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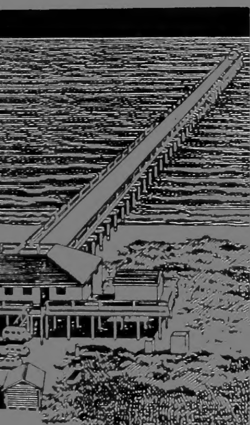

REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-CO-3

CASE HISTORIES OF CORPS BREAKWATER AND JETTY STRUCTURES

Report 1
SOUTH PACIFIC DIVISION

by

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Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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The following two letters used as part of the number designating technical reports of research published under the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program identify the problem area under which the report was prepared:

Problem Area		Problem Area	
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP — Field Research Facility, Duck, North Carolina.

BOTTOM — View of 25-ton tetrapods at the head of the Crescent City Harbor outer breakwater, Crescent City, California.

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This report is the first in a series of case histories of US Army Corps of Engineers (Corps) breakwater and jetty structures at nine Corps divisions. Herein, case histories are presented for 28 breakwater and jetty structures located within the US Army Engineer Division, South Pacific (SPD), which encompasses the entire California shoreline. Presently, there are approximately 171,870 lin ft of breakwater and jetty structures managed by SPD. These structures are predominantly of rubble-mound construction. Twenty-one of the projects have undergone repair and/or modification during their lifetimes. A variety of repair methods have been utilized including replacement and/or addition of armor stone, placement of concrete armor units, and use of concrete and concrete caps.

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PREFACE

This report was prepared as part of the Coastal Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was carried out jointly under Work Unit 32278, "Rehabilitation of Rubble-Mound Structure Toes," of the REMR Program and Work Unit 31269, "Stability of Breakwaters," of the Civil Works Coastal Area Program. For the REMR Program, Problem Area Monitor is Mr. John H. Lockhart, Jr., Office, Chief of Engineers (OCE), US Army Corps of Engineers (Corps). REMR Program Manager is Mr. William F. McCleese of the US Army Engineer Waterways Experiment Station's (WES's) Structures Laboratory, and Coastal Problem Area Leader is Mr. D. D. Davidson of WES's Coastal Engineering Research Center (CERC). Messrs. John G. Housley and Lockhart, OCE, are Technical Monitors of the Civil Works Coastal Area Program.

This report is the first in a series of case histories of Corps breakwater and jetty structures at nine Corps divisions. The case histories contained herein were extracted from information obtained from several sources (where available) which included inspection reports, conferences, telephone conversations, project plans and specifications, project files and correspondence, design memorandums, literature reviews, model studies, surveys (bathymetric and topographic), survey reports, annual reports to the Chief of Engineers, House and Senate documents, and general and aerial photography. Unless otherwise noted, only prominent changes to the prototype structures subsequent to March 1986 are included in this report.

This work was conducted at WES during the period April 1985 - July 1986 under general direction of Dr. James R. Houston, Chief, CERC, and Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC; and under direct supervision of Mr. C. Eugene Chatham, Jr., Chief, Wave Dynamics Division (CW), and Mr. D. D. Davidson, Wave Research Branch (CW-R), CW. This report was prepared by Mr. Robert R. Bottin, Jr., CW. Messrs. Robert D. Carver and Peter J. Grace, CW-R, conducted site inspections and collected much of the data contained herein. This report was edited by Ms. Shirley A. J. Hanshaw, Information Products Division, Information Technology Laboratory, WES.

COL Dwayne G. Lee, CE, was Commander and Director of WES during the publication of this report. Dr. Robert W. Whalin was Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
miles (US statute)	1.609347	kilometres
pounds (force)	4.448222	newtons
square feet	0.09290304	square metres
tons (2,000 lb force)	8896.443353	newtons

CASE HISTORIES OF CORPS BREAKWATER AND JETTY STRUCTURES

SOUTH PACIFIC DIVISION

PART I: INTRODUCTION

Background

1. The Corps of Engineers (CE) is responsible for a wide variety of coastal structures located along the Atlantic and Pacific Oceans, the gulf coast, the Great Lakes, the Hawaiian Islands, other islands, and inland waterways. Coastal improvements such as breakwaters and/or jetties are necessary to provide harbor protection and the safe passage of vessels. These structures usually are constructed on movable-bed materials and are subjected continuously to wave and current forces. Under these conditions, structural deterioration may occur and, in time, maintenance may be required when the structure fails to serve the needs of the project. Some projects have been maintained for 150 years or more. Methods of construction (and repair) have varied significantly during this time principally because of a better understanding of coastal processes and existing wave climates, availability of construction materials, regional construction practices, and economic considerations.

Purpose

2. The purposes of this report are to provide insight into the scope, magnitude, and history of coastal breakwaters and jetties under CE jurisdiction; to determine maintenance and repair history; to determine methods of construction; to make this information available to CE personnel; and to address objectives of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) research program. To accomplish these objectives, case histories of CE breakwaters and jetty structures have been developed to quantify past and present problem areas (if any), to take steps to rectify these problems, and to subsequently evaluate the remedial measures. General design guidance can be obtained from the solutions that have been most successful. Information in this report should be of particular value to CE personnel in the US Army

Engineer Division, South Pacific (SPD), and its coastal districts and possibly to non-Corps personnel. Further research is being conducted to address problems where adequate solutions are lacking or where specific guidance is required (i.e. general armor stability, toe protection, localized damage, use of dissimilar armor, wave runup, and overtopping).

PART II: SUMMARY OF CORPS BREAKWATER AND JETTY STRUCTURES IN SPD

3. SPD has a total of 28 projects which include breakwater and/or jetty structures. Fourteen of these projects are within the US Army Engineer District, San Francisco's (SPN's), boundaries, and 14 are within the US Army Engineer District, Los Angeles's (SPL's) area of responsibility. Locations of these projects are shown in Figures 1 and 2. Overall, there are approximately 171,870 lin ft* of breakwater and/or jetty structures in the Division. Breakwaters account for about 60 percent of this total, and the remaining 40 percent are jetty structures. Although a variety of construction methods and materials have been used, most of the structures (97 percent) are constructed entirely of stone. Other construction materials used include concrete armor units (dolosse, tetrapods, tribars, quadripods), concrete blocks, concrete sheet pile, and concrete monolith walls and head sections.

4. Twenty-one of the projects are situated in an ocean environment, and seven are located in the San Francisco Bay area. Many of the Pacific Ocean structures are periodically subjected to very severe storm wave conditions which have resulted in frequent maintenance and/or modifications at some locations. Structures within SPD have experienced problems in all four major REMR problem areas (runup and overtopping, localized damage, toe stability, and use of dissimilar armor). Twenty-one of the Division's 28 projects have been repaired or modified since construction.

5. Most breakwaters and jetties in SPD have been constructed on top of existing sediments (usually fine to coarse sand); however, portions of some structures are constructed on bedrock. These structures have crest elevations ranging from 10 to 26 ft and crest widths ranging from 6 to 26 ft, and they have been constructed in water depths ranging from 8 to 45 ft. Side slopes vary from 1V:1.25H to 1V:5H. Design guidance for breakwater cross sections (stone sizes, crest height, width, etc.) is provided in the Shore Protection Manual (1984) or appropriate CE engineering manuals. Several of SPD's projects have been model tested at the US Army Engineer Waterways Experiment Station (Baumgartner, Carver, and Davidson 1985; Baumgartner, et al. 1986; Bottin, Sergeant, and Mize 1985; Bottin and Acuff 1985; Bottin (in preparation); Brasfeild 1965; Brasfeild and Ball 1967; Carver 1984; Chatham 1968;

