A PHASED-DREDGING PROGRAM FOR SANTA CRUZ HARBOR

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SUMMARY

This project was undertaken to define the littoral processes and resultant shoaling mechanisms at the Santa Cruz Harbor California, entrance channel and to develop and evaluate alternative methods of mitigating the shoaling effects. Since November 1963, when the construction of the entrance channel was finished, the channel has shoaled such that it was almost completely closed during the winter months. The study involved analysis of shoaling mechanisms and contour changes and review of past dredging procedures. Sixteen structural and non-structural alternatives for mitigation of shoaling were analyzed. A phased-dredging procedure was developed and tested over 3 winter seasons. The concept was to dredge the channel periodically each winter while shoaling occurs, thereby keeping the Harbor open to navigation most of the time. The experience gained at this site may be of benefit to others in solving a shoaling problem or in designing a new small-craft harbor.

INTRODUCTION

History

Santa Cruz Harbor, shown in figures 1 and 2, is located on the northern coast of Monterey Bay, about 65 miles south of San Francisco and 14 miles north of Moss Landing. Construction of the Harbor was authorized in 1958[3]. The authorized improvements included two rubble mound jetties, an entrance (outer) channel, an inner channel, a turning basin, and a sand-bypassing plant. The Harbor, figure 3, was created by dredging a 20-foot-deep channel, connecting a lagoon to the Ocean. The channel and Harbor are protected by two jetties that extend about 900 feet seaward of the beach that existed prior to the project. The jetties are 400 feet apart and the updrift (west) jetty is doglegged. The Harbor provides berthing facilities for 1,000 boats. Construction of the Harbor was initiated in February 1962 and the project was completed in November 1963, with the exception of the sand-bypassing plant which was deferred until the littoral-transport rate could be more accurately determined.

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[3] The River and Harbor Act of 1958, House Document No. 357, 85th Congress, 2nd Session.

