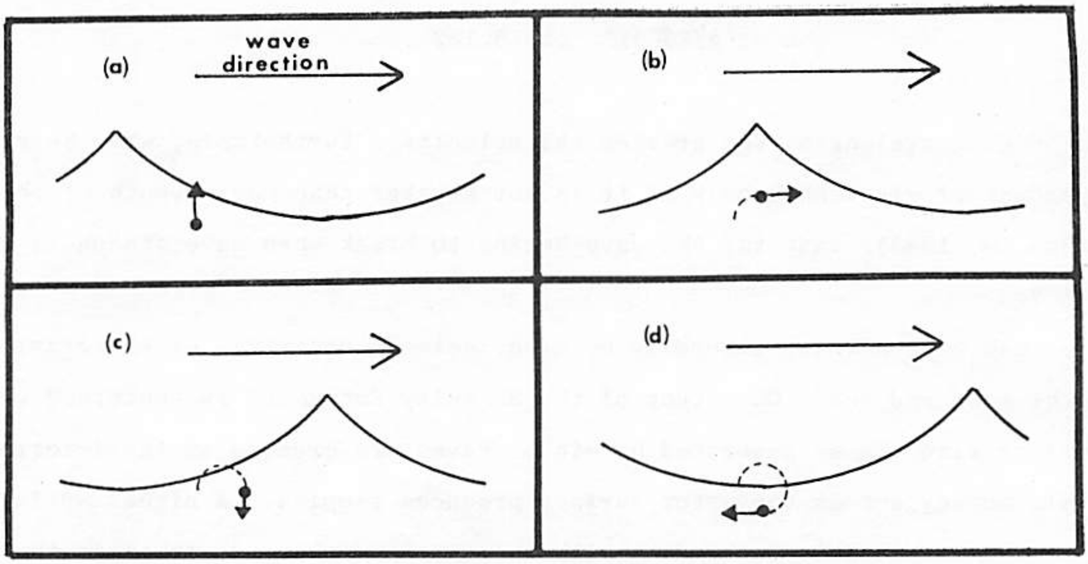

FIGURE 2. Orbital Motion of Water Particles.

All the orbits of particles in a vertical line are in phase. When the water is shallow, as in most of the Berkeley Embayment, vertical movement of the particles is restricted. The orbits become horizontal ellipses, each deeper ellipse flatter than the one above it, and the ellipse at the bottom being completely flattened out, such that the particle moves back and forth in a horizontal path. It is important to note that these orbits are not completely closed, but instead new orbits are formed as particles have a net shift in the direction the wave travels. This forward motion of particles is called mass transport.

Waves in the Berkeley Embayment are a mixture of those propagated from the Pacific Ocean, waves generated over central San Francisco Bay, and locally-generated waves. Most of the waves are shallow-water waves, those that travel in water depths of less than one-half the wavelength. Thus, the way waves act depends on the basin as well as the wave characteristics.

As waves approach the shoreline, especially in shallow waters like the Berkeley Embayment, they reflect, diffract, and refract (Bascom, 1980; Wiegel, 1964). Reflection occurs when a wave encounters a vertical obstacle and is cast back with little loss of energy. Diffraction is the flow of energy perpendicular to the direction of wave motion, that is, the flow of energy laterally along the crest of a wave. This is responsible for waves propagating into otherwise sheltered regions. Waves are said to refract when they change directions due to a change in wavelength, which affects velocity. Wave fronts tend to become parallel to the shore because of the decreasing water depths which shorten wavelength.

Waves approaching the East Bay shoreline are reflected, diffracted and refracted by projections from the shore, such as the southwest peninsula of the Berkeley Marina landfill (FIGURE 1). Wave fronts from seven-feet deep water--measured at mean lower low tide (U.S. Department of Commerce, 1981)--reflect off the riprap along the west side of the peninsula near Seawall Drive (FIGURE 3). Diffraction of incident waves occurs close to the tip of the peninsula. To the south of the peninsula the waves are almost unaffected until the waves enter the geometric shadow of the landform. In this region the diffracted waves and the incident waves superimpose. In the geometric shadow northeast of the tip, the wave crests almost form the arc of a circle with its center at the peninsula tip. Refracted waves tend to contour around the peninsula, and are convex to the shoreline (FIGURE 4).