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

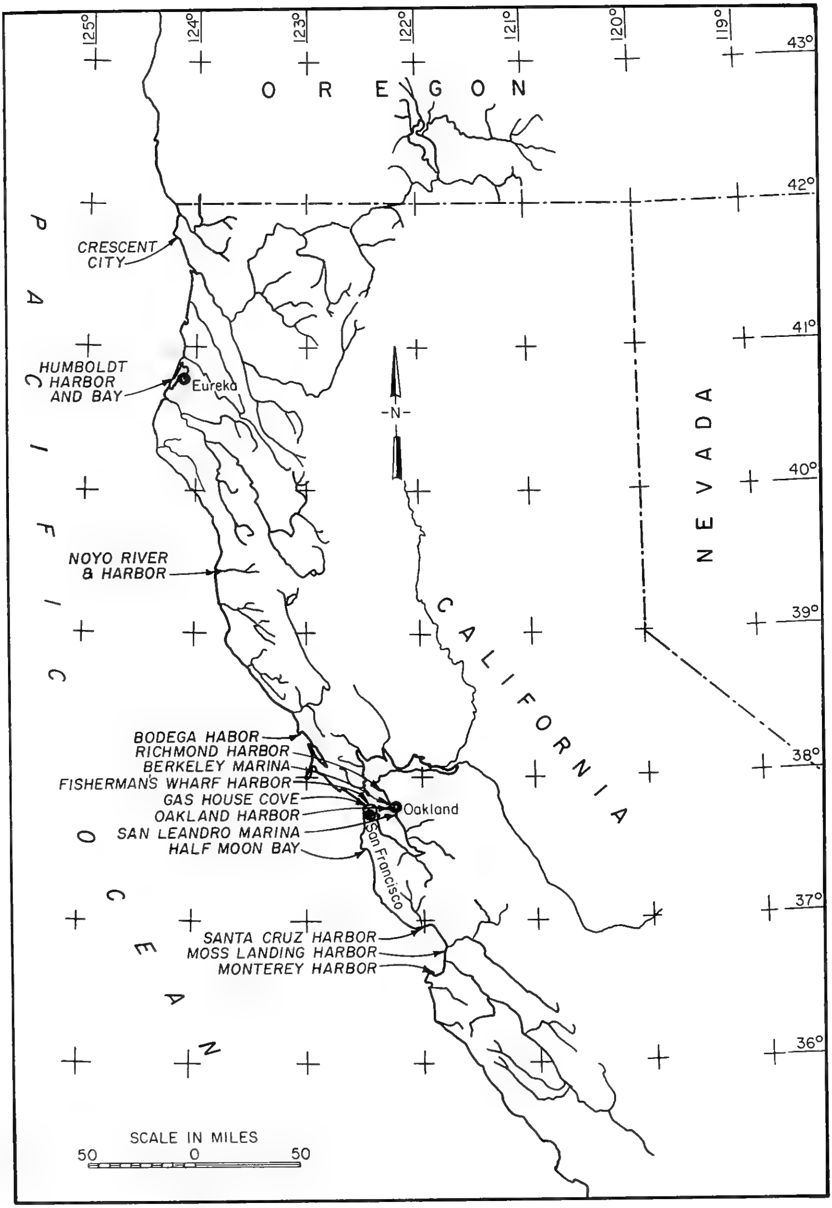

Figure 1. Location of SPN's breakwater and jetty projects

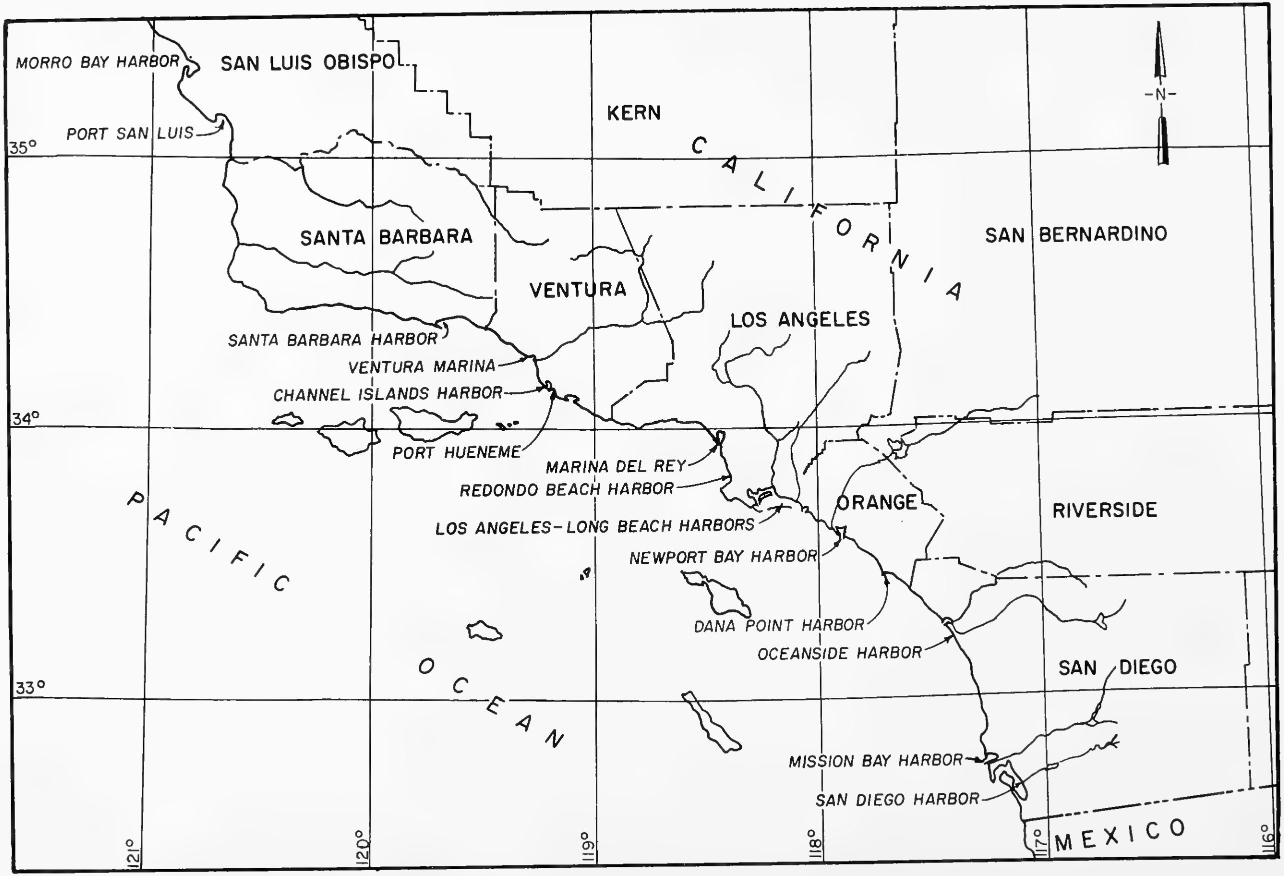

Figure 2. Location of SPL's breakwater and jetty projects

Curren 1983; Dai and Jackson 1966; Davidson 1969; Davidson 1971; Jackson 1961; Markle 1983; Senter 1971; Senter and Brasfeild 1968; US Army Engineer Waterways Experiment Station 1953, 1956; Wilson 1965, 1966, 1967).

6. Case histories for SPD's breakwater and jetty structures are shown in Tables 1-28. Structure alignments and cross sections are included also as Figures 1-35 accompanying the various tables. General characteristics of these structures are shown in the following tabulation:

Table	Location	Structure Type & No.*	Armor Type**	Cumulative Structure Length, ft	Date of Origin	Improvement†
1	Crescent City Harbor	B(2)	S,D,T	6,270	1920	M, R
2	Humboldt Harbor and Bay	J(2)	S,D,T, C,CB	9,600	1889	M, R
3	Noyo River and Harbor	J(2)	S,C	579	1924	R
4	Bodega Harbor	J(2), B(1)	S,C	4,048	1943	M, R
5	Richmond Harbor	B(1)	S	10,000	1923	R
6	Berkeley Marina	B(2)	S,C	1,165	1965	M
7	Oakland Harbor	J(2)	S	21,500	1921	N
8	San Leandro Marina	B(1)	S	700	1977	N
9	Fisherman's Wharf Harbor	B(3)	C	1,917	1985	N
10	Gas House Cove	B(1)	C	117	1975	N
11	Halfmoon Bay	B(2)	S	8,090	1961	M
12	Santa Cruz Harbor	J(2)	S,Q	1,975	1963	R
13	Moss Landing	J(2)	S	1,230	1947	R
14	Monterey Harbor	B(1)	S	1,700	1932	M
15	Morro Bay Harbor	B(2)	S	3,717	1943	M, R
16	Port San Luis	B(1)	S	2,400	1913	R

(Continued)

* Indicates number of structures (i.e., B(2) indicates two breakwaters).
** B-breakwater, J-jetty, S-stone armor, C-concrete sheet pile or wall, Q-quadripods, Tr-tribars, T-tetrapods, D-dolosse, CB-concrete blocks.
† R-repair, M-modification, N-none (no modifications or repairs since construction).

Table	Location	Structure Type & No.*	Armor Type**	Cumulative Structure Length, ft	Date of Origin	Improvement†
17	Santa Barbara Harbor	B(1)	S	2,365	1928	M
18	Ventura Marina	B(1), J(3)	S,Tr	4,075	1963	M
19	Channel Islands Harbor	B(1), J(2)	S	4,870	1959	N
20	Port Hueneme	J(2)	S	1,800	1940	N
21	Marina Del Rey	B(1), J(2)	S	5,090	1965	M
22	Redondo Beach King Harbor	B(2)	S	4,885	1958	M, R
23	Los Angeles and Long Beach Harbors	B(3)	S	43,002	1898	M, R
24	Newport Bay Harbor	J(2)	S	4,480	1934	N
25	Dana Point Harbor	B(2)	S	7,750	1968	R
26	Oceanside Harbor	J(1)	S	1,350	1961	M
27	Mission Bay Harbor	J(3)	S	9,620	1949	M, R
28	San Diego Harbor	J(1)	S	7,500	1894	R

7. These tables (Tables 1-28) summarize the construction and rehabilitation histories of SPD's structures. Current and more specific data at a particular site may be obtained from the latest complete summary condition survey report through SPD's district offices for readers who need additional information.

Table 1

Crescent City Breakwater

Crescent City Harbor, California

Date(s)	Construction and Rehabilitation History
1920-1926	The initial work at the project (Figure 3) provided for a 3,000-ft-long rubble-mound breakwater, 6 to 11 ft above mean lower low water (mllw) with a 20-ft crest width. The first 2,245-ft length of breakwater was completed in 1926. Ten-ton armor stones were used for slope protection (Figure 4).
1928-1930	A 14-ft-wide concrete cap was added to the original 2,245 ft of structure raising the crest elevation to 14 ft mllw.
1931	An additional 755 ft of breakwater construction was completed resulting in a 3,000-ft-long structure.
1939	Construction of a rubble-mound sand barrier connecting Whaler Island to the shore (Figure 3) was completed to prevent shoaling. The barrier structure was 17 ft wide at its crest with an elevation* of +10 ft mllw (Figure 4). An armor layer of 4- to 6-ton stones protected the ocean side of the sand barrier.
1946	Construction of a 1,200-ft-long inner breakwater was completed to provide protection to a small-craft basin. The inner breakwater extended from Whaler Island northwest (Figure 3). The crest el of the structure was +18 ft mllw (Figure 4) and 10- to 12-ton armor stones were utilized during construction.
1948	A 1,000-ft-long extension of the original (outer) breakwater extending toward Round Rock (Figure 3) was completed. Ten- to 12-ton armor stones were used.
1948-1949	During storms of 1948 and 1949, the 1,000-ft-long extension of the outer structure suffered considerable damage.
1950	The crest el of the entire outer breakwater, with the exception of a 300-ft segment (sta 12+50 to 15+50), was raised to +20 ft mllw with a 22-ft-wide concrete cap to prevent overtopping.
1950-1951	Winter storm seasons resulted in further damage to the outer breakwater. Damages consisted of displacement of the concrete cap and armor stones down to about 0.0 mllw in all of the extension located seaward of sta 37+00.
1952	A modification was authorized which provided for a 1,000-ft-long extension of the outer breakwater on a bearing of S80° E (Figure 3) and for abandonment of the existing structure seaward of sta 36+70.

(Continued)

* All elevations (el) cited herein are in feet referenced to National Geodetic Vertical Datum (NGVD) of 1929.

Table 1 (Continued)

Date(s)	Construction and Rehabilitation History
1957	The 1,000-ft-long outer breakwater extension, as authorized in 1952, was completed. Twelve-ton stone protection was used from sta 36+70 to 41+20. From sta 41+20 to 46+70, 25-ton unreinforced tetrapods (1,836 units) were placed on the seaward slope (Figure 5). Model tests were conducted (US Army Engineer Waterways Experiment Station (WES), Hydraulics Laboratory (HL) 1953, 1956).
1957-1964	Damages occurred to a portion (sta 36+70 to 41+20) of the outer breakwater, and in 1964 were repaired using 12-ton stones and 140 25-ton tetrapods. The tetrapods were not model tested for their adequacy for placement in this area, and they were destroyed over a period of years.
1973	Repairs were made to the concrete cap of the outer breakwater between sta 35+40 and 37+00.
1974	Rehabilitation of the outer breakwater between sta 34+70 to 37+00 was completed. Two layers of 40-ton unreinforced dolosse (246 units) were placed on the seaward slope.
1974	Construction of a 400-ft-long extension of the inner breakwater was completed (Figure 3). Model testing was conducted to determine optimum wave conditions (Senter and Brasfeild 1968, Senter 1971).
1979	Repairs were made to the following reaches of the outer breakwater using 18- to 30-ton stone: sta 19+00 to 20+00, 22+00 to 24+00, 24+60 to 27+20, 28+90 to 29+50, 30+50 to 31+00, and 37+00 to 41+20. Repairs to sta 15+50 through 17+50 also were made using stone in the 14- to 25-ton range.
1983	Major storms in the winter of 1983 resulted in broken dolosse on the outer breakwater. Estimated damage to the structures was $4,400,000.
1984	Approximately 23,300 tons of stone were placed to repair various sections of the outer breakwater between sta 17+30 to 33+90.
1986	The outer breakwater is presently in poor condition. The problem area is primarily between sta 34+70 through 37+00 where missing and/or damaged dolosse are apparent. A contract was issued to rehabilitate the dolosse section of the outer structure (sta 34+70 through 37+00) with 700 fiber-reinforced 42-ton dolosse. The dolos perimeter used special placement, and the dolosse on the outer portion of the seaward transition were entrenched and buttressed with 25-ton stone (Baumgartner, Carver, and Davidson 1985). About 80 of the constructed dolosse were stockpiled on the leeward side of the jetty for repair contingencies. This rehabilitation effort was also used to gather data on prototype forces on dolosse. Twenty of the dolosse (painted red) were instrumented and placed in the main dolos section at about sta 36+00. As of this date, no data have been received from the prototype dolos study.