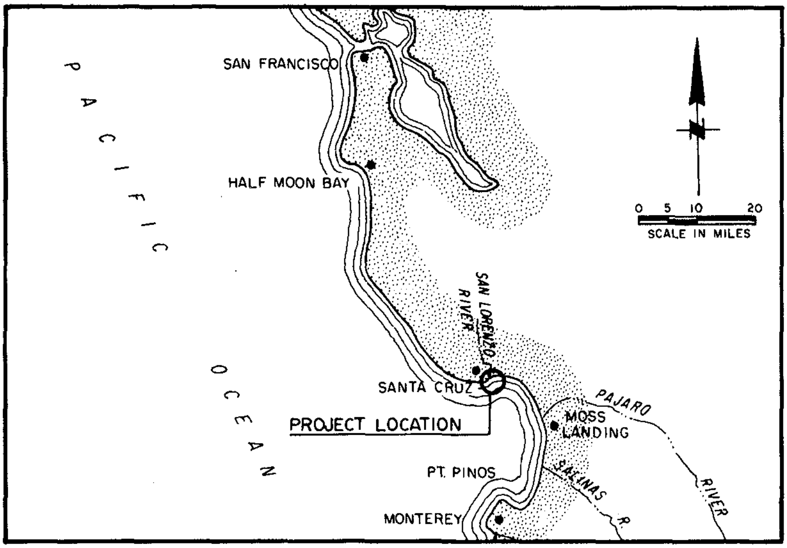

FIGURE 1: LOCATION MAP

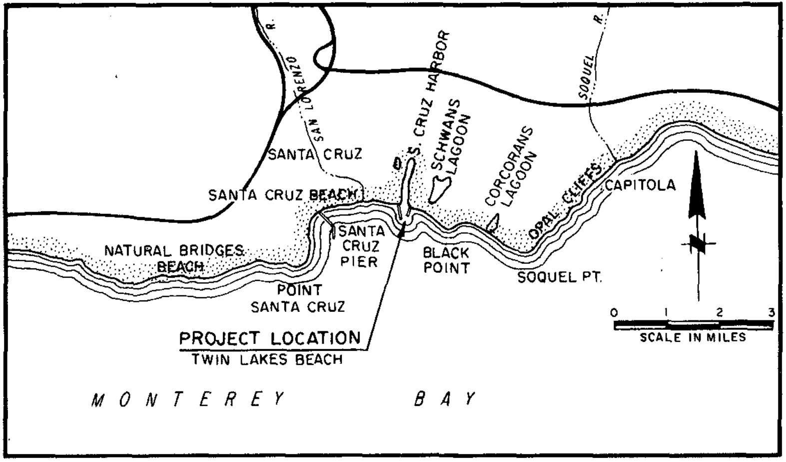

FIGURE 2: VICINITY MAP

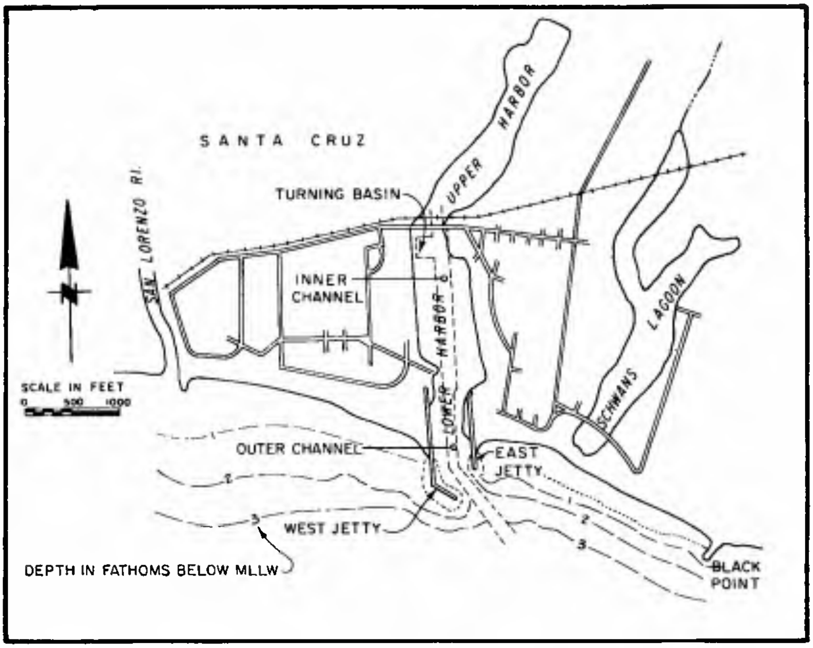

FIGURE 3: PROJECT FEATURES

PHOTO 1: SANTA CRUZ HARBOR IN SHOALED CONDITION

The entrance channel began to shoal in 1965 and navigation was severely impaired by a dangerous shoal, shown in photograph 1, for 4 months during each winter. Annual maintenance dredging on the order of 100,000 cubic yards per year had been required in the spring of each year from 1965 until 1977, when a multiyear, dredging program was implemented to maintain the channel during the winter season. In addition to the maintenance dredging, an experimental jet-pump bypassing system was installed in 1976 by the Waterways Experiment Station (WES) to field-test this new equipment. This eductor field test was terminated in March 1978.

Purpose and Scope

This study was conducted in 1977 to develop both short-term and long-term solutions to the shoaling problem with the short-term solution to suffice for the next few years. The objective was to define the littoral transport and shoaling mechanisms, with the view of developing a reliable engineering solution from existing data. This approach differs considerably from that of Seymour, et al. (1980), who were concerned with correlating potential littoral transport rates (predicted by analysis of results of a wave-gage array) with quantities of material dredged.

Physiography

The shoreline region lying northwest of 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 drift at Santa Cruz. Near the Ocean, the steep-gradient streams originating in the Santa Cruz Mountain Range have small drainage areas and their flows are characterized by flash floods. The San Lorenzo River, 0.5 miles west of Santa Cruz Harbor, has a relatively small drainage basin of 137 square miles and an annual runoff of 125,000 acre-feet. The heaviest runoff occurs during the winter months, October through April. Estimates U.S. Army Corps of Engineers (1974) indicate that the annual sediment discharge of the San Lorenzo River is between 88,000 and 133,000 cubic yards. Of this total, 20 percent, or 18,000 to 27,000 cubic yards had sand sizes similar to those found on beaches in the study area. Yancey (1968) also determined, by studying minerals of the River basin and beaches, that the San Lorenzo River is not a primary contributor of beach sand.

Grain-size distributions for beach sediments indicate a medium-to-fine sand with sediments shoaled in the navigation channel being slightly finer than the sand found in the splash zone. The beach slope is 1 on 15 flattening to 1 on 20 toward the 20-foot depth contour, where it flattens to a very gentle slope. Most beach erosion and accretion has occurred shoreward of the 20-foot contour.

LITTORAL-TRANSPORT ANALYSIS

Wave-energy-flux calculations were made to estimate the potential for wave-induced littoral transport. Data from the wave gages described by Seymour (1980) were not available. Furthermore, a longer period of record was required to estimate long-term averages. Therefore, several sources of wave hindcasting and observation data were analyzed to compose a composite description of the 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 landmass geometry of Monterey Bay and the bathymetry off Santa Cruz allow swell to approach from the east clockwise through west-northwest.

Most of the wave energy reaching Santa Cruz is from Northern Hemisphere swell generated primarily by extratropical cyclones in the Northern Pacific. These cyclones are most prevalent and intense during the winter and spring seasons, generating waves from the northwest that refract around Point Santa Cruz and have heights of up to 20 feet and periods ranging from 8 to 16 seconds. The National Marine Consultants (1960) 3 year hindcasts, modified by refraction and shoaling, were used for description of Northern Hemisphere swell.

Swells generated by storms in the Southern Hemisphere occurs from May through October, but are most common during August and September. Typical Southern Hemishere swell has wave heights between 1 and 3 feet and wave periods ranging from 13 to 21 seconds. These waves approach Santa Cruz from the south through southwest. The Marine Advisors (1960) description of the Southern Hemisphere swell was used.