As waves approach the shore, wavelength and velocity decrease because of the shallowing basin, and thus, waves refract. The waves become steeper until the wave height becomes so great in relation to the water depth that the waves become unstable and break, releasing their energy in a tumultuous moment. This happens when the depth is roughly equal to 1.3 times the wave height (Bascom, 1980). In the case of the Berkeley Beach, breakers may occur 150 feet from the riprap bank along Frontage Road at low tide due to the shallow and level basin. The energy of the

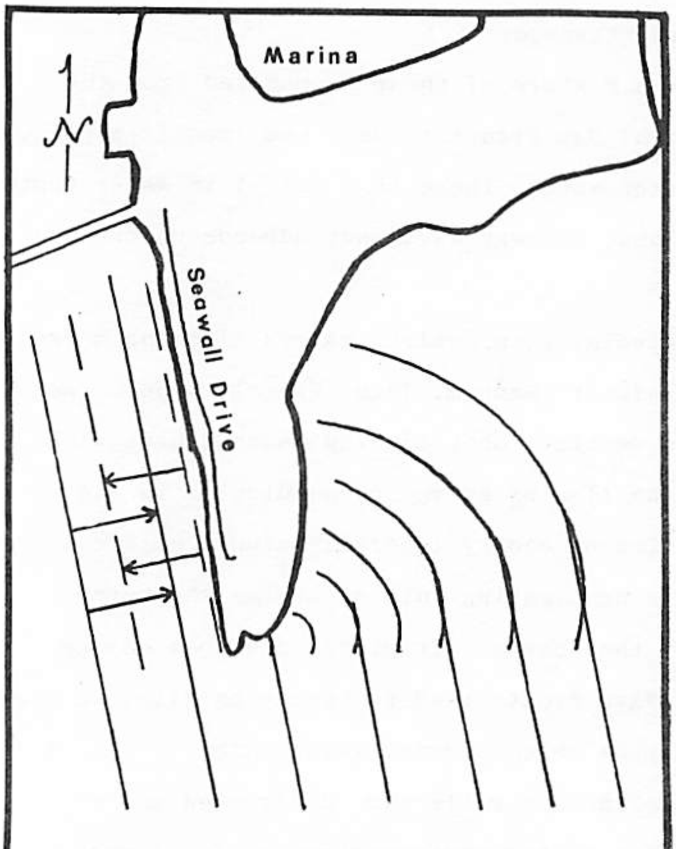

FIGURE 3. Wave Reflection and Diffraction

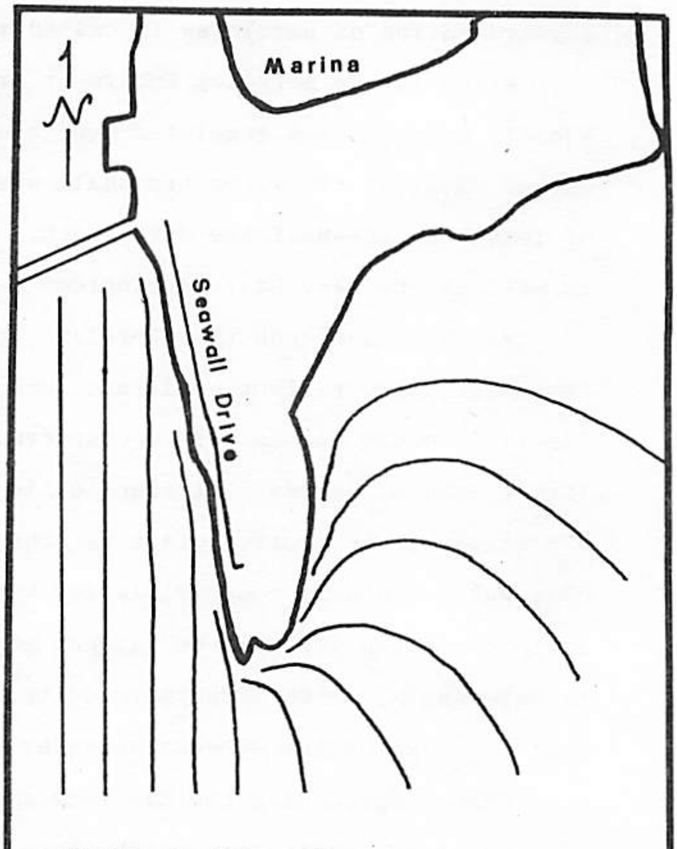

FIGURE 4. Wave Refraction

breaking waves suspends sand particles off the bottom and carries them shoreward. Depending on the wave action and the size of the sand particles, the particles may be carried seaward by the backwash. Wave action changes with the season. Waves are larger in the winter than in the summer, and therefore energy is expended on the beach at a higher rate in the winter. This energy erodes the beach, which is built by the mild summer waves too small to carry sand seaward in the backwash. Thus, it can be said of the wave-sand interaction: "The waves change the sand at the same time the sand is changing the waves" (Bascom, 1980, p. 219).

Although waves tend to become parallel to the shore as a result of refraction, this process is usually not complete. Breaking at an angle with the shore, waves usually produce a littoral current or a littoral drift. Combined with the continuous breaking of waves, the littoral drift is the primary means of transporting sand along the coast (Johnson and Wiegel, 1958). Particles suspended by breakers are relocated either by the littoral drift or a rip current (a continuous flow from the shore back to the sea through an eroded channel) (Bascom, 1980). These natural processes, which move sand back and forth, are the foremost concern involved with artificially creating a beach, and without proper understanding and foresight, expensive erosion could result.