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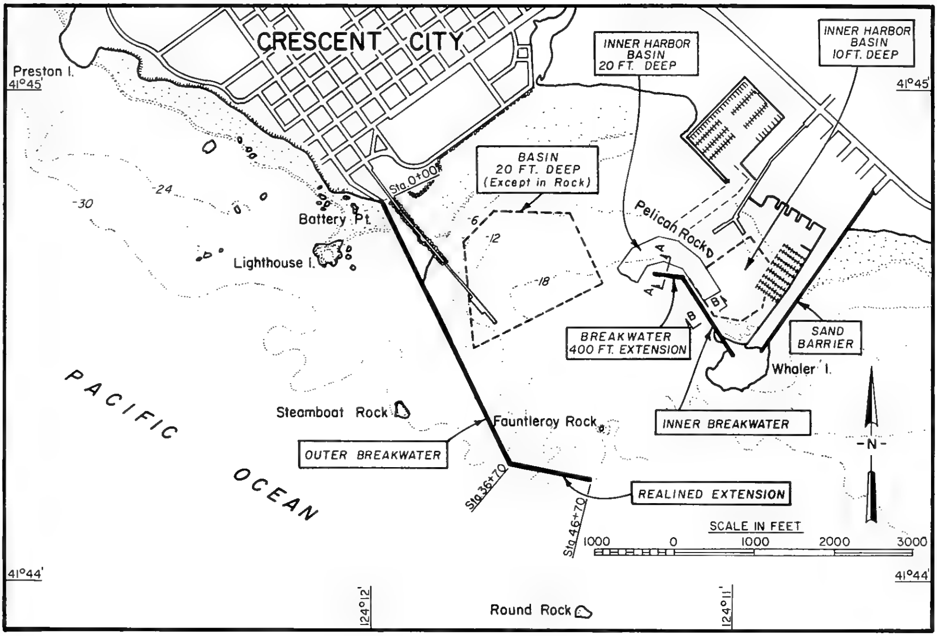

Figure 3. Cresent City Harbor, California

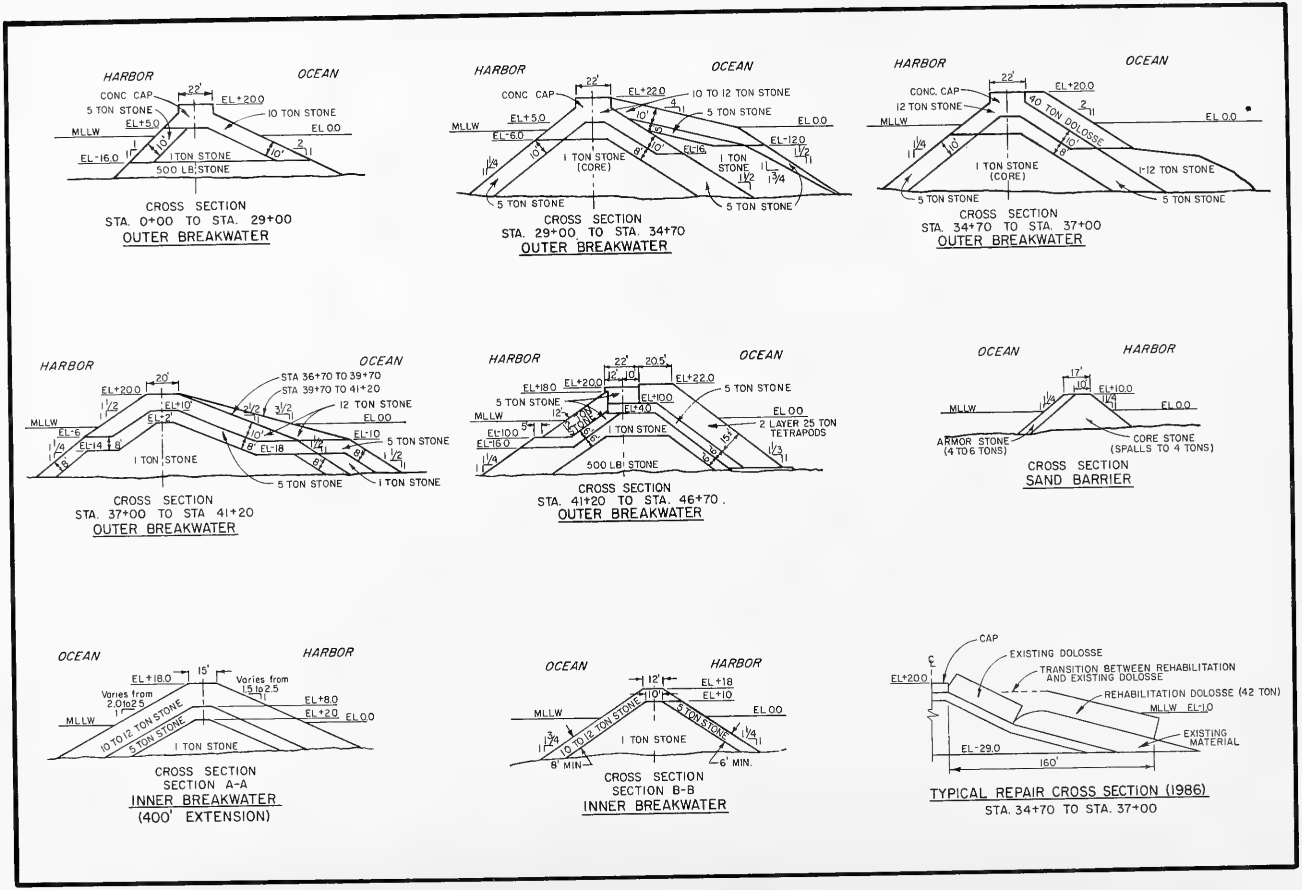

Figure 4. Typical structure cross sections, Crescent City Harbor, California

Figure 5. View of tetrapods at head of Cresent City Harbor outer breakwater

Table 2

Humboldt Bay Jetties

Humboldt Harbor and Bay, California

Date(s)	Construction and Rehabilitation History
1889-1899	The initial construction of the north and south jetties was completed at the site (Figure 6) during this time frame. The south jetty was 4,000 ft long with a +10-ft mllw crest el. The ocean-side slope was 1V: 2.65H, and the channel-side slope was 1V:2.25H. The north jetty was constructed to a length of 1,500 ft with a crest el of +12 ft mllw. The ocean-side slope was 1V:2.42H, and the channel-side slope was 1V:1.85H. Stones used in the jetties were composed of rock up to 8 tons in weight. The jetties terminated at approximately the 18-ft contour.
1900-1907	During this period the jetties deteriorated from lack of maintenance. The channel shoaled, and by 1907 the outer ends of the jetties were completely buried in the sand of the uncontrolled bar.
1911-1915	Reconstruction of the south jetty was in progress. Structure design consisted of 1V:2H side slopes with crest el ranging from +14.8 ft to +19 ft mllw. Class I stones (10 to 20 tons) were used for facing the sea-side slope of the outer 2,400 ft of the jetty; Class II stones (1 to 10 tons) made up the main part of the jetty; and Class III stones (3 to 500 lb) were used to level off the top and fill in the voids between the larger stones. A 2-ft-thick, 20-ft-wide concrete slab was placed on the crown.
1915	Reconstruction of the north jetty was completed. The jetty was reconstructed with 1V:1.5H side slopes with the following classes of stones: Class I rocks ranged from 6 to 20 tons averaging at least 10 tons; Class II stones ranged from 500 lb to 6 tons and averaged at least 1 ton; and Class III rocks ranged from 3 to 500 lb. Most of the Class III stones were used at the shoreward end of the structure, the proportion decreasing as the jetty approached its outer end. Class III rocks were used for the jetty core, Class II for the enrockment over the core, and Class I as a facing for the side slopes, the larger pieces being used on the exposed side of the jetty. The top was leveled off and all voids filled with small stones. The structure then was capped with a 2-ft-thick, 20-ft-wide concrete slab.
1925-1927	The north and south jetties were completed to their present lengths (north jetty, 4,500 ft; south jetty, 5,100 ft). The side slopes of the jetties were approximately 1V:1.5H (Figure 6) with a crest width of 20 ft. The el of the crest varied from about 12 to 19 ft mllw at the seaward end. Parapet walls and concrete caps were included on both jetties, and mass concrete was poured on channel-side slopes to stabilize armor stone. The parapet walls were located on the south sides of the jetties and were about 4 ft high and 6 ft wide.

(Continued)

Table 2 (Continued)

Date(s)	Construction and Rehabilitation History
1931-1932	Extensive repairs were made to the outer ends of both jetties. Precast concrete blocks (4 by 9 ft) were used in lieu of stone and piled one on top of another for constructing the forms for concrete monoliths. North jetty repairs using 1,200 cu yd of concrete* were completed in 1931 at a cost of $53,246. In 1932 north jetty repairs using 266 cu yd of concrete and south jetty repairs using 15,986 cu yd of concrete were completed for $247,038.
1933	North jetty repairs using 4,748 cu yd of concrete and 6,435 tons of stone and south jetty repairs using 926 cu yd of concrete were comleted for $105,932.
1935	North jetty repairs using 1,370 cu yd of concrete were completed at a cost of $17,366.
1936	North jetty repairs using 1,203 cu yd of concrete and south jetty repairs using 1,209 cu yd of concrete were completed at a cost of $28,933. It was determined by this time that the rectangular concrete blocks were moved easily by the sea. Large stone, however, was not obtainable at a reasonable price and was replaced by concrete blocks. When placed in the parapet, the blocks were concreted in place.
1937	South jetty repairs using 1,552 cu yd of concrete were completed at a cost of $25,400.
1939	Heavy storms caused great damage to both jetties. The monoliths at the outer end of the south jetty were undermined, causing them to tilt and sink. Breaches occurred in the jetty immediately shoreward of the monolithic end. A partial breach occurred through the north jetty just shoreward of its monolithic end. In addition, considerable damage was done to the side slopes of both jetties. During the year south jetty repairs were completed using 12,450 cu yd of concrete at a cost of $151,025.
1940	North jetty repairs using 7,418 cu yd of concrete and 2,200 tons of stone and south jetty repairs using 29,772 cu yd of concrete were completed at a cost of $311,848.
1941	North jetty repairs using 15,158 cu yd of concrete and 1,705 tons of stone were completed at a cost of $141,220.
1942	North jetty repairs using 8,809 cu yd of concrete were completed for a cost of $124,220.
1943	North jetty repairs using 7,560 cu yd of concrete and south jetty repairs using 2,550 cu yd of concrete were completed at a cost of $189,812.

(Continued)

* Concrete used for jetty repairs was mass poured unless otherwise noted.

