A SEDIMENT TRAPPING EXPERIMENT AT SANTA CRUZ, CA.

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INTRODUCTION

Santa Cruz Harbor is located on the northern coast of Monterey Bay, California, approximately 104 kilometers south of San Francisco and 22 kilometers north of Moss Landing, as shown in Figures 1 and 2.

Harbor construction was authorized by Congress under the Rivers and Harbors Act of 1958, which provided for a harbor to accommodate light-draft vessels in Woods Lagoon at the eastern boundary of Santa Cruz. The authorized improvements included two rubblemound jetties 360 meters long and 243 meters long, on the west and east sides of an entrance channel, respectively -- an entrance channel approximately 270 meters long, 30 meters wide and 6 meters deep, reducing to 45 meters in depth at the same width for an additional 111 meters -- an inner channel, 240 meters long, 45 meters wide, 45 meters deep, reducing to 3 meters in depth at the same width for an additional 100 meters -- a turning basin approximately 90 meters long, 75 meters wide, and 3 meters deep, and a sand-bypassing plan. Figure 3 shows the project features. The armor units of the seaward side of the west jetty are 28-ton quadripods. The west jetty also has a concrete cap extending to elevation +4.8 meters MLLW.

Construction of the harbor was initiated in February of 1962 with the dredging of Woods Lagoon and the start of work on the west jetty. The west jetty was completed in February 1963. Then work began on the east jetty, and it was completed in April 1963. The entrance channel was dredged to the project dimensions in the summer of 1963. Construction of Santa Cruz Harbor was completed in November 1963, with the exception of the sand-bypassing plant. Construction of the sand-bypassing plant was deferred until the littoral drift rate could be more accurately determined.

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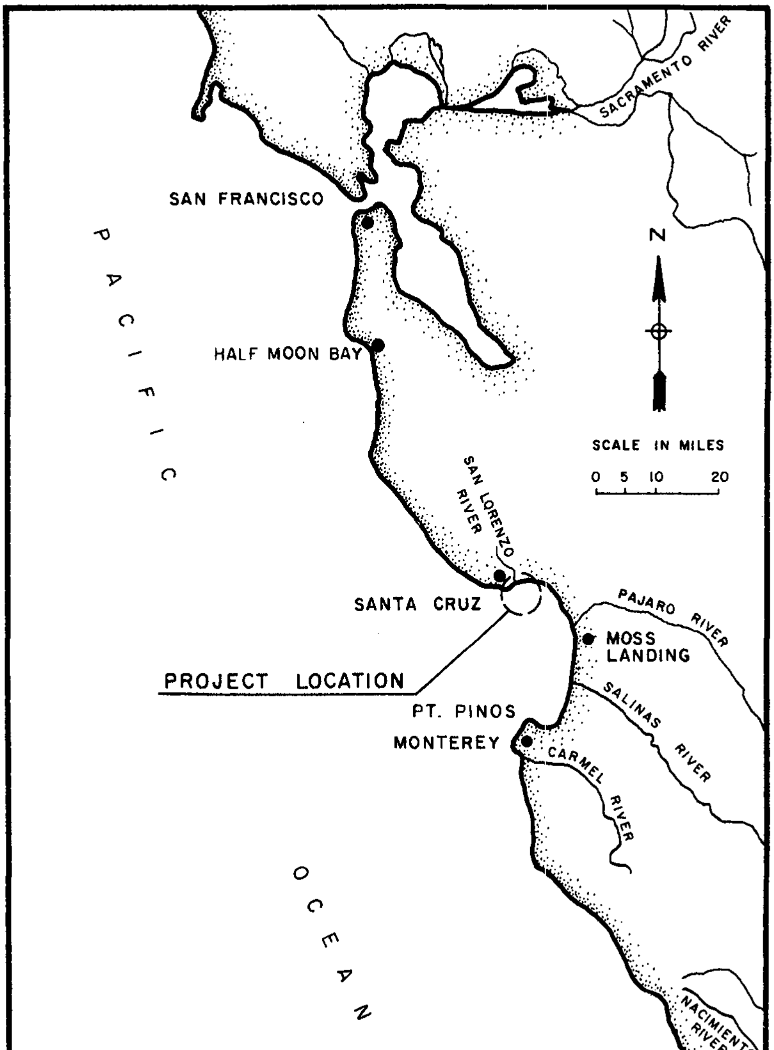
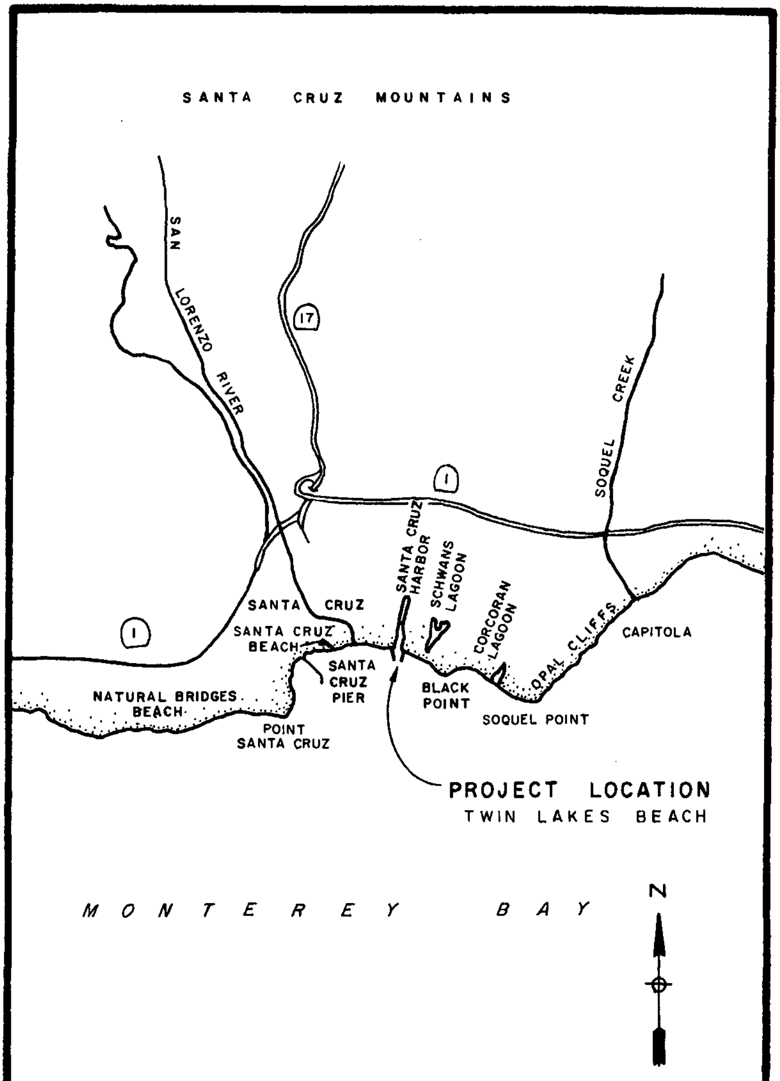
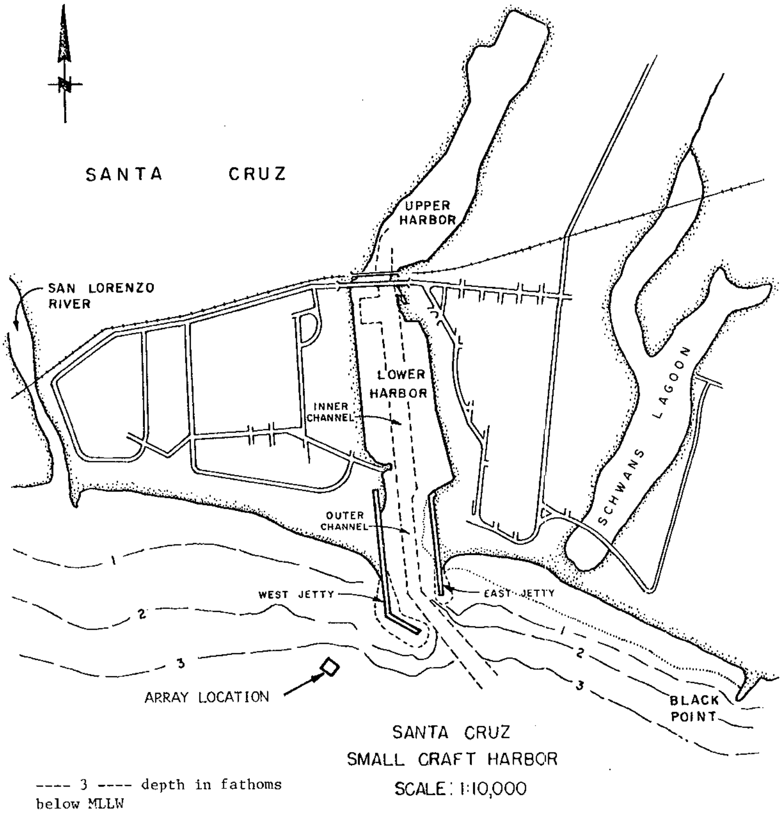