Locally generated seas at Santa Cruz are most severe from December through February. Predominant winds are from the northwest and north. Locally generated seas were described using the National Marine Consultants (1960) data set for waves from the south-southeast to west and were hindcast using the Summary of Synoptic Meterological Observations (1976) (SSMO) wind rose for fetches exposed to the east and southeast.

Monthly variations of the longshore energy flux plotted in figure 4 were calculated for shoreline of various alignments by transforming the waves to their breaking position. The local seas and the Northern Hemisphere swell are the dominant factors during the winter between December and May. February has the most active contribution of wave-energy flux and the greatest longshore component of energy flux.

The longshore littoral-transport rate was estimated by applying an empirical factor to the longshore component of energy flux (P_{ls}):

$$Q = 7.5 \times 10^3 P_{ls}$$

where Q is the longshore transport rate in cubic yards per year and P_{ls} is the longshore component of energy flux in foot-pounds per second per foot.

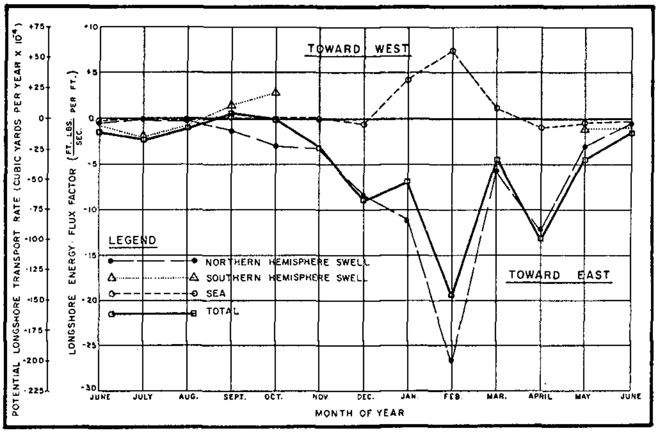

FIGURE 4: DISTRIBUTION OF MONTHLY POTENTIAL ENERGY-FLUX FACTOR

The variation of the potential longshore transport rate by month is also presented in figure 4. The potential net littoral-transport rate was estimated to be 488,000 cubic yards per year to the east. Approximately 80 percent of this transport occurs during the winter, between December and April. The Northern Hemisphere swell causes primarily an unidirectional eastward transport. During January, February, and March the local seas tend to cause a mild westward transport an order of magnitude less than the eastward transport.

CHANNEL SHOALING

The shoaling patterns of the entrance channel have been documented by monthly hydrographic surveys. Figure 5 shows a typical monthly progression of the 10-foot depth contour into the navigation channel during the winter season. Figure 6 shows a section of the channel between the heads of the two jetties. The patterns developed in similar fashion each year, with a tip shoal developing and then extending from the head of the west jetty across the channel toward the head of the east jetty. By January, the 10-foot depth contour had closed across the channel and the beach on the east side had receded. The influx of material into the channel during the winter appears to result primarily from sand bypassing the head of the sand-saturated west jetty. This is discussed in the following paragraph.

A fillet accreted west of the west jetty after the jetty was constructed in 1962. Figure 7, shows the advance of the shoreline at two range lines west of the west jetty. By 1965, the west jetty had trapped a fillet which extended the shoreline to 400 feet seaward of the preproject beach. The jetty was not long enough to trap additional material; therefore, in 1965, significant quantities of material bypassed the west jetty.