Date(s)	Construction and Rehabilitation History
1944	North jetty repairs using 10,840 cu yd of concrete and south jetty repairs using 1,502 cu yd of concrete were completed at a cost of $56,740.
1945	South jetty repairs using 3,342 cu yd of concrete were completed for $50,560.
1950	The south jetty was breached over a 70-ft span on the sea side. Side slopes were reconstructed with mass concrete to conform to existing adjacent slopes to el of +18 ft mllw.
1951	South jetty repairs using 1,081 cu yd of concrete were completed at a cost of $59,805. Also, twelve 100-ton concrete blocks were installed.
1952	South jetty repairs using 470 cu yd of concrete were completed at a cost of $12,107.
1957	Major damage was sustained on the channel side of the north jetty. The total length of damage on the jetty was 410 lin ft at five locations. Also, the concrete monolith at the outer end of the structure was completely devoid of stone or concrete protective side slopes at this time. Major damage to the south jetty had similarly occurred. Breaches through the center section had occurred at two locations with major loss of side slopes at three locations. The concrete monolith at the outer end was exposed in a manner similar to that of the north jetty. The condition of the jetties at this point was not due to a specific storm but represented deterioration over a period of years. Tetrapods weighing 25 tons were placed on the north jetty and 15 tons on the south jetty, all on a slope of 1V:1.5H. North jetty repairs using 611 cu yd of concrete and 1,540 tons of stone were completed for $100,418.
1957-1958	Severe winter storms deteriorated the north and south jetties to such an extent that repair work constituted a major construction project.
1958	Mass concrete was poured to fill eroded areas on crests, and armor stones were replaced in areas that were breached and washed out. Concrete blocks (11 by 11 ft) weighing 100 tons and 12-ton tetrahedrons were placed on the heads of both jetties.
1959	Major side slope losses on the south sides of both the north and south jetties occurred.
1960-1963	Rehabilitation of both jetties was accomplished. Jetty trunks were repaired with 12-ton stones placed on 1V:1.5H slopes in the eroded areas. Jetty heads were reconstructed using 20-ton blocks to form head perimeters, and centers were filled with mass concrete. Two-hundred and fifty 100-ton concrete blocks were placed around the seaward tip of the south jetty head. The concrete monolith at

(Continued)

Table 2 (Continued)

Date(s)	Construction and Rehabilitation History
	seaward end of the north jetty was completed in 1961 and within the year was undermined by wave action resulting in part of the monolith breaking off. The monolith was repaired by placing rocks around the head section on 1V:2H side slopes and grouting the rocks with concrete. The elevation of the concrete at the north jetty was raised to +25 ft mllw and at the south jetty to +26 ft mllw at the tip. The heads were protected with 12-ton stones with a cover layer of 100-ton concrete blocks.
1963-1965	Winter storm waves washed away most of the newly placed 100-ton concrete blocks.
1969-1970	The concrete monolith at south jetty was undermined and broken. Heads of both jetties were totally destroyed.
1971-1972	Rehabilitation of both jetties was completed. Concrete monoliths were reconstructed, and 42-ton dolosse were placed around the seaward quadrant of both jetty heads. Four unreinforced, 1,271 steel-reinforced, and 17 steel-fiber-reinforced dolosse were placed on the north jetty; and 22 unreinforced and 1,423 steel-reinforced dolosse were placed on the south jetty head. Dolosse (43-ton) also were placed on the shoreward transition sections of both jetty heads. Two layers of dolosse were placed using a concentration of 11 dolosse per 1,000 sq ft of slope. Cost of this work was $10,108,764. Model testing was conducted prior to these repairs (Davidson 1971).
1973	South jetty repairs using concrete and stone were completed at a cost of $20,400.
1975	An earthquake of 5.2 magnitude on the Richter scale occurred near the site. Inspection trips subsequent to the earthquake revealed fresh cracks along the south jetty running along the edges of the crest and slope for a distance of about 800 ft on the channel side and 300 ft on the seaward side. Blowout holes also were observed at several locations on the south jetty. On the north jetty, three of the dolosse had moved about 50, 100, and 150 ft from the placement area, respectively. Only minor settling of the remaining dolosse had occurred, and no cracking or unraveling of the dolos units was apparent.
1977	South jetty repairs using concrete and rock were completed. Approximately 15,000 tons of stone ranging from 1 to 20 tons were used for these repairs.
1977-1978	The jetties were subjected to severe storms combined with high tides and winds. On occasion, waves covered both jetties over their entire lengths. Waves also were observed breaking over the dolosse and concrete monoliths of the jetty heads. North jetty repairs using stone were completed at a cost of $450,000.

(Continued)

Table 2 (Concluded)

Date(s)	Construction and Rehabilitation History
1978	An inspection revealed that the north jetty slope was eroded at several locations, and 12 blowout holes were apparent in the concrete cap. Also, at the north jetty head, waves had broken away a 20-ton concrete block from the concrete monolith which washed across the monolith and was resting against a tip of a dolos. The slope of the south jetty had eroded in numerous locations, and the parapet wall had broken at four stations. Nineteen blowout holes were observed in the south jetty concrete cap. Also a 7-ft stone had broken out of the parapet wall and was deposited on the concrete cap.
1983	Major storms resulted in an estimated $2,000,000 in damages to the jetties.
1984	Repair of the south jetty consisting of 4,900 tons of 15- to 25-ton stones and replacement of 20-ton concrete blocks at the jetty head was completed. Also 16,665 tons of 15- to 25-ton stones and 16,665 tons of 18- to 31-ton stones were stockpiled on the harbor side of the jetty.
1985	Repair of the jetty heads was completed using a total of approximately 1,000 42-ton dolosse in various areas and the construction of toe berms.

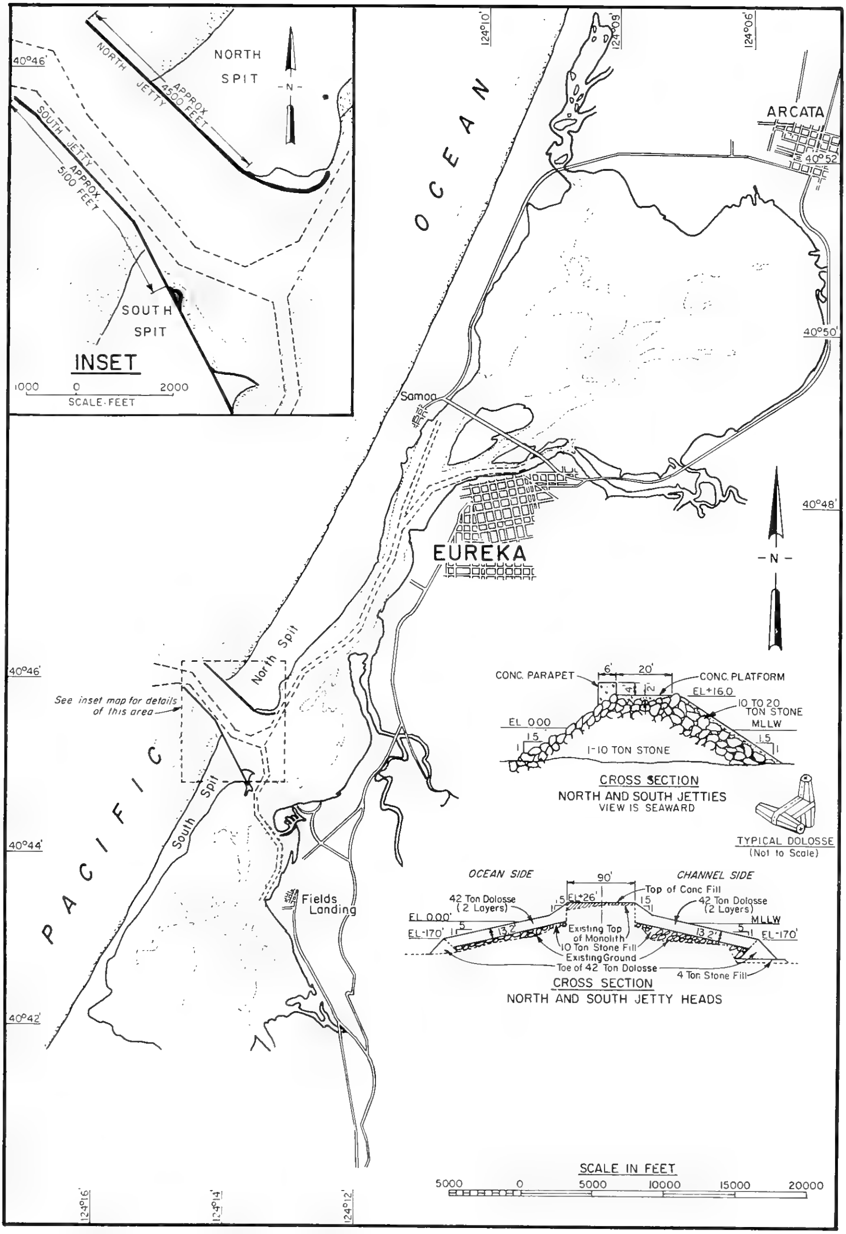

Figure 6. Humboldt Harbor and Bay, California

Table 3

Noyo Jetties

Noyo River and Harbor, California

Date(s)	Construction and Rehabilitation History
1924	Construction of two jetties across a sand bar was completed at the mouth of Noyo River. These were rubble-mound structures spaced approximately 125 ft apart. The initial lengths of the north and south jetties were 648 and 110 ft, respectively.
1931	Work at the Noyo River entrance, which included dredging, rock removal, and reconstruction of the jetties, was completed. The jetties were constructed to their present lengths (Figure 7). The north jetty was constructed of mass concrete. It was 345 ft long and connected to a 620-ft-long concrete wall. The south jetty was constructed 234 ft long with concrete. Both structures had crest els of +14 ft mllw.
1945	A 1,100-ft-long outer rubble-mound south breakwater was authorized (Figure 7). This structure has not been constructed.
1954	Stone (10-ton) was added to the seaward side of the north breakwater (Figures 7 and 8).
1961	Minor rehabilitation of the jetties and north wall was completed.
1962	A 500-ft-long outer rubble-mound north breakwater was authorized (Figure 7). This structure has not been constructed.
1970	The two outer breakwaters authorized by the Acts of 1945 and 1962 were reclassified from an active to inactive category. They were not economically feasible because of the high cost of construction and maintenance. Model testing of the structures was conducted (Wilson 1967).
1983	Restoration of the north jetty head was completed. Materials used consisted of approximately 2,500 tons of capstone, 10 cu yd of concrete, 1,500 cu yd of sandfill, and 4,100 tons of quarrystone fill.
1986	The jetties are presently in good condition. Model testing currently is being conducted to optimize the location of a structure in the immediate area of the River entrance (Bottin, in preparation).