CENTRAL CALIFORNIA COASTLINE
SHOWING LOCATION OF SANTA CRUZ HARBOR
AT NORTH END OF MONTEREY BAY

FIGURE 1



NORTHERN MONTEREY BAY COASTLINE
SHOWING LOCATION OF SANTA CRUZ HARBOR
FIGURE 2



PLAN OF SANTA CRUZ HARBOR
SHOWING WAVE GAGE ARRAY LOCATION

FIGURE 3

During and subsequent to construction of Santa Cruz Harbor jetties, the beach west of the jetties experienced rapid accretion, building out from the 1962 pre-project shoreline about 75 meters by 1965 and about 150 meters by 1977. The growth of the beaches has protected the bluffs along East Cliff Drive from rapid erosion by wave action. Soon afterward, substantial littoral transport during winter months would shoal the entrance to the harbor closing it to all vessel traffic.

In 1977, the U.S. Corps of Engineers undertook a study of the shoaling problem with the purpose to develop and evaluate alternative methods of mitigating the shoaling effects. The study defined the coastal processes and the resultant shoaling mechanism at the harbor entrance. The littoral processes study led to the conclusion that the net littoral transport rate was 230,000 cubic meters to 382,000 cubic meters per year from west to east. Shoaling of the channel has required annual maintenance dredging reported to be on the order of 76,400 cubic meters per year since 1965.

Estimated littoral transport rates used by Walker, et al. (1978) indicated that a potential for reversals in transport exists but that shoreline east of the harbor was so oriented that these reversals during the winter months were not likely to cause significant shoaling in the channel.

DEEPWATER WAVE CLIMATE

The waves arriving at Santa Cruz can be divided into three categories according to origin:

> Northern Hemisphere swell, Southern Hemisphere swell, and seas generated by local winds.

The geometry and bathymetry off Santa Cruz allow swell to approach from the south clockwise through west- northwest, whereas locally generated seas can approach from the east clockwise through west-northwest. The following description of the wave climate is taken from Marine Advisors (1961).

Northern Hemisphere Swell. Most of the wave energy reaching Santa Cruz is from Northern Hemisphere swell generated primarily by extra-tropical cyclones in the northern Pacific. These cyclones, also referred to as Japanese-Aleutian storms, typically originate in the vicinity of Japan and move eastward across the higher latitudes to the Gulf of Alaska. These storms are most prevalent and intense during the winter and spring seasons. Infrequently, storms originating in the vicinity of the Hawaiian Islands move eastward across the mid-latitudes and produce swell that reaches Santa Cruz. However, this southwesterly swell is rarely as large as that produced by the Japanese-Aleutian storms. Tropical storms and hurricanes, called chubascos, which develop off the coast of Mexico, during the months of July through October, rarely move as far north as Southern California, although they do generate moderate swell that reaches most of the California coast.