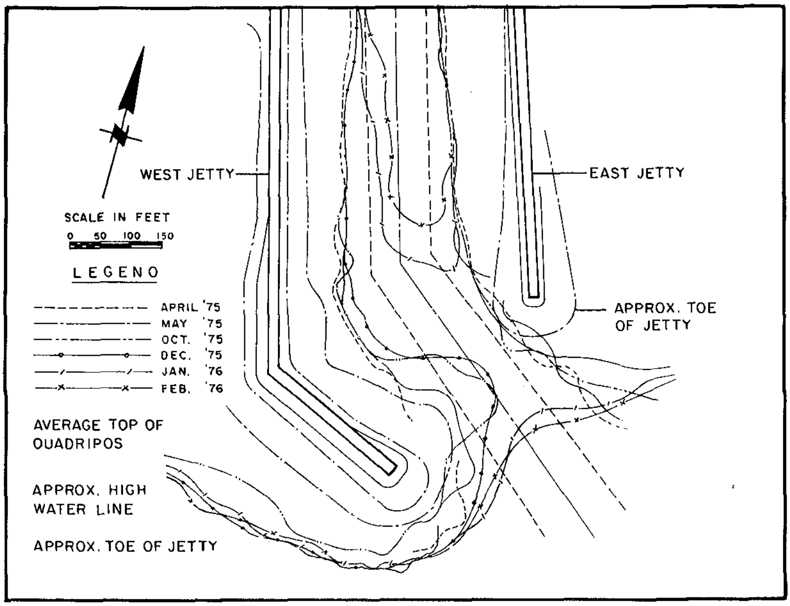

FIGURE 5: EVOLUTION OF CHANNEL SHOALING, 10 FT. CONTOUR

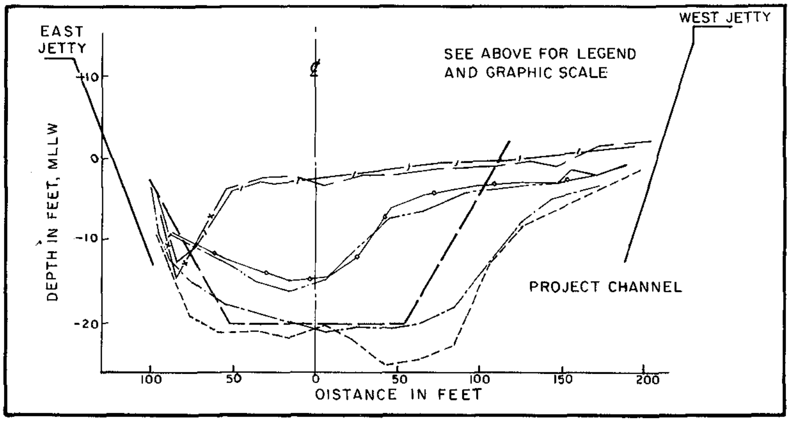

FIGURE 6: CROSS-SECTION BETWEEN HEADS OF JETTIES SHOWING SHOALING

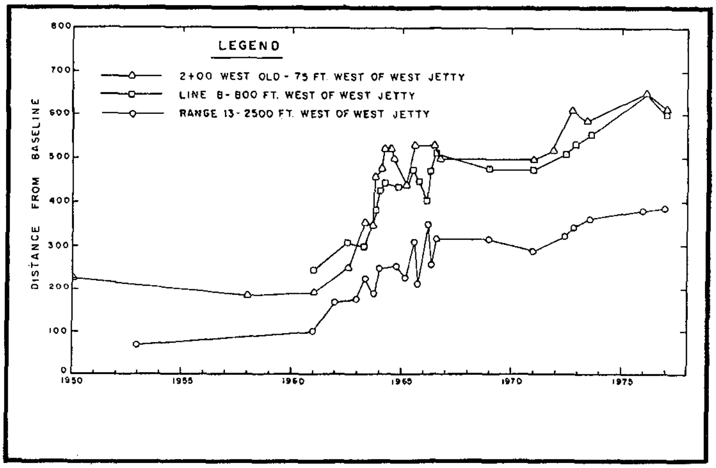

FIGURE 7: WEST BEACH SHORELINE CHANGES

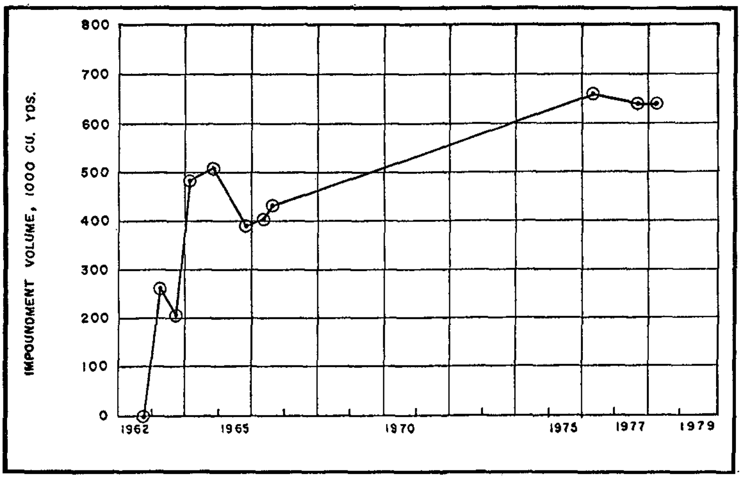

FIGURE 8: IMPOUNDMENT WEST OF WEST JETTY

Primary criteria for evaluation of the alternatives were cost effectiveness, engineering-feasibility, and minimization of adverse environmental effects. Bypassing was considered a satisfactory solution; however, material would still shoal the Harbor during storms unless the west beach were cut back to pre-1965 conditions. Citizens and homeowners who have become accustomed to a wide beach would object. Furthermore, some material would enter the Harbor by wind transport, leakage through the voids in jetty arm or units, and by reversals in littoral transport. A dredge would have to be mobilized for maintenance of the 20-foot project depth. Structural solutions would require considerable first costs; further, they would require bypassing of the net littoral transport into the area. Sealing the west jetty with a diaphragm would eliminate one of the shoaling mechanisms and reduce shoaling by about 10 percent of the total. The material would then bypass the head of the jetty, after which some material would bypass the channel and some would enter the channel. This is not considered a primary solution but could be implemented at a later date in conjunction with another system, such as an offshore breakwater. Maintenance dredging is the most direct method, wherein existing equipment and technology could be used. Therefore, a maintenance-dredging program was determined to be the most cost-effective, feasible, and reliable solution.