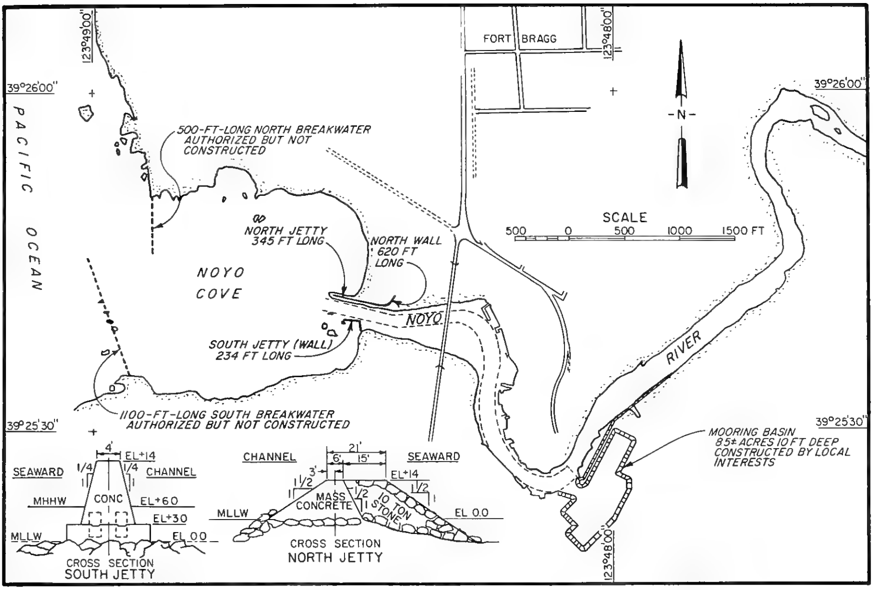

Figure 7. Noyo River and Harbor, California

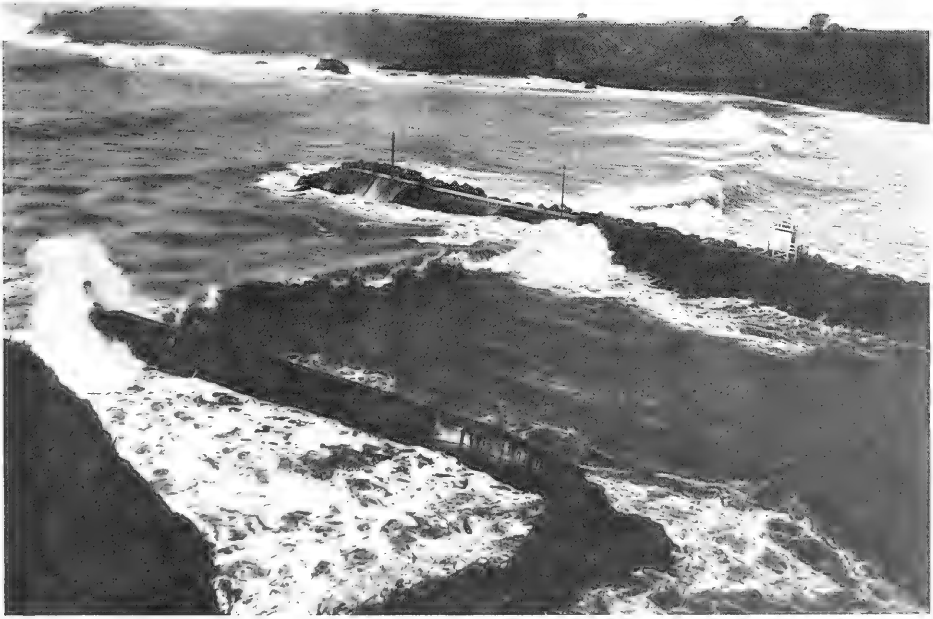

Figure 8. View of the jetties at Noyo River entrance

Table 4

Bodega Harbor Jetties

Bodega Bay, California

Date(s)	Construction and Rehabilitation History
1943	The initial construction of the north and south jetties was completed at the site (Figure 9). The north and south jetties were rubble-mound structures with lengths of 1,130 and 1,650 ft, respectively, with crest els of +12 ft mllw and 1V:1.5H side slopes.
1961	Rehabilitation of the channels and south jetty was completed for a cost of $399,800. Stone was added to the seaward side of the jetty between sta 14+00 and 16+00. The side slope of the structure over this 200-ft length was changed to 1V:2H.
1985	A 1,268-ft-long baffled-concrete pile breakwater was constructed by local interests in the northern portion of Bodega Harbor (Figure 9) to protect small craft moored there from damages resulting from wave action. The breakwater was approved for maintenance by the CE in November.
1986	The structures presently are in satisfactory condition.

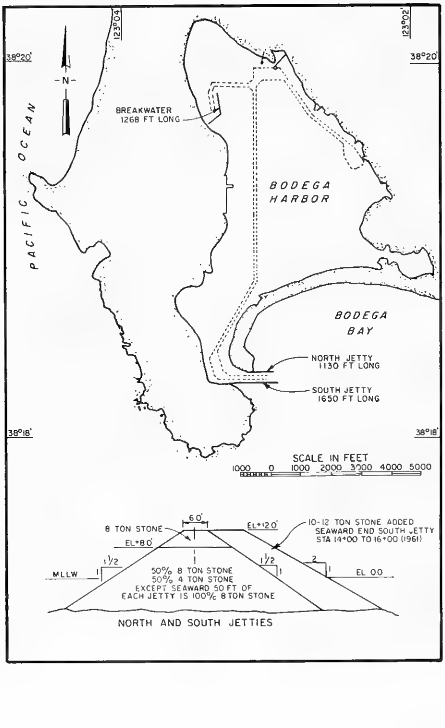

Figure 9. Bodega Harbor, California

Table 5

Richmond Harbor Breakwater

Richmond Harbor, San Francisco Bay, California

Date(s)	Construction and Rehabilitation History
1923-1931	Construction of a 10,000-ft-long breakwater (also referred to as a training wall) was completed (Figure 10) during this time frame. The seaward 3,000-ft-long portion of the breakwater had a 10-ft crest width and a 10-ft mllw crest el. Side slopes were 1V:1.5H. The remaining portion of the breakwater entailed a 10-ft mllw crest el and a 4-ft crest width. Side slopes were 1V:2H on the bay side and 1V:1.5H on the channel side.
1967	Rehabilitation of the breakwater was performed. The extent of the work is not known, however.
1985	The breakwater again underwent repairs and is considered to be in good condition.

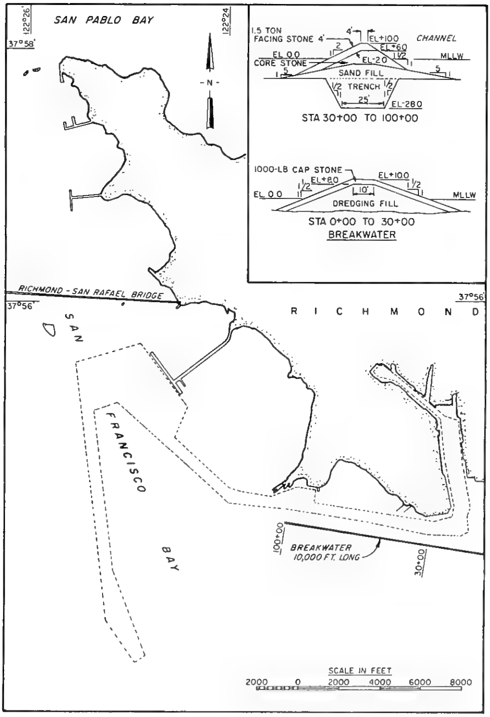

Figure 10. Richmond Harbor, San Francisco Bay, California

Table 6

Berkeley Marina Breakwater

Berkeley Marina, San Francisco Bay, California

Date(s)	Construction and Rehabilitation History
1936	The existing small-craft harbor was constructed from dredged fill and solid waste disposal under a Federal Public Works Administration Program. The harbor entrance was approximately 300 ft wide.
1965	A 725-ft-long detached rubble-mound breakwater (Figure 11) was constructed by the CE bayward of the harbor entrance to protect it from ocean swells from west-southwest. The crest el of the structure was +13 ft mllw, and it was constructed with side slopes of 1V:1.5H. Construction costs were approximately $311,000.
1975	Waves, up to 5 ft in height from west-northwest, entered the harbor and caused extensive damages to the berthing facility and small craft moored there. Prior to this date, waves from this direction had resulted in damages in the harbor on several occasions.
1980	Construction of a 440-ft-long concrete sheet-pile breakwater was completed (Figure 11). The structure's crest was installed at an el of +15 ft mllw.
1986	No maintenance or repairs have been required since breakwater construction, and the structures are in good condition.

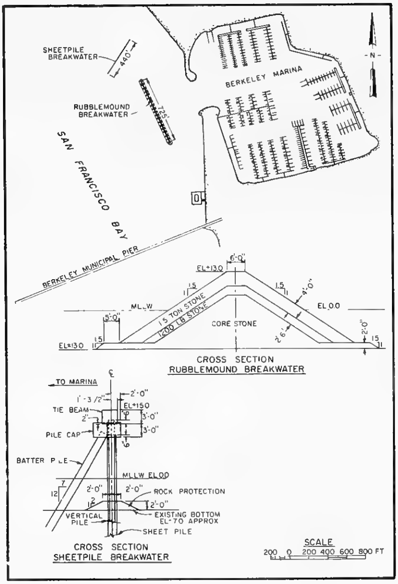

Figure 11. Berkeley Marina, San Francisco Bay, California

Table 7

Oakland Harbor Jetties

Oakland Harbor, San Francisco Bay, California

Date(s)	Construction and Rehabilitation History
1921-1927	Construction of a 9,500-ft-long north jetty and a 12,000-ft-long south jetty was completed (Figure 12) during this period of time. The jetties were constructed of stone.
1962	Maintenance of the structures along with maintenance dredging was adopted by the Corps of Engineers as authorized by the River and Harbor Act of 1962.
1986	Over the years the shore has been extended bayward on the outside of both jetties, and they function similar to revetments or absorbers. There are no records of maintenance to the jetties, and they are assumed to be in fair condition.

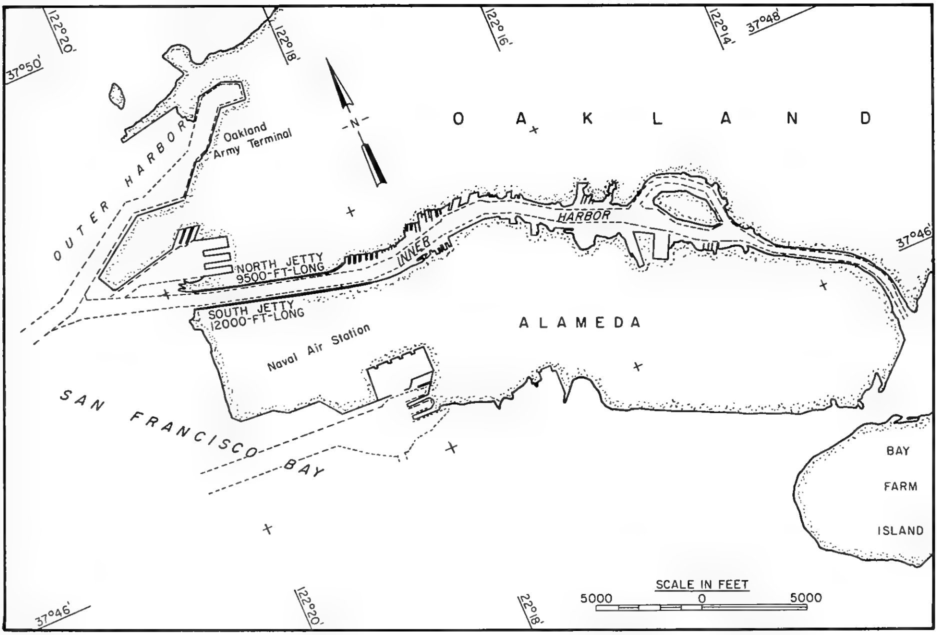

Figure 12. Oakland Harbor, San Francisco Bay, California

Table 8

San Leandro Marina Breakwater

San Leandro Marina, San Francisco Bay, California

Date(s)	Construction and Rehabilitation History
1963	Construction of the Marina by dredging and landfill operations was completed by the City of San Leandro.
1966	The City completed construction of a 750-ft-long dredged material breakwater. It was composed of stiff clays dug from the adjacent channel during dredging and had a crest el of +13 ft mllw. After construction the breakwater eroded, and gaps were filled periodically with dredged material as a temporary solution.
1977	The CE completed improvements to the breakwater which consisted of shaping the mud island and placing riprap protection. The finished structure was 700 ft long with a crest el of +12 ft mllw and side slopes of 1V:4H (Figure 13). The breakwater was designed to withstand breaking waves of 4 ft. Cost of the improvements was $348,579. After construction, top soil was placed on the structure, and lost vegetation was replaced to restore wildlife.
1986	There is no record of maintenance or repairs subsequent to Federal improvements, and the structure is in good condition.