Southern Hemisphere Swell. During the austral winter, storms of great intensity and size occur in the high and mid-latitudes of the southern Pacific. The storms are comparable with the extra-tropical storms of the Northern Hemisphere but are often more severe. Swell generated by these storms occur from May through October, but are most common during August and September. Because of the great decay distances, these waves have low heights and long periods when they reach Santa Cruz. Typical southern hemisphere swell has heights between 0.3 and 0.9 meters and periods ranging from 13 to 21 seconds. These waves approaching Santa Cruz are from the south through southwest.

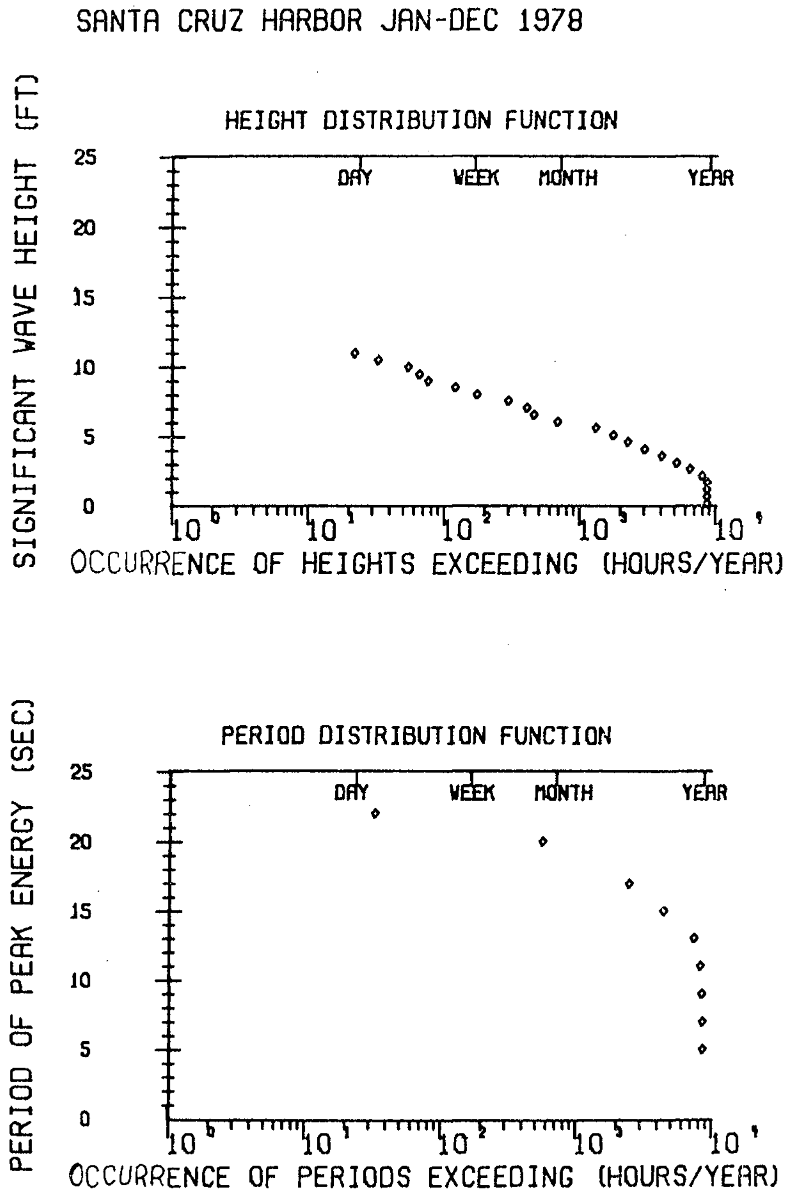
Data collected by the wave gage array for 1978 is summarized in Figure 4. This figure presents the measured height and period distribution functions.

POTENTIAL SEDIMENT SOURCES

The shoreline region lying northwest of Santa Cruz, extending from Half Moon Bay to Point Santa Cruz, comprises sea cliffs and small pocket beaches which occur mostly at the mouths of small creeks. Wave- induced erosion of the sea cliffs is a possible source of littoral material at Santa Cruz. Sea cliffs comprise shale and cretaceous sediments in most of the southern two-thirds of this reach. However, these sediments may not be the significant contributors of beach material at Santa Cruz. Marine terrace deposits overlay the sea cliffs along the southern two-thirds of the region and may be the primary contributors of beach material.

Drainage in the region is typified by short, steep-gradient streams originating in the Santa Cruz mountain range. Near the ocean, the rivers have the character of drowned river valleys. The streams have small drainage areas, and flows are characterized by flash floods. No deltas are found offshore because the wave climate rapidly removes sediment and distributes them along the beach and offshore.

The reach of shoreline between Point Santa Cruz and Soquel Point includes Santa Cruz Beach, the San Lorenzo River, and stretches of sea cliffs. The San Lorenzo River, 0.8


SANTA CRUZ HARBOR JAN-DEC 1978
HEIGHT DISTRIBUTION FUNCTION
SIGNIFICANT WAVE HEIGHT (FT)
25
20
15
10
5
0
DAY
WEEK
MONTH
YEAR
10 0
10 1
10 2
10 3
10 4
OCCURRENCE OF HEIGHTS EXCEEDING (HOURS/YEAR)
PERIOD DISTRIBUTION FUNCTION
PERIOD OF PEAK ENERGY (SEC)
25
20
15
10
5
0
DAY
WEEK
MONTH
YEAR
10 0
10 1
10 2
10 3
10 4
OCCURRENCE OF PERIODS EXCEEDING (HOURS/YEAR)

kilometers west of Santa Cruz Harbor, has a drainage basin of 355 square kilometers and an annual runoff of 0.1541 cubic kilometers. The heaviest runoff occurs during the winter months, October through April. Estimates made by the Corps of Engineers (1974) indicate that the annual sediment discharge of the San Lorenzo is between 67,232 and 101,612 cubic meters. Of this total, 20 percent, or 13,725 to 20,628 cubic meters was assumed to be of sand sizes found on beaches in the study area.