Figure 8 plots sand volumes impounded in the fillet west of the west jetty. Within the first 2 years of the project, 500,000 cubic yards were impounded; less than 200,000 more were impounded over the next 14 years. During this period of initial fillet-formation, the downdrift beaches experienced erosion, (Griggs 1975). The initial high rate of fillet impoundment may be partially be attributed to a relatively severe flood in 1963, which caused the San Lorenzo River to have a peak discharge rate of 13,400 cubic feet per second as compared to the long-term average of the annual maximum discharge rates of 7,961 cubic feet per second.

The shoreline east of the east jetty to Black Point had a more complex and variable evolution than that of the west beach. The jetties apparently shadow the predominantly westerly waves in the winter and cause a crescent-shaped beach to form near the east jetty. Comparison of the summer and winter shoreline configurations shows that the summer shoreline tends to rotate about 6 degrees clockwise relative to the winter shoreline.

MAINTENANCE-DREDGING RECORDS

The quantity of littoral drift that has shoaled in the entrance channel was determined through analyses of hydrographic surveys and maintenance-dredging records. Figure 9 shows the volume of littoral drift that accumulated between June 1972 and April 1978 within the control area shown in figure 10. The accumulation of material in the control area increased during each winter and was dredged in the late winter or in the spring. This dredging program was modified in 1977, when a series of multiyear, phased-dredging programs were implemented.

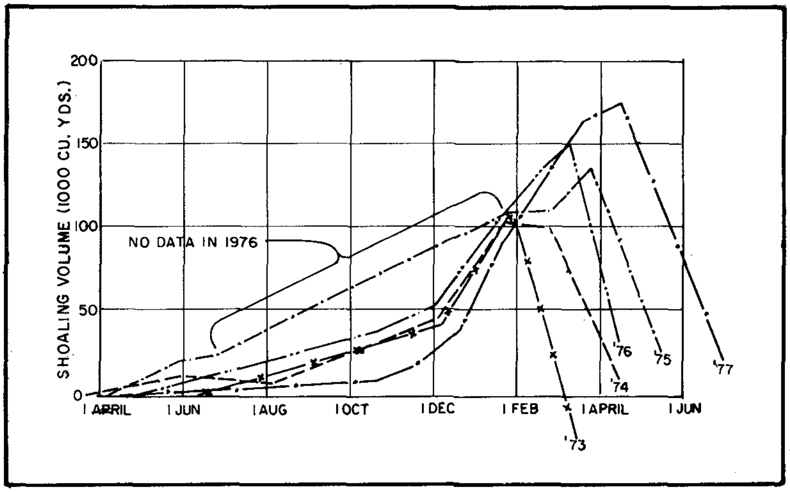

FIGURE 9: COMPARISON OF ACCRETION AND DREDGING QUANTITIES BY MONTH (1972 - 1977)

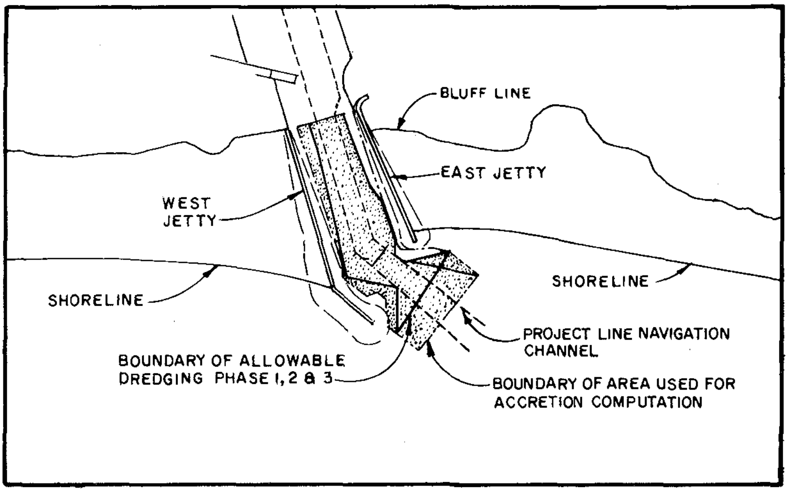

FIGURE 10: SHOALING BOUNDARIES

Maintenance-dredging records are plotted in figure 11. "Pay yardage" represents the quantity of material for which the Government agreed to pay the contractor. Pay yardage is not necessarily equal to the quantity of material actually removed. The dredgerman estimated that they actually removed as much as twice the pay yardage prior to 1977, when pay quantities were determined by comparing pre-dredging and postdredging surveys. This gave erroneous results when the dredging occurred simultaneously during the late winter and in the spring when shoaling also occurred.