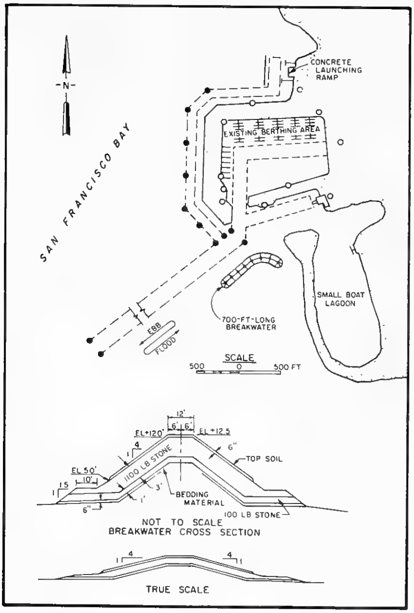

Figure 13. San Leandro Marina, San Francisco Bay, California

Table 9

Fisherman's Wharf Breakwaters

Fisherman's Wharf Harbor, San Francisco Bay, California

Date(s)	Construction and Rehabilitation History
1985-1986	Construction of a 1,509-ft-long solid, concrete-pile breakwater (Figure 14) was completed. In addition, two segmented breakwaters (28-ft solid walls with 6-ft openings) were constructed. These structures were 150 and 258 ft long and were built along Pier 45 (Figure 14). The solid sections of the segmented breakwaters also were constructed with precast concrete piles. The crest el of all three breakwaters was +12 ft mllw. The segmented structures were constructed to provide wave protection against storm waves from northeast and east-northeast and yet permit tidal currents to pass through for flushing of the harbor. The structures were model tested (Bottin, Sargent, Mize 1985) prior to construction.

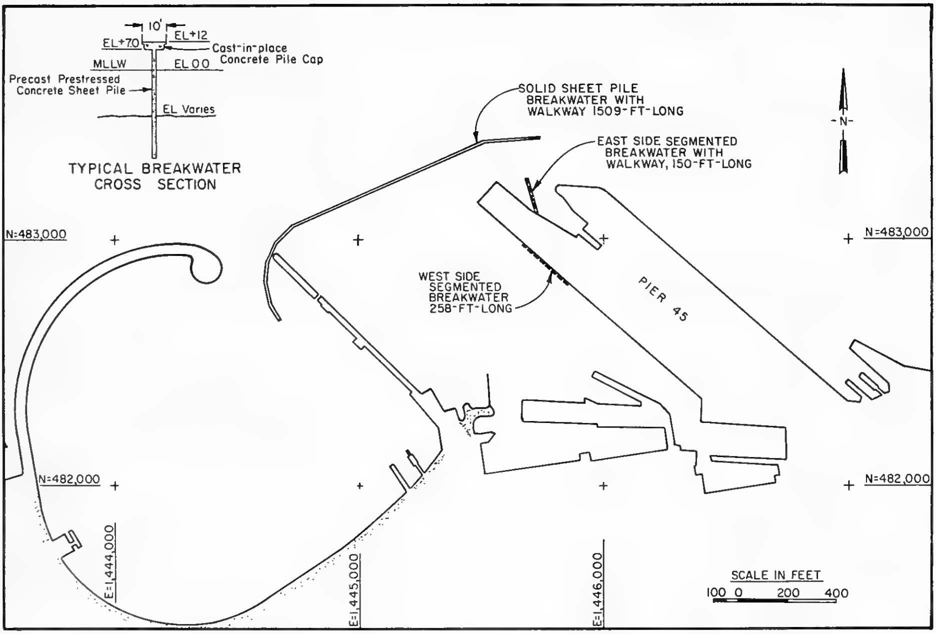

Figure 14. Fisherman's Wharf Harbor, San Francisco Bay, California

Table 10

Gas House Cove Breakwater

Gas House Cove, San Francisco Bay, California

Date(s)	Construction and Rehabilitation History
1965	Construction of the harbor was completed by the City of San Francisco. Two concrete sheet-pile breakwaters (Figure 15), totaling 840 ft in length, initially were constructed by the City. Boat owners immediately complained of excessive wave action and damage to boats and marine facilities resulting from waves entering the basin from the west through the gap in the existing breakwaters and reflecting within the harbor off the vertical walls of Mason Pier.
1975	The CE completed construction of a 117-ft-long concrete sheet-pile breakwater between and joining the two existing breakwaters. The crest el of the structure was +12.7 ft mllw, and the cost of the project was $334,090.
1986	There is no record of maintenance or repairs since construction of the breakwater. The structure is in good condition.

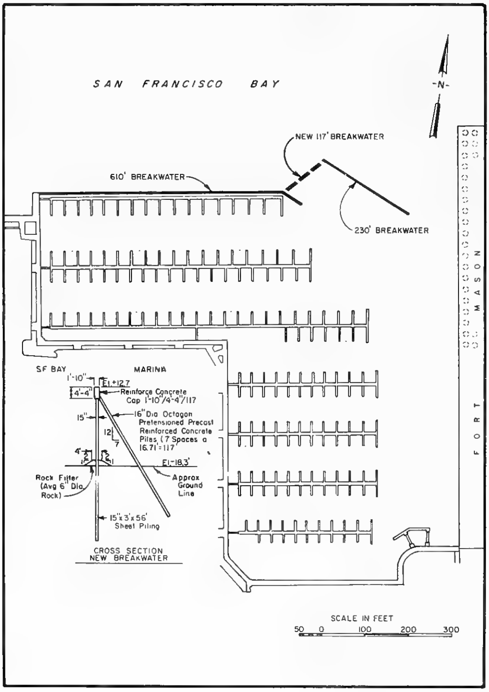

Figure 15. Gas House Cove, San Francisco Bay, California

Table 11

Halfmoon Bay Breakwaters

Halfmoon Bay, California

Date(s)	Construction and Rehabilitation History
1961	The CE completed construction of two rubble-mound, shore-connected breakwaters to protect the harbor during severe storms (Figure 16). The west breakwater was 2,620 ft long, and the east breakwater 4,420 ft long. The crest of each structure varied from +11 to +13 ft mllw with side slopes of 1V:1.5H and 1V:1.75H (Figure 13). The cost of the project was $4,840,000.
1961-1964	Storms experienced subsequent to breakwater construction indicated they did not provide adequate protection during periods of heavy seas and swell. Between 1961 and 1964, 58 moored vessels were lost or damaged, various marina facilities suffered damages, and two lives were lost during storm conditions.
1967	A 1,050-ft-long extension of the west breakwater in an easterly direction (Figure 16) was completed to alleviate undesirable wave conditions in the harbor (Wilson 1965). The breakwater extension was constructed with a crest el varying from +13 to +15 ft mllw. The side slopes on the harbor side of the structure were 1V:1.5H with 1V:1.75H side slopes on the sea side for the first 900 ft. The side slopes on the head varied from 1V:1.5H to 1V:2.25H. The cost of the extension was approximately $1,957,400.
1986	A condition survey of the navigational facilities presently is under way.

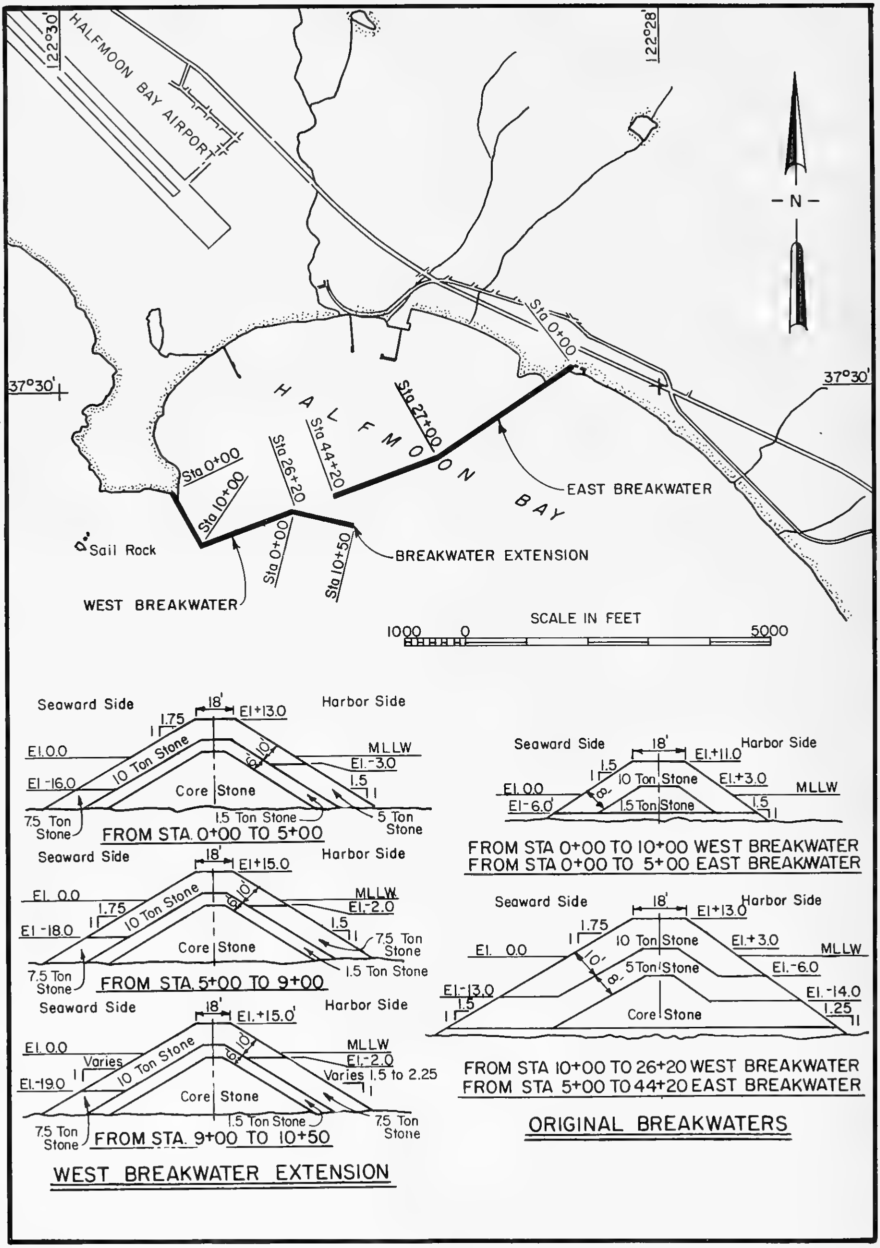

Figure 16. Halfmoon Bay, California

Table 12

Santa Cruz Jetties

Santa Cruz Harbor, California

Date(s)	Construction and Rehabilitation History
1963	Construction of two rubble-mound jetties at the site (Figure 17) was completed along with dredging of channels and a turning basin. The east and west jetties were 850 and 1,125 ft long, respectively, with crest els ranging from +12 ft to +16 ft mllw. Side slopes were 1V:1.5H on the channel side and 1V:2H on the bay side of the jetties. Both structures were rubble mound with 3- to 15-ton armor stone. The outer half of the west jetty on the bay side is protected by two layers of 25-ton quadripods. An aerial photograph of the jetties is shown in Figure 18.
1983	The west jetty was sealed in an effort to minimize shoaling in the channel. This sealing was not very effective, and dredging requirements were excessive following storms of 1983. A fixed sand bypassing plant has subsequently been authorized and constructed. The Santa Cruz Harbor District and the CE purchased (through cost sharing) a dredge to maintain the harbor entrance. The Harbor District is now responsible for maintenance dredging.
1986	The jetties are in good condition, and there are no records of jetty maintenance since their construction.