Offshore of the project site is a narrow continental shelf which drops off into the Monterey Canyon located in the middle of Monterey Bay. Figure 5 shows the general bathymetric features of the Santa Cruz embayment. The beach slopes steeply to the 6 meter depth contour, then slopes very gently to the south. The bottom comprises hard rock outcroppings which are partially overlain with unconsolidated sediment.

WAVE MEASUREMENT SYSTEM

In February, 1978 a directional wave measurement array was installed near the harbor entrance to assess the forcing function for longshore transport. Scripps Institution of Oceanography (SIO), under contract to the San Francisco District, U.S. Army Engineers, added this installation to the network of wave measurement stations as described in Seymour and Sessions (1976). The point of measurement is at a depth of 7 meters approximately 100 meters west, or updrift, of the jetties.

The wave measurement system consists of a directional array, a shore terminal containing suitable electronics to allow for remote automatic data logging and analysis, and the necessary interconnecting cable. The array is a square steel space frame, 6 meters on a side, with short vertical risers at the corners. At the top of each riser is a cylindrical container capable of storing approximately 15 meters of three conductor waterproof cable. Attached to these cables are pressure sensor instruments in waterproof housings. External pressure is transmitted to the instrument by means of an oil filled diaphragm. The use of the long cable allows divers to bring the pressure sensors to the surface, remove them for service or replacement, and reconnect the new instrument using reliable connectors that cannot be reconnected under water. The diaphragms are protected from marine growth by a pad of copper gauze coated with antifouling paint and contained in a perforated cap. The frame, which is made of steel pipe, serves as conduits for all branch cabling so that no cables are exposed after the system is installed. The main power and signal cable is polyurethane jacketed with internal steel armor and is strain relieved at the frame. The density of the cable is sufficient to insure rapid self burial under

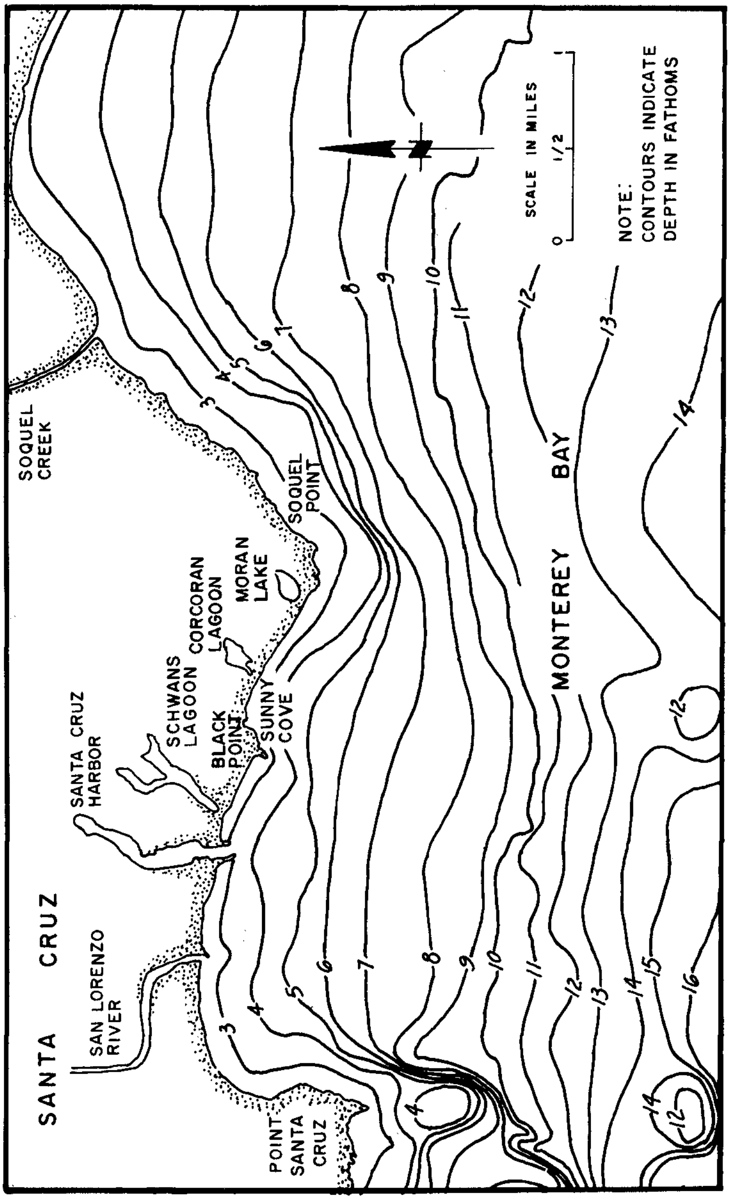


FIGURE 5 BATHYMETRIC FEATURES IN SANTA CRUZ REGION

even moderate wave conditions. Experience during several severe winter storms has shown that the cable will remain buried even during periods of gross beach erosion. The cable is trenched into the sand with a backhoe above the high water line. Figure 6 shows an array frame on the stern of a LARC amphibious truck prior to being towed to its installation site.

The shore terminal is a weatherproof enclosure, approximately one meter square containing the interface electronics. The analog output of each pressure sensor is converted to a frequency modulated signal within the sensor housing so that there are no line losses or distortion to contend with in the cable. This FM signal is then converted to a digital output sampled at 1 hz within the shore terminal for each sensor output. All sensors are sampled simultaneously so that phase relationships are accurately preserved for directional analysis. The digitized pressure values are stored in solid state memory using a pushdown scheme that retains the most recent 1024 values. This allows for storing slightly more than 17 minutes of data for each sensor.