The Waterways Experiment Station (WES) experimental jet-pump sand-bypassing system started operating on 26 June 1976. The bypassing system comprised three movable jet pumps operating in the channel off the west jetty, a movable jet pump at the head of the west jetty, and a stationary jet pump on the west side of the west jetty. The system was capable of bypassing about 100 cubic yards of sand per hour. The discharge area was 1,000 feet downdrift of the channel entrance, on the east beach. During the period July 1977 to June 1978, the WES plant dredged an additional 57,000 cubic yards.

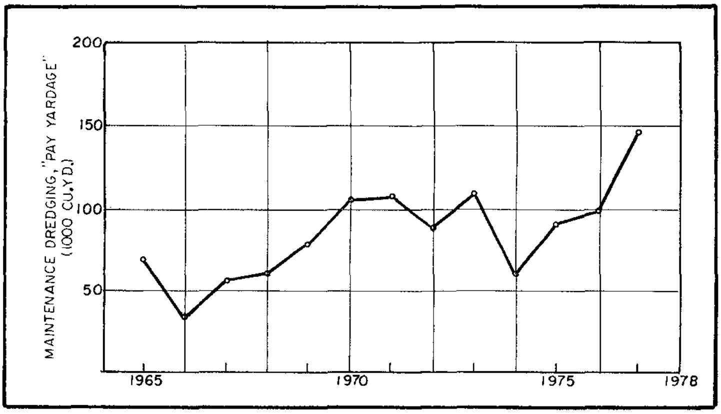

FIGURE 11: ANNUAL MAINTENANCE DREDGING HISTORY

SHOALING PROCESSES

Shoaling of the Santa Cruz Harbor entrance channel can be attributed to a number of disparate littoral processes, including: bypassing a saturated jetty (acting as a groin), leakage through voids in armor units on the jetties, wind transport, onshore transport, tidal-current transport, and updrift movement. This section describes each process and analyzes the history of shoaling to estimate the relative importance of each process. The nature of the available data and the state-of-the-art of defining littoral processes render it difficult to assign a definitive percentage of quantity of littoral transport to each process. However, for design purposes, it is often necessary to make certain assumptions in areas where precise quantification is not possible. Therefore, in order to prepare a plan to mitigate shoaling, estimates of the quantity of littoral transport attributable to each of the processes were made for design purposes.

Bypassing Saturated Jetty

Sand bypassing the head of the west jetty is the primary source of channel shoaling. Within 3 years after construction of the jetties, the west fillet had grown such that it reached the angle-point of the doglegged west jetty. As the west beach moved seaward during this period, maintenance-dredging pay yardage increased to quantities of more than 100,000 cubic yards per year.

Leakage Through Voids In Jetties

The west jetty is a rubble mound, armored with quarrystone and quadripods. The seaward portion of the west jetty has a concrete cap, but the jetty is not impermeable and sand can be pumped through the voids in the large armor and underlayer stones of the structure. An estimated 20,000 cubic yards of sand leaks through the voids of the west jetty into the channel annually. The east jetty has a better seal and is exposed to less wave energy. The transport into the Harbor through the east jetty is estimated to be less than 1,000 cubic yards per year.

Wind Transport

The fine sand on the beaches is susceptible to windblown transport. An estimated 5,000 cubic yards are transported eastward over the west jetty annually while 2,000 cubic yards are transported westward over the east jetty.

Onshore Transport

Onshore transport of sediments near the Harbor entrance can be a source of shoaling; however, it is difficult to estimate the quantity involved. Long-term and seasonal bathymetric measurements of the offshore area indicate very little change in the bottom at depths of greater than 20 to 25 feet. This is consistant with a limit depth calculated by methods described by Hallermecier (1978). The contribution of offshore sources is therefore estimated to be relatively minor compared with that of longshore transport because the jetty 20 feet of water.

Tidal-Current Transport

The maximum tidal currents in the navigation channel are estimated to be less than 0.15 feet per secon; therefore, the contribution of tidal-current transport to shoaling is minimal. The tidal prism of the Harbor is 9.8 x 10^6 cubic feet or 42 acres of water-surface area with a 5.3-foot mean tidal range. The crossectional area of the channel maintained a 400 square foot area as predicted from the O'brien (1968) equation.

Updrift Movement

The total potential westward component of the littoral-transport rate is about 40 percent of the eastward component; however, conditions are appropriate for westward transport primarily during times of short-duration, local storm winds, at which time the east beach is well shoreward from the head of the east jetty. Thus, the actual updrift contribution to channel shoaling is smaller than the potential updrift contribution and is estimated to be 20,000 cubic yards per year.

Natural Bypassing

Some of the littoral drift that reaches the Harbor area is believed to bypass the Harbor entrance by natural processes. The sediment budget indicates that approximately 50,000 cubic yards of littoral drift shoals in the entrance each year. Some fraction of this is accumulating on the sides of the channel. Nearly twice as much drift as that which shoals in the channel may naturally bypass the Harbor via the bar that forms across the entrance during the winter. Removal of the bar during the winter by maintenance dredging would tend to increase the amount of material trapped in the Harbor and decrease natural bypassing. The long-term solution had to be designed with this large potential bypass taken into account.