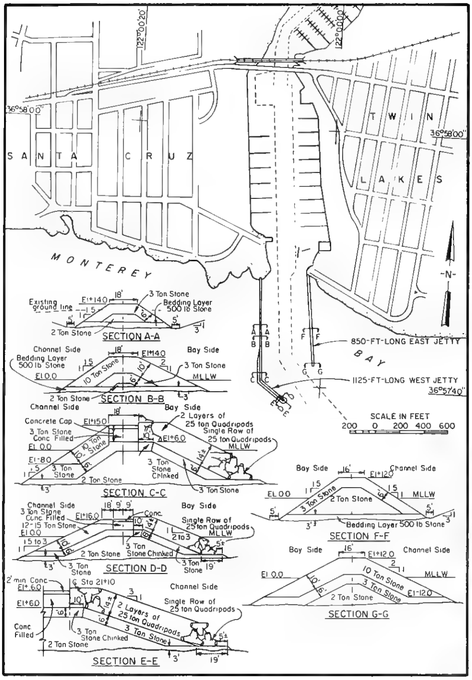

Figure 17. Santa Cruz Harbor, California

Figure 18. Aerial view of Santa Cruz Harbor jetties

Table 13

Moss Landing Jetties

Moss Landing Harbor, California

Date(s)	Construction and Rehabilitation History
1947	Construction of protective jetties at the site was completed to stabilize the entrance (Figure 19). The north and south jetties are 900- and 330-ft long, respectively, and are roughly parallel. Crest els of the jetties range from +8 ft to +12 ft mllw, and side slopes vary from 1V:1.5H to 1V:1.75H. During project construction severe storms resulted in scouring and deep cutting of the sand adjacent to the jetties. Emergency stone placement was undertaken along the south jetty from the shore to a point 320 ft seaward. Stone protection for the north jetty was placed throughout its 900-ft length, and additional placement was made along the north and south shorelines of the jetties. A total of 47,946 tons of stone was required for this work.
1949	To add permanence to the emergency work of 1947, additional armor stone was placed on the previous enrockment. This effort required a total of 24,625 tons of stone.
1949-1965	Severe erosion around the jetties and the unprotected shorelines adjacent to them was experienced during this time frame.
1966-1967	Approximately 285 ft of the north jetty and the entire length of the south jetty were repaired. Also about 280 ft of curved revetment work was added to the north jetty and about 380 ft added to the south jetty. This work required the placement of 77,560 tons of stone. The north jetty head was not repaired because of the movement of the canyon head and the possibility that damage may occur to any repairs in that vicinity.
1975	A field inspection revealed the jetties in satisfactory condition except for damage on the seaward ends due to erosion and subsequent stone displacement. The deep submarine canyon head at the seaward end of the north jetty appeared to have stabilized.
1976	A basis for design of repairs to the jetties and revetment was prepared. Estimated cost of these repairs was $290,000, and approximately 7,400 tons of stone would be required.
1986	Work is still required at the jetty heads. Except for the erosion at these locations, the jetties historically have performed satisfactorily and suffered relatively minor damages.

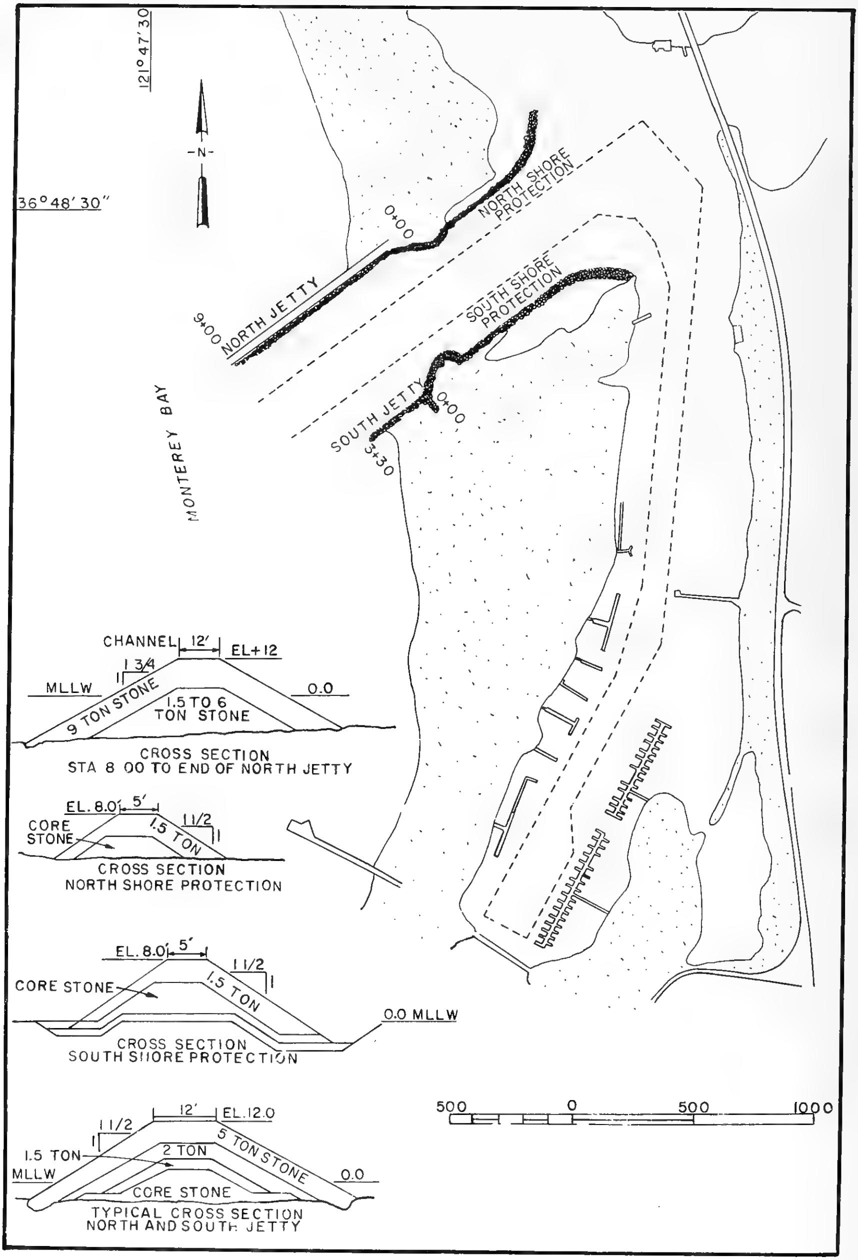

Figure 19. Moss Landing Harbor, California

Table 14

Monterey Breakwater

Monterey Harbor, California

Date(s)	Construction and Rehabilitation History
1932	The construction of a 1,300-ft-long rubble-mound breakwater was completed (Figure 20). The crest el of the structure was +10 ft mllw, and the side slopes were 1V:1H on the harbor side and 1V:1.5H on the ocean side. The armor stones used weighed 10 tons each.
1934	A 400-ft rubble-mound extension to the breakwater was built under the Public Works Administration Program (Figure 20). The extension was constructed with a crest el of +10 ft and with 1V:1H side slopes on the harbor side. Side slopes on the ocean side were 1V:1.25H from the existing ground to el -16 ft mllw and 1V:1.5H from el -16 to +10 ft mllw. Armor stones used ranged from 4 to 12 tons. Total cost of the breakwater through 1934 was $652,951.
1960	Improvements consisting of a 3,300-ft-long north breakwater and a 1,100-ft-long east breakwater (Figure 20) were authorized. These structures were never constructed; however, model tests were conducted to optimize the improvements (Chatham 1968).
1969	Model tests for a proposed tribar breakwater section were conducted (Davidson 1969).
1974	The project authorized in 1960 was reclassified as inactive due to lack of local support.
1986	There is no history of maintenance of the breakwater, and it is in satisfactory condition.

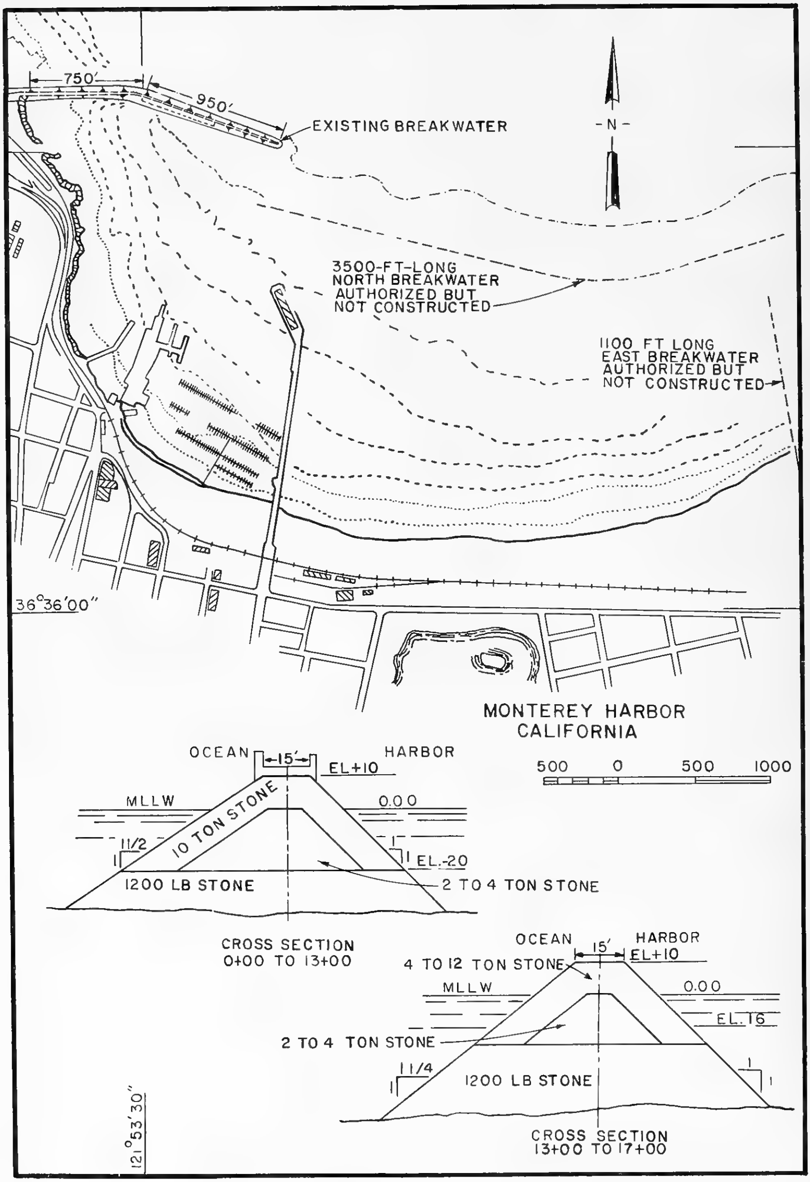

Figure 20. Monterey Harbor, California

Table 15

Morro Bay Breakwaters

Morro Bay Harbor, California

Date(s)	Construction and Rehabilitation History
1942 1943	A 1,000-ft-long north breakwater was constructed, and a 1,832-ft-long south breakwater was completed at the site (Figure 21) to serve as a base for naval patrol craft. The structures were rubble-mound and built at an el of +16 ft mllw with 1V:1.5H side slopes and a crest width of 16 ft.
1943- 1944	Storm waves during this period damaged the north breakwater. The south breakwater received no appreciable damage.
1945	The north breakwater was repaired and extended to 1,800 ft in length. This work also included widening the crest from 16 to 20 ft. The project was adopted and completed under the supervision of the CE using funds provided by the US Navy.
1946	The north breakwater again suffered damage from storm waves.
1948	Maintenance work was performed on the north breakwater. Damaged sections of the structure were restored, and the cap was bound with concrete across the crest to an el of -2 ft mllw on both sides.
1949- 1960	The north breakwater continued to deteriorate, and shoaling occurred in the channels. The south breakwater still had suffered no observable damage since its construction in 1943.
1964	The north breakwater was reconstructed at a cost of $1,561,882. The new rubble-mound structure was built at an el of +18 ft mllw, with a 20-ft-wide crest and 1V:2.5H side slopes. The structure was rebuilt about 100 ft bayward of the original north breakwater location and extended to 1,885 ft in length (Figure 21). The breakwater included larger armor stone than the original structure. Also included was a concrete monolithic breakwater head. Model tests were conducted (Jackson 1961).
1983	Major storms resulted in approximately $1,430,000 in damages to the breakwaters.
1985	Maintenance repair of the north and south breakwaters was completed which included the placement of approximately 18,000 tons of capstone. Capstones ranged in weight from 6-21 tons each.
1986	The structures presently are in good condition.