An example of an unsuccessful effort to create a beach is the Robert Crown Memorial Beach in Alameda. The park shoreline eroded over 250 feet in twelve years after it was built in 1958 (U.S. Army Corps of Engineers, 1979). The beach construction, an artificial fill of fine sand, was completed in 1959. Presently, little or no beach remains along Shoreline Drive, and the park facilities and the road are now in imminent danger of yielding to erosion. The San Francisco District, U.S. Army Corps of Engineers initiated a beach erosion control study in response to a 1968 request by the East Bay Regional Park District (EBRPD). Of eleven alternative plans of action to stabilize the beach, most of the desirable alternatives were too costly. For example, the cost of a plan similar to one supported by EBRPD (a series of spits or "sand catchers" and breakwaters) was estimated to exceed $6 million. Therefore, with the Alameda beach as an object lesson, certainly no beach should be instigated in Berkeley without substantial studies having taken place.

Methods

The data were collected intermittently in March, April and May. Our first step toward understanding wave conditions that would affect a Berkeley beach was measuring wave dimensions. Wave measurements were made in various locations within the Berkeley Embayment from a twelve foot motor boat, using a graduated staff. Initially, we tried to use the motor to stabilize the boat, while the staff was held vertically in the water. We had numerous problems with this, and other methods of measuring the waves, until our third outing, when we decided to inject the staff into the sediment below. Because the staff was now self-supporting, we could read wave height and frequency (per 60 seconds) without physically interfering with the measurements. We then calculated the other three wave dimensions, period, wavelength and velocity, from the relations

$$T = (f)^{-1}$$

$$L = 5.12T^2, \text{ and}$$

$$v = 5.12L \quad \text{respectively.}$$

Unlike a simple wave train, the sea is filled with all sorts of waves of different dimensions traveling in different directions at different speeds, all superimposed on the water surface. We felt there was a large degree of uncertainty over which waves to read. In our frustrations at trying to make some sense of the waves, we did not register the smaller waves in the data, nor did we take into account the crossing of the numerous different wave trains.