ALTERNATIVE SOLUTIONS

The 16 preliminary alternative solutions for mitigating the shoaling of Santa Cruz Harbor were developed and evaluated. Alternatives were classified in three categories: maintenance, bypassing, and structural (table 1). Maintenance pertains to the removal of material from the project channel and disposal of the material on the downdrift beach. Bypassing is a preventive procedure wherein sand is trapped or intercepted outside of the project channel and transported to the downdrift beach. A structural alternative either provides protection for a dredge or prevents material from entering the Harbor. Structural solutions must be supplemented by some form of maintenance or bypassing. In all cases, sand was to be deposited on the downdrift beach.

TABLE 1 - ALTERNATIVE SOLUTIONS

Maintenance

1. Annual Dredging - Floating Plant
2. Phased Dredging - Floating Plant (selected plan)
3. Hopper Dredge - "Currituck"
4. Mechanical Dredging Systems
5. Fixed Hydraulic System - Eductor
6. Fixed Hydraulic System - Zipper

Bypassing

7. Fixed Hydraulic System - Eductor
8. Mobile Hydraulic System - Eductor
9. Fixed Hydraulic System - Zipper
10. San Lorenzo River Sediment Trap

Structural

11. Long Offshore Breakwater - Annual Dredging
12. Short Offshore Breakwater - Continuous Bypassing
13. Extend West Jetty - Jetty
14. Modify Both Jetties or Construct a New Entrance
15. Weir Jetty or Groin - Continuous Bypassing
16. Enhance Ebb Currents - Dredge basins

PHASED-DREDGING PROGRAM

Description

The philosophy of phased dredging is to maintain the entrance channel for a greater length of time each year by periodically in phases removing the shoaled material during the year rather than once annually. A phased-dredging contract would be awarded late in the calendar year to mobilize a dredge onto the site by November 15. The dredge would be activated several times between November 15 and April at times when the channel has shoaled to a minimum depth of 10 feet. A final dredging episode in April would bring the channel to over-depth and over-width project dimensions in order to create as large a storage capacity as feasible with the present entrance configuration and thus to maintain a navigable entrance channel until the following winter season.

A review of the dredging and accretion histories of Santa Cruz Harbor for the period between 1972-1977 indicates that the shoaling rate decreases between April and November and that dredging of the navigation entrance to the full project width and depth in April results in a navigable channel through the busy summer boating season. Periodic maintenance dredging would be required between November and April to keep the channel open to navigation. A total sand bypassing program with the existing Harbor entrance configuration would not be feasible because there is neither adequate protection to keep a dredge operating during storms nor sufficient storage capacity to create an effective sediment trap.

Two conflicting problems evolve. The channel should be wide and deep enough for safe navigation, yet narrow and shallow enough to maximize the natural bypassing of littoral drift during the winter. A compromise between these conflicting problems would be to reduce the project depth, at least during the winter. For example, if the navigation channel could be maintained at a depth varying between 10 and 15 feet MLLW over a width of 100 feet, it should be reasonably safe for navigation (except during storm wave episodes) and yet not completely interfere with the movement of littoral drift that naturally bypasses the Harbor entrance seaward of the 10-foot depth contour.

Figure 12 shows the shoaling quantities and figure 13 shows the idealized phased-dredging program. Figure 13 also shows variation in shoaling quantities that have occurred and how the variation affects the program. Note a final dredge episode at the end of the winter season to clear the channel to project depth.

Results of Phased-Dredging Program

The phased-dredging program was initiated in the winter of 1977. The first contract was awarded for 2 years to Shellmaker, Inc. and the second 2 year contract was awarded to Watson, Inc. The purpose of a multiyear contract was to spread the cost of mobilization and demobilization of the dredge over more than 1 year. A longer contract period was considered; however, the experience gained during the first 2 years would benefit both contractors and the Government.