The shore terminal is connected to an ordinary telephone line with a data coupler. When the assigned telephone number is dialed, the control circuitry locks the data in the memories, and transmits an identifying code followed by the data stream. The entire contents of the four memories are transmitted in less than one minute. Data are received by a dedicated computer at SIO and, after transmission quality checks, are written to magnetic tape. If the computer detects unusable data it will recall the station. If telephone company circuit overloads prevent a completed call after three attempts, the system will move that station to the end of the calling queue for a later attempt.

Wave data were collected at ten hour intervals during 1978 and part of 1979. During the fall of 1979, the interval between data runs was reduced to 6 hours.

DATA ANALYSIS METHODS

Longuet-Higgins, et al. (1963) shows that an estimate of the longshore component of the radiation stress, Sxy, can be obtained from knowledge of the surface elevation and the components of sea surface slope at a point. This methodology was developed for use with a pitch and roll measuring buoy in deep water but is equally applicable to shallow water if a method exists for measuring the slope components. In the present scheme, the components of sea surface slope are obtained from the differences between pairs of sensors. The components are rotated to a

DIRECTIONAL WAVE ARRAY FRAME
MOUNTED ON LARC VEHICLE PRIOR TO
BEING TOWED INTO POSITION. OIL
DRUMS ARE TEMPORARY FLOTATION.

FIGURE 6

coordinate system based upon the local onshore and longshore directions as determined by smoothing the bathymetry in the vicinity of the array. Since the estimate of Sxy is formed by cross-spectral analysis, the difference fourier coefficients can be corrected from pressure differences to surface elevation differences by linear wave theory, as described in Seymour and Higgins (1978).

Each data run obtained from the slope array is analyzed using the computer at La Jolla. The analysis products include:

Significant wave height
Period of peak energy
Distribution of energy by frequency (energy spectrum)
Distribution of Sxy by frequency

These statistics are published monthly and are made available to any investigators concerned with the study area. Figures 7 and 8 show typical examples of the analysis summaries for wave energy and Sxy.

The most commonly used estimator for longshore transport is the Bagnold-Inman-Komar model which is reported with the most recent values of the empirical coefficient in the CERC Shore Protection Manual. Seymour and Higgins (1978) shows that this formulation can be readily transformed so that transport is proportional to Sxy and to the square root of the significant wave height, resulting in an equation of the form:

$$Q = k \ Sxy \ (Hs)^{1/2} \qquad (1)$$

where Q is the longshore mass transport,
k is the proportionality coefficient,
and Hs is the significant wave height.

The assumptions embodied in Eq. (1) include:

1. The bathymetry between the measurement point and the breaker line is regular. Since the measurement point is in relatively shallow water, this is a reasonable approximation on almost all beaches. This assumption allows for conservation of Sxy.
2. Sxy is conserved to the break point.
3. The depth at breaking can be estimated from the significant wave height at the measurement point.

The advantage of the slope array for applications where sediment transport estimates are required is immediately

SANTA CRUZ HARBOR
APR 1980

LOCAL DAY/TIME		SIG. HT (CM.)	TOT. EN (CM. SQ)	PERCENT ENERGY IN BAND (TOTAL ENERGY INCLUDES RANGE 2048-4 SECS) BAND PERIOD LIMITS (SECS) 22+	22-18	18-16	16-14	14-12	12-10	10-8	8-6	6-4
1	0405	67.0	280.4	9.4	9.2	3.3	4.2	32.7	19.4	7.2	8.2	6.8
1	1007	63.3	250.7	7.1	7.1	6.5	6.3	22.2	18.6	7.2	9.6	15.9
1	1610	66.7	278.1	3.3	6.8	16.8	3.3	21.5	18.3	12.6	8.0	9.9
1	2205	66.6	277.2	8.6	11.9	15.2	10.5	14.5	12.2	11.7	8.6	7.3
2	0405	71.0	314.6	5.2	5.0	24.4	12.4	15.5	10.6	10.3	8.7	8.4
2	1005	82.1	421.0	4.6	5.4	19.6	21.9	13.2	12.1	6.2	8.5	8.9
2	1607	65.8	270.8	2.8	6.6	14.1	15.9	27.6	8.9	7.0	10.2	7.3
2	2205	70.2	307.9	5.0	8.1	9.8	39.0	20.6	4.3	2.5	4.7	6.4
3	0405	66.8	278.5	5.5	9.3	18.5	26.5	19.2	6.9	2.6	4.9	7.0
3	1005	56.7	201.2	4.3	1.9	10.2	24.7	28.4	9.0	5.1	7.4	9.4
3	1610	74.5	346.5	3.4	2.7	18.3	41.1	13.4	8.2	1.9	5.6	5.8
3	2205	66.2	273.8	4.0	1.9	9.3	54.0	14.7	6.2	2.0	3.5	4.9
4	0405	71.2	316.5	5.4	1.8	14.4	26.0	34.5	8.5	1.6	4.0	4.2
4	1005	68.8	295.8	3.7	0.9	11.8	29.7	33.6	5.8	1.7	4.0	9.3
4	1605	79.2	391.8	2.9	0.9	8.1	8.8	18.7	10.8	7.3	4.4	38.6
4	2205	118.6	879.5	1.3	0.6	2.5	4.6	7.6	4.9	1.8	28.2	49.0
5	0405	131.8	1085.7	1.5	0.4	2.2	8.2	9.9	4.0	1.3	27.5	45.5
5	1005	99.6	619.8	2.2	0.5	6.3	7.3	24.6	11.7	5.5	19.6	22.6
5	1605	98.6	608.0	2.4	0.8	3.2	7.0	23.2	16.2	9.2	20.0	18.6
5	2205	106.4	707.9	3.7	1.2	3.9	19.0	23.5	11.3	10.9	14.2	12.6
6	0405	124.0	960.5	5.8	2.1	7.5	16.3	23.6	18.1	8.1	10.5	8.5
6	1007	159.1	1581.9	6.2	1.7	18.1	22.9	17.3	8.6	7.3	11.3	7.1
6	1011	159.1	1582.7	6.2	1.7	18.1	22.8	17.3	8.7	7.3	11.3	7.1
6	1606	143.7	1290.8	6.6	1.1	5.4	36.0	24.7	5.6	4.2	11.5	5.4
6	2205	122.6	939.5	7.4	1.5	3.7	25.7	34.9	6.5	5.3	10.3	5.1
7	0405	128.1	1025.5	9.2	1.1	2.8	40.2	17.3	11.5	5.8	8.5	4.1
7	1005	114.9	825.7	7.1	1.1	2.7	18.2	30.5	20.7	6.9	7.3	6.1
7	1605	124.0	961.1	5.2	0.7	4.4	31.6	36.0	6.4	4.8	8.2	3.2
7	2205	107.2	717.8	7.4	1.6	4.2	29.2	30.5	10.8	5.0	7.4	4.4
8	0405	100.6	632.0	5.6	0.9	7.2	51.1	11.1	10.3	3.5	5.8	5.1
8	1030	102.9	662.3	3.3	0.6	7.1	15.0	46.8	12.9	3.5	6.3	4.9
8	1605	95.4	569.4	4.8	0.5	11.3	43.1	18.7	5.2	4.4	8.3	4.1
8	2205	81.0	410.0	4.1	0.9	5.1	43.8	16.8	9.6	8.0	7.6	4.6
9	0405	77.1	372.0	4.8	1.6	5.1	28.6	37.6	7.4	3.9	6.7	4.8