To get an idea of the littoral flow, we dropped fluorescene dye in the water and tried to follow its dispersal. The dye was bound in facial tissue to permit a single clean injection into the water; the tissue gradually dissolved and the dye slowly dispersed. The dye was dropped approximately twenty feet from the shore in two locations: one west of the southern portion of the Brickyard Peninsula and the other west of the central region of the proposed Berkeley Beach (FIGURE 1).

Wind speeds were measured with a wind anemometer, and both wind and wave directions were measured with a magnetic compass.

Results

Wave and wind data were collected over a period of two months and are summarized in TABLES 1 and 2, respectively. Wave directions were observed to be dominantly from the west, although sometimes they came from the northwest and the southwest. These directions were usually the same as those of the wind, which ranged in speed from 0 to 26 knots. Generally at higher wind speeds, the waves were pretty high, splashing over the side of the boat. On several occasions the wind speeds fluctuated throughout the day, and, correspondingly, the dimensions of the waves fluctuated. Such was the case on March 6. The wave data for the majority of that day are not shown on TABLE 1 because our technique of working with the graduated staff had not yet been perfected; the measurements listed for 4:15 p.m. were visual estimates. The waves for that day were observed as follows: at 9:30 a.m. the water was as smooth as glass, but by 1:30 p.m. the surface was all choppy water. At 2:43 p.m. the water was as calm as in the morning, but the wind had picked up again by 4:15 p.m. and had created ripples.

The tests with the fluorocene dye started twenty feet from the shore, which appears to have been too far away. Instead of a measure of littoral flow, the dye served to indicate a shorebound surface current, which we already knew from our drogue study (see Linda Goad's report). By the time the dye reached the shore, much of it had dispersed and was difficult to observe. We did, however, see that

DATE	TIME	HEIGHT AVG/MAX (IN)	FREQUENCY (SEC^{-1})	PERIOD (SEC)	WAVELENGTH (FEET)	VELOCITY (KNOTS)
2/27/82	-	-	-	-	-	-
3/06/82	4:15 p.m.	4/--	.57	1.8	15.9	5.4
3/12/82	9:00 a.m.	3/7	.73	1.4	9.5	4.1
	11:10 a.m.	4/8	.62	1.6	13.5	4.9
	1:50 p.m.	5/--	.75	1.3	9.1	4.0
	3:20 p.m.	9/15	.50	2.0	20.5	6.6
	4:30 p.m.	5/--	.50	2.0	20.5	6.6
4/09/82	6:30 a.m.	3/--	-	-	-	-
	2:15 p.m.	4/--	.78	1.3	8.5	3.9
4/17/82	8:50 a.m.	2/6	.68	1.5	11.0	4.4
	11:05 a.m.	4/--	.90	1.1	6.3	5.7
	1:30 p.m.	7/15	.67	1.5	11.5	4.5
5/14/82	10:05 p.m.	6/12	.67	1.5	11.5	4.5
	11:40 p.m.	6/10	.67	1.5	11.5	4.5

- = no data

TABLE 1. Wave Data.

DATE	TIME	DIRECTION (FROM)	SPEED (KNOTS)	GUSTS (KNOTS)
2/27/82	-	-	-	-
3/06/82	8:30 a.m.	NE	15.1	-
3/12/82	9:46 a.m.	NW	7.3	-
	12:42 p.m.	WNW	8.1	-
	1:35 p.m.	W	7.6	-
	3:20 p.m.	W	15.6	18.3
	4:30 p.m.	W	18.3	21.0
4/09/82	6:30 a.m.	N	3.8	-
	8:25 a.m.	W	1.1	-
	12:30 p.m.	SW	3.2	-
	2:15 p.m.	W	6.5	-
4/17/82	8:50 a.m.	WSW	2.7	5.4
	11:05 a.m.	WSW	7.3	-
	1:30 p.m.	W	13.0	-
5/14/82	11:40 a.m.	SW	4.3	-

- = no data

TABLE 2. Wind Data.

some dye moved equally north and south along the shore of the Brickyard Peninsula, and north along the proposed Berkeley Beach. We did not record any rates of littoral flow because we could not visibly determine the front of the dye mass in solution.