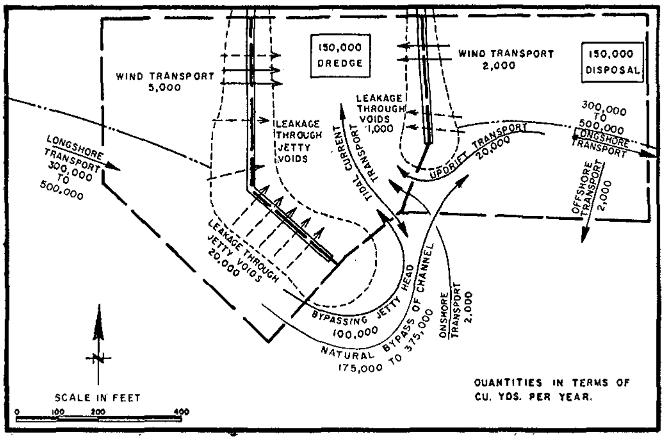

FIGURE 12: SEDIMENT BUDGET

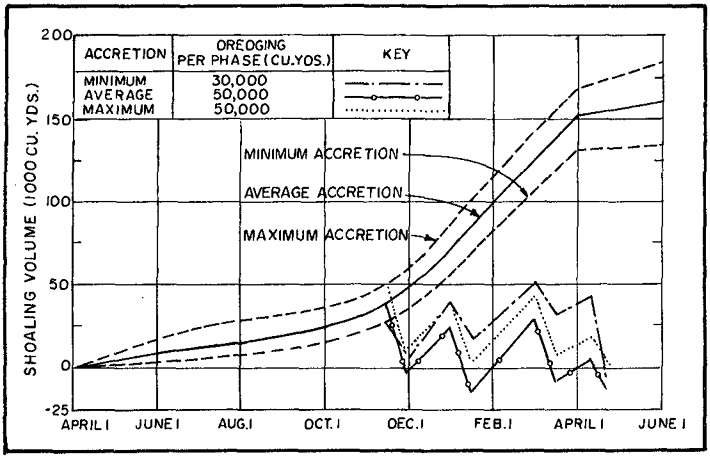

FIGURE 13: CUMULATIVE RATES OF ACCRETION AS MODIFIED BY PROPOSED DREDGE PROGRAM

TABLE 2-RESULTS OF PHASED-DREDGING PROGRAM

PHASE	CONTRACTOR ESTIMATE CUBIC YARDS	PAY YARDAGE CUBIC YARDS	CONTRACT COST*
	WINTER 1977-1978		
1	28,000	28,000	
2	42,000	36,000	
SPECIAL	34,000	24,000	
3	18,000	18,000	
FINAL	75,000	56,000	
WES Eductor Experiment	57,000	57,000	
Total	254,000	219,000	$451,000
	WINTER 1978-1979		
1	0	0	
2	35,000	22,000	
3	32,000	25,000	
FINAL	42,000	38,000	
TOTAL	109,000	85,000	$429,000
	WINTER 1979-1980		
1	53,000	53,000	
2	75,000	43,000	
3	35,000	30,000	
FINAL (estimated)	50,000	40,000	
TOTAL	213,000	166,000	$379,000

*Includes mobilization and demobilization

Contractual and permit problems have delayed implementation of the project. The basic concept was to mobilize the dredge by 15 November each year; however, starting dates have been 19 December 1977, 19 January 1979, and 12 December 1979. The first and last delays were for legal reasons and resulted in several months of a partially closed harbor. The 1978 to 1979 winter was very mild and dredging was not required until mid-January.

The results of the first 3 years of the program are summarized in table 2. Two estimates of the quantities of material reportedly dredged during each episode and the total cost, including mobilization and demobilization for each dredging season are included. The Government pay yardage was estimated by taking leadline soundings from the back of the dredge as it operates and comparing them with predredging soundings. This method minimized the amount of material that can shoal during the dredging operation as was the case in measuring procedures prior to 1977; however, comparison of the contractor estimate compared with the government estimate reveals some large inconsistencies. In the cases revealing large inconsistencies, such as for phase 2 of the 1979-1980 winter, the contractor claimed that he dredged nearly twice the amount of material for which he was paid. The differential in estimates represents the amount of material that shoals from the time of predredge survey are taken until the time soundings were made. The dreging episodes typically last for 2 weeks. The average shoaling rate during a 2-week period is about 10,000 cubic yards. A severe storm over a 2- 3-day period can deposit three times that amount. The dredgeman estimated a 26 percent greater total quantity than the Government allowed. The improved method of estimating dredged quantities has improved the differential between the amount the Government pays for and the amount the contractor claims he removes.

CONCLUSIONS

The phased-dredging program solved the shoaling problem at Santa Cruz during the first 3 years to the satisfaction of Harbor users. A large part of the success of the program is attributable to having an experienced and reliable dredgerman in charge of the operations. The system requires no initial capital expenditure for permanent structures and can be modified or adjusted to account for differences in littoral transport regimes seasonally. If at some future date, an efficient eductor system is developed and proven reliable, it can be installed at such a time.

The phased-dredging program has doubled the quantity of pay yardage compared with the previous system of dredging once in the spring. This is attributed to three factors:

1. unusually severe winters;
2. improved method of calculating pay yardage by taking soundings from the dredge; and
3. interruption of natural bypassing that occurs, when a shoal exists in the entrance channel.

RECOMMENDATIONS

1. The phased-dredging program should be considered as a viable nonstructural alternative to harbors with shoaling problems similar to those of Santa Cruz Harbor.
2. If in the future a structural solution is sought for Santa Cruz, careful consideration should be given to designing the capacity of the equipment to trap or handle an even greater quanitity of material than the phased-dredging program has had to handle. For example, if a fixed eductor system is to be installed to maintain the channel to project depth, it should be prepared to remove at least 400,000 cubic yards per year.

ACKNOWLEDGEMENTS

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