TYPICAL DATA ON WAVE ENERGY AT SANTA CRUZ HARBOR. FROM APRIL 1980 MONTHLY REPORT OF CALIFORNIA COASTAL DATA COLLECTION PROGRAM

FIGURE 7

SANTA CRUZ HARBOR ARRAY
APR 1980

LOCAL DAY	/TIME	SIG. ANG (DEG)	TOT. SXY (CM. SQ)	ANGULAR DISTRIBUTION IN PERIOD BANDS (ANGLES IN DEGREES) BAND PERIOD LIMITS (SECS) 22+	22-18	18-16	16-14	14-12	12-10	10-8	8-6	6-4
1	0405	24.8	-1.8		18.4	14.2	16.6	19.7	31.5	26.6	30.9	33.4
1	1007	29.9	14.7		28.4	15.5	16.0	34.7	25.0	31.0	35.5	36.2
1	1610	24.0	-5.4		13.9	18.9	29.2	20.3	24.4	23.5	30.6	33.7
1	2205	26.0	2.5		14.1	17.2	21.7	36.4	25.1	24.4	26.7	35.3
2	0405	27.4	10.2		27.8	22.0	32.1	25.9	31.5	28.7	27.3	32.2
2	1005	26.6	8.9		21.3	20.1	23.2	37.3	29.0	27.8	27.5	29.7
2	1607	23.9	-4.7		29.2	14.7	22.0	29.2	25.3	18.0	24.9	28.9
2	2205	24.5	-2.3		16.9	16.0	20.0	35.3	30.4	30.1	28.0	21.7
3	0405	21.0	-15.5		18.5	18.2	17.5	21.0	32.8	30.1	24.8	23.8
3	1005	21.2	-12.4		11.0	18.6	17.5	19.6	26.9	19.3	24.6	33.1
3	1610	20.4	-24.8		8.8	14.6	19.8	26.0	21.5	33.5	19.5	23.3
3	2205	23.0	-8.2		7.3	22.7	22.1	24.6	25.3	25.6	25.5	24.8
4	0405	22.4	-13.1		21.4	12.3	20.1	26.7	26.2	18.0	24.0	27.9
4	1005	22.3	-12.8		11.6	17.8	17.5	24.8	34.9	17.6	26.7	27.1
4	1605	23.6	-6.7		12.2	17.8	18.2	27.1	26.0	32.2	32.8	21.3
4	2205	19.4	-60.6		-64.8	20.1	18.9	32.5	23.6	21.0	22.0	15.3
5	0405	13.2	-162.4		5.6	18.1	20.1	27.0	27.2	17.4	13.3	6.7
5	1005	22.5	-23.7		52.1	13.8	18.3	22.8	26.5	22.4	25.9	20.5
5	1605	25.1	3.8		20.5	21.0	19.8	33.8	23.3	27.5	23.4	19.9
5	2205	28.4	36.4		22.8	31.9	19.7	35.3	28.6	27.3	30.6	26.2
6	0405	27.1	30.7		14.4	21.9	23.8	34.1	25.4	26.1	25.7	24.6
6	1011	28.6	85.1		26.7	22.5	31.1	30.7	27.3	31.5	28.8	29.5
6	1606	28.3	63.8		34.4	21.7	23.4	36.9	31.1	33.2	27.5	25.4
6	2205	31.0	84.7		20.4	25.8	25.7	37.0	30.8	30.2	28.7	30.4
7	0405	28.6	54.8		5.0	24.5	27.8	28.6	31.6	30.1	28.1	29.5
7	1005	26.3	13.9		23.5	17.7	23.9	24.9	27.8	31.7	27.3	31.1
7	1605	29.1	62.2		30.7	22.5	27.5	32.7	24.5	28.3	27.0	33.0
7	2205	28.4	35.6		20.0	21.2	25.4	32.3	28.4	27.1	29.0	31.6
8	0405	25.4	1.6		8.1	22.8	21.0	37.7	28.9	26.5	32.1	34.0
8	1030	23.8	-14.7		24.2	5.1	22.4	24.0	28.6	31.2	26.3	30.6
8	1605	23.1	-18.3		45.7	21.7	21.7	22.8	29.2	24.9	24.5	33.5
8	2205	25.2	0.6		17.6	1.3	22.0	37.4	25.7	26.9	25.7	28.1
9	0405	27.7	14.4		8.2	18.8	25.6	28.2	28.1	36.8	34.5	31.7

TYPICAL DATA ON WAVE DIRECTIONAL CHARACTERISTICS AT SANTA CRUZ HARBOR. FROM APRIL 1980 MONTHLY REPORT OF CALIFORNIA COASTAL DATA COLLECTION PROGRAM.