Discussion

The Berkeley Beach is exposed to steady wave action. Although the largest waves I recorded from March to mid-May were fifteen inches high, an overall average height for this time is approximately four to five inches. Wave velocities averaged seven feet per second, or 4.2 knots, and the periods averaged 1.5 seconds each. Apparently these waves were wind waves generated over the central bay; ocean waves would have had a much longer period (fifteen to twenty seconds) and, since they funnel through the Golden Gate Strait, would lose most of their energy to diffraction (Pirie, pers. comm., 1982). Wind waves of this size don't appear to pose much of a problem for a beach if the grain size is coarse.

The even dispersal in both directions of the fluorecene dye along the Brickyard Peninsula indicates no littoral drift at the time of the test, which was mid-ebb tide. The northward dispersal along the central Berkeley Beach suggests a northward littoral drift. However, to measure a net littoral flow, experiments would have to be conducted repeatedly during all tide conditions. Since our experiment was conducted only on one mild ebb (the tidal difference was 4.1 feet), I cannot make any conclusions about the net littoral drift.

Although I recorded a maximum wind velocity of 26 knots, which does not seem to create substantial waves to deteriorate a beach of coarse sand grains, I must add that I was unable to collect data during the fierce storm at the end of March. Storms move most of the sediment away from a beach, and having collected no data in storm conditions, which are frequent in winter, I cannot infer much about the overall stability of the Berkeley Beach. Furthermore, during winter, the winds often blow from the east or southeast (Conomos, 1979), which will have different effects on the wave-sand interaction than the westerlies I recorded. I would contend that a Berkeley Beach can be stable through calm seasons in March, April and May, but, obviously, a beach must be stable year-round. I would certainly like to see a beach in Berkeley, but since so many interested groups of people are involved and so much money is at stake, I would suggest the wave experiments be conducted over a period of several years, so that assurance can be expressed before any beach construction takes place.

REFERENCES CITED

Bascom, Willard, 1980. Waves and Beaches: 2nd Edition, New York, Anchor Press/Doubleday, 366 pp.

Conomos, T.J., 1979. Properties and Circulation of San Francisco Bay Waters, pp. 47-84 in Conomos, T.J., ed., San Francisco Bay: The Urbanized Estuary, American Association for the Advancement of Science, San Francisco, California, 493 pp.

Johnson, J.W. and R.L. Wiegel, 1958. Investigation of Current Measurement in Estuarine and Coastal Waters: Berkeley, California State Water Pollution Control Board, Standard Service Agreement No. 12C-18, 233 pp.

Manning, Curt, 1979. The Reconstruction of Berkeley Beach: Oakland, Penthouse Printing, 14 pp.

Pirie, Douglas, Coastal Engineer, U.S. Army Corps of Engineers. Personal communication, February 12 and May 19, 1982.

Russell, R.C.H., and Commander D.H. Macmillan, 1952. Waves and Tides: London, Hutchinson's Scientific and Technical Publications, 348 pp.

U.S. Army Corps of Engineers, 1979. Study of Beach Erosion Control, City of Alameda: San Francisco, Corps of Engineers, 40 pp.

U.S. Department of Commerce, 1981. Nautical Chart 18649: San Francisco Entrance, Washington, D.C., National Oceanic and Atmospheric Administration, National Ocean Survey.

Wiegel, Robert L., 1964. Oceanographical Engineering: London, Prentice-Hall, Inc., 532 pp.

I would like to thank George Domurat and Douglas Pirie for their help in setting up the study and interpretation of results: Paul Kamen for general bearings in the water and his offers of assistance in the study; Peter Gee, Sr., whose accommodation of the boat and supplies and tolerance of minor damage made the entire Berkeley Beach study possible; and Doris Sloan, whose continuous encouragement kept me from the verge of despair.