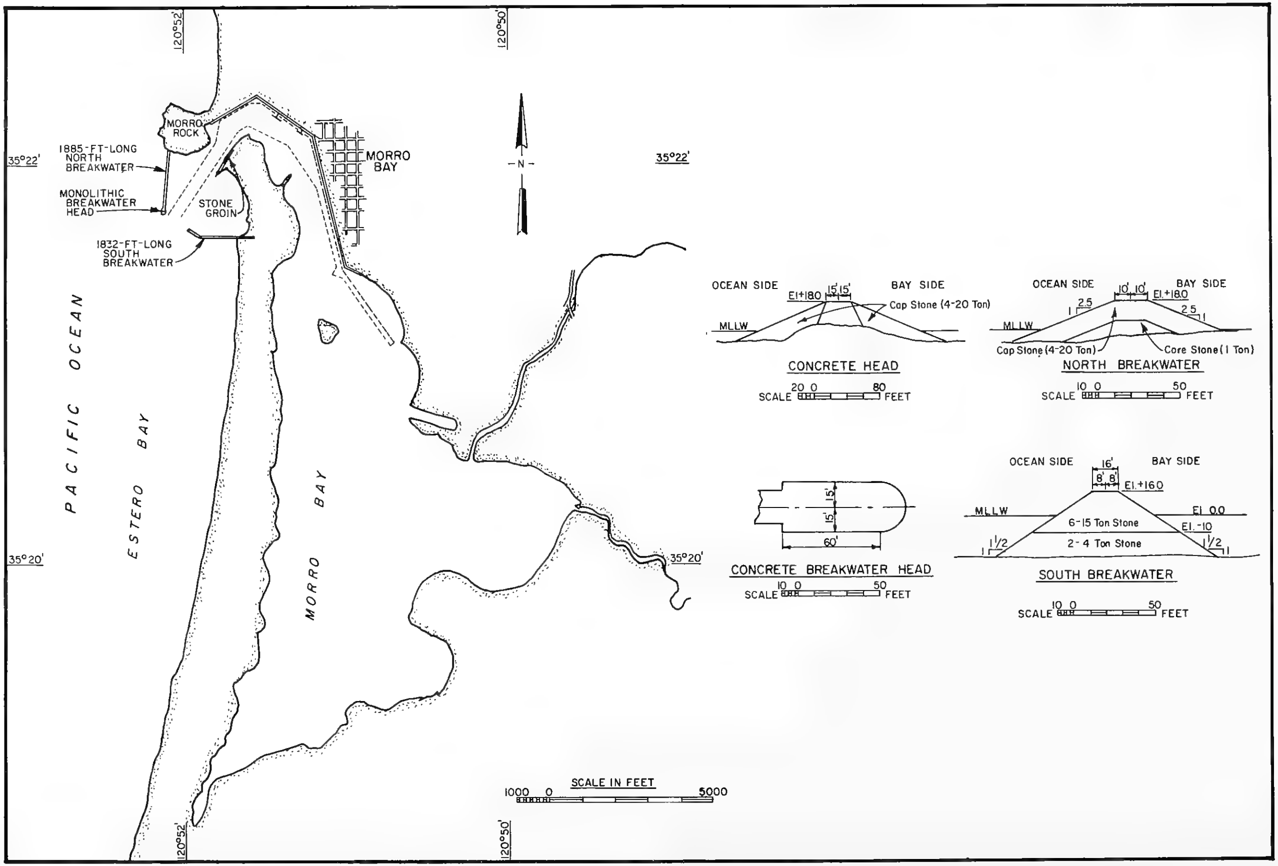

Figure 21. Morro Bay Harbor, California

Table 16

Port San Luis Breakwater

Port San Luis, California

Date(s)	Construction and Rehabilitation History
1888-1913	Construction of a rubble-mound breakwater, approximately 2,400 ft long, was completed at the site (Figure 22) during this time frame. The crest el of the structure varies from +14 ft to +18 ft mllw with a 14-ft width. The side slopes are 1V:1.5H on the ocean side and 1V:1.25H on the harbor side.
1924	The structure was breached in a zone about 300 ft seaward of Whalers Island (Figure 22) by storm waves.
1927	The breach formed in 1924 was filled with a concrete cap.
1931	The concrete cap placed in 1927 was washed away because of storm wave activity. Also, the head of the breakwater was damaged.
1935	Repairs were made to damaged areas of the structure. The slopes in the damaged zones were covered with 14-ton stones to els of -10 to -15 ft mllw.
1976	Modification of the existing project was authorized. Included were a 750-ft-long south breakwater, a 3,615-ft-long detached breakwater, and dredging of associated channels and anchorage areas (Figure 22). These structures have not been constructed.
1983	Major storms resulted in approximately $578,000 in damages to the breakwater.
1984	Maintenance repair of the existing breakwater was completed which consisted of approximately 8,700 tons of capstone placement and resetting of 40 existing capstone. The crest width of the structure was increased to 20 ft. Plans and specifications for construction of the modified project (authorized in 1976) were about 80 percent complete.
1986	The breakwater currently is in satisfactory condition.

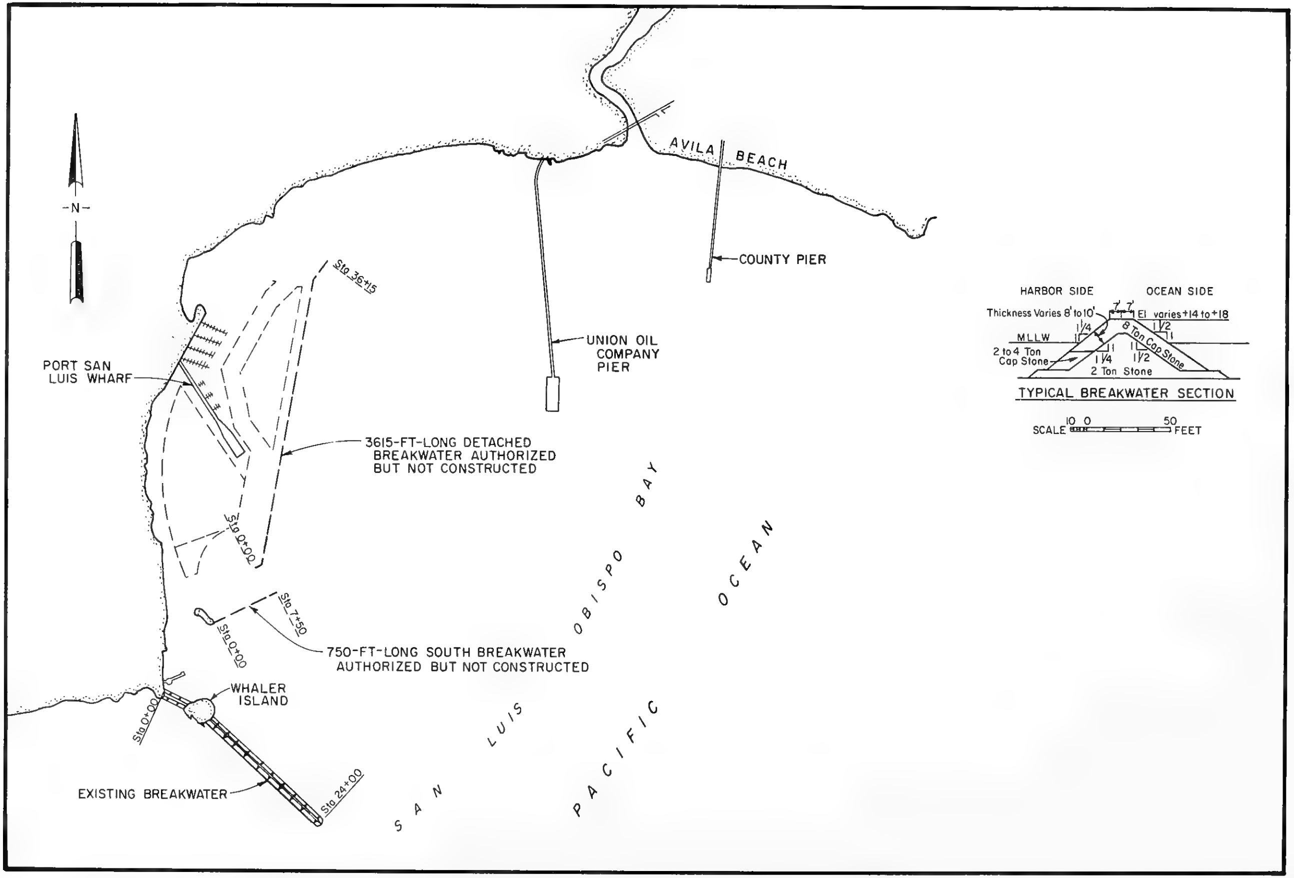

Figure 22. Port San Luis, California

Table 17

Santa Barbara Breakwaters

Santa Barbara Harbor, California

Date(s)	Construction and Rehabilitation History
1928	Construction of a 1,800-ft-long rubble-mound breakwater parallel to and about 600 ft from the shore was completed. The crest el of the structure was +12 ft mllw with side slopes of 1V:1.5H. Ten-ton stones were placed on the ocean side with 5-ton stones on the harbor side. The breakwater afforded protection from southwesterly waves; however, shoaling occurred in the lee of the breakwater.
1929	Navigational difficulties were experienced at the west end of the Harbor as a result of the shoal.
1930	The breakwater was extended to its present length of 2,365 ft and connected to shore. An 18-ft-wide concrete walkway was installed along the crest of the structure. After construction, sediment migrated around the breakwater and deposited in the lee of the eastern end forming a spit that encroached on the channel. Maintenance dredging was initiated.
1962	Modification of the existing project was authorized and included a 500-ft-long west breakwater extension, a 1,600-ft-long detached breakwater, a 2,500-ft-long east breakwater, and dredging of associated channels, basins, etc. (Figure 23). Construction of the modification has not been initiated, although it has been model tested (Brasfeild and Ball 1967).
1969	Modification of the existing project was reclassified to an inactive category.
1986	The structure presently is in satisfactory condition.