FIGURE 8

apparent. This system produces an unbiased estimate of Sxy which can be readily converted to estimates of longshore transport by eq. (1). In theory, Sxy can be calculated from a knowledge of the directional spectrum. However, as shown in Higgins, Seymour and Pawka (1980), linear arrays designed to give good definition of directional spectra yield biased estimates of Sxy. Since linear arrays are characteristically much larger than the slope array and cannot be prealigned on the shore, they tend to be much more expensive to install. The slope array system offers, therefore, an inexpensive alternative which sacrifices some definition of the full directional spectrum to achieve the best definition of Sxy.

MODEL FOR SEDIMENT IMPOUNDMENT

Since the harbor is dredged to contract limits approximately at yearly intervals, at the end of the winter maintenance dredging season, the total amount of dredged material removed is a reasonable estimate of the annual amount of material impounded by the jetties. It has been assumed by many, including the authors, that a significant amount of the longshore transport is bypassed during the intervals when the harbor entrance is severely shoaled. Walker, et al. (1978), in a study of the dredging problem at Santa Cruz Harbor, suggest that the amount of material bypassing the entrance is much larger than the amount impounded. Nevertheless, in the present work, it was hypothesized that there was a correlation between the apparent longshore transport, as estimated by eq. (1), and the observed impoundment, derived from the dredging workload.

The period chosen for testing this hypothesis lays between two occasions when the dredging had been completed to design depth in the harbor entrance. The baseline was after the dredging completion in mid-March, 1978. This was assumed to be a zero level of accretion. The study extended to the next such event which occurred 15 months later at the end of May, 1979.

In the period including these events, from February 1978 to June, 1979, the slope array was sampled approximately 2500 times, or over 700 hours of actual wave data were collected. Each data run was analyzed to produce values of Sxy and Hs. These were then employed in Eq. (1) to provide a time history of estimated longshore transport. This series can be summed in a variety of ways to provide estimates of net or gross transport. In Figure 9, the transport estimates have been summed for complete months. It can be seen that the drift towards the east is dominant, but that intervals of small westward transport are predicted during the summer months.

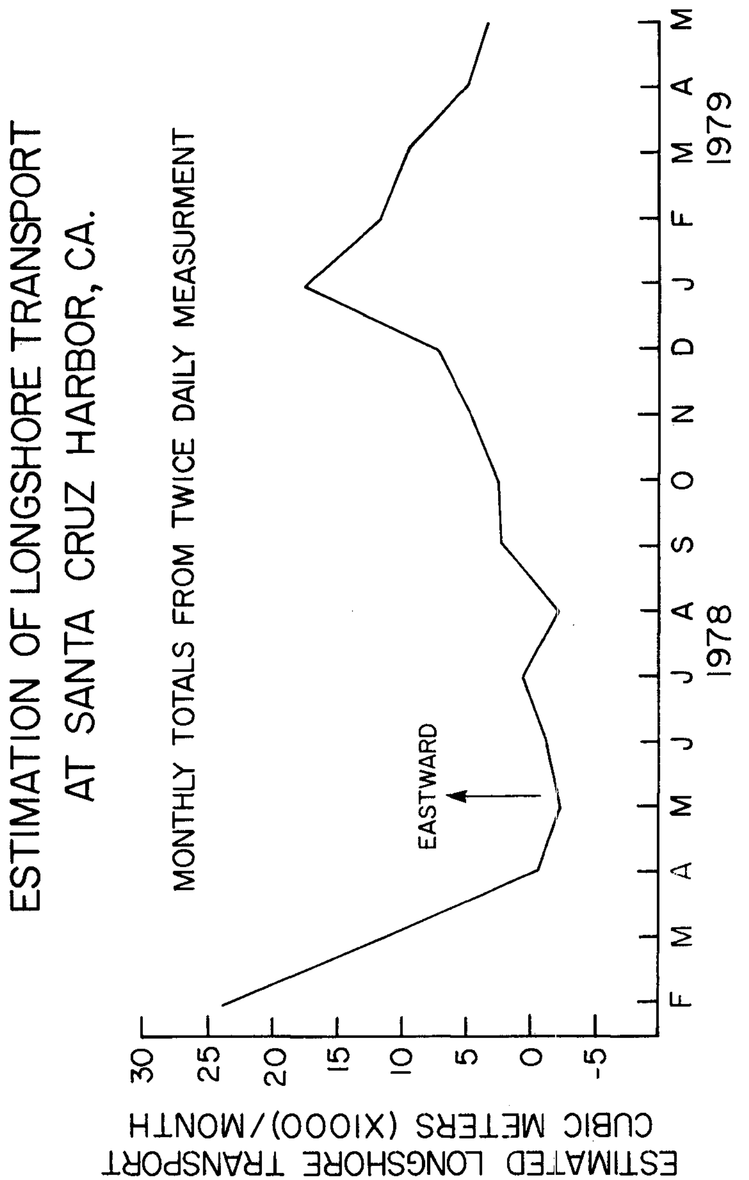

ESTIMATION OF LONGSHORE TRANSPORT
AT SANTA CRUZ HARBOR, CA.
MONTHLY TOTALS FROM TWICE DAILY MEASURMENT
EASTWARD
ESTIMATED LONGSHORE TRANSPORT
CUBIC METERS (X1000)/MONTH
30
25
20
15
10
5
0
-5
F M A M J J A S O N D J F M A M
1978
1979

FIGURE 9

The authors then postulated a simple model for sediment impoundment in the harbor. Since the feeder beach to the west was characteristically full, it was assumed that all eastward transport would be trapped between the jetties. Conversely, since the eastern beach was usually stepped well shoreward of the jetty, it was assumed that the small amounts of westward transport would be stored in the eastern feeder beach and would not be carried around the jetty. The impoundment load in this model was then, simply, all of the eastward transport and none of the westward transport.

The impounded sediment volume, as a function of time, was then calculated by this scheme for the period between the two baseline dredging events. During this interval, there were two other dredgings. These were not made to the contract limits, but by subtracting their output volumes at the appropriate times, the accumulation time history could be made more realistic. The final accumulation volume was then reduced by the amount of the last baseline dredging episode. The residue or deficit volume would then represent the difference between the estimate of the impounded sediment and the actual value, since a perfect estimate of the accumulation would be exactly balanced by the dredging removals and the final volume would be zero.

Figure 10 shows the result of this estimation of the impounded volume. The estimate provided a residue of approximately 3000 cubic meters, which is about 5 percent of the total dredging load for the period. Therefore, the simple model for impoundment, and the closely spaced intervals of directional wave observation, provided a gratifyingly close estimate of the actual accumulation in the harbor entrance.

These same data can be employed to construct an annual net transport rate. The longshore transport estimate for the period from February, 1978 through January, 1979 is 62,000 cubic yards. It is interesting to compare this with an estimate made in Walker, et al. (1978). In this report, longshore transport was estimated by using deepwater wave statistics inferred from ships' observations and hindcasts from meteorological records. The deepwater waves were then refracted into shore and the same basic transport equation used to estimate a net longshore drift of 373,000 cubic meters. Since the transport relationships utilized were the same, this indicates that the hindcast thrust of the waves was six times that actually measured by the slope array.

OBSERVATIONS AND CONCLUSIONS

The slope array provides a convenient method for estimating the gross and net longshore transport of sediment in the

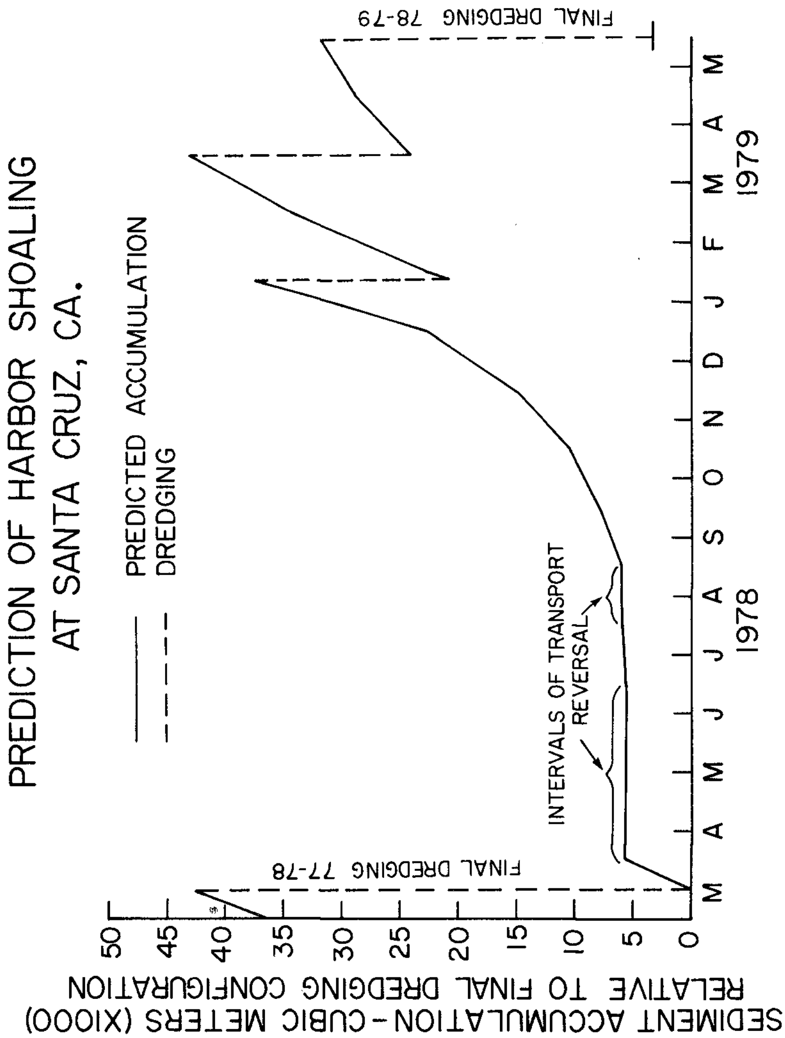

PREDICTION OF HARBOR SHOALING
AT SANTA CRUZ, CA.
PREDICTED ACCUMULATION
DREDGING
FINAL DREDGING 77-78
FINAL DREDGING 78-79
INTERVALS OF TRANSPORT
REVERSAL
M A M J J A S O N D J F M A M
1978
1979
50 45 40 35 30 25 20 15 10 5 0
SEDIMENT ACCUMULATION-CUBIC METERS (X1000)
RELATIVE TO FINAL DREDGING CONFIGURATION

FIGURE 10

vicinity of the measuring point. For a particular 15 month period at Santa Cruz Harbor, CA, the net transport in the eastward, or dominant, direction provided a very efficient estimator of the sediment volume impounded in the harbor entrance.

There appeared to be little, or no bypassing of sand around the harbor entrance. During this particular winter storm period, staged dredging kept the harbor mouth from closing completely. This was not true during other winters, when there may have been substantial bypassing.

The longshore transport appears to be substantially less during the winter of 1978-79 than is predicted by using average deepwater wave climates refracted into this location.

The results suggest that a nearly complete trap of longshore transport was provided by Santa Cruz Harbor during the winter of 1978-79. It is believed that this is the first trap experiment of this duration in which accurate, continuous measurements of wave direction and energy were obtained. It provides another valuable data point confirming the efficiency of the presently accepted formulation for longshore transport.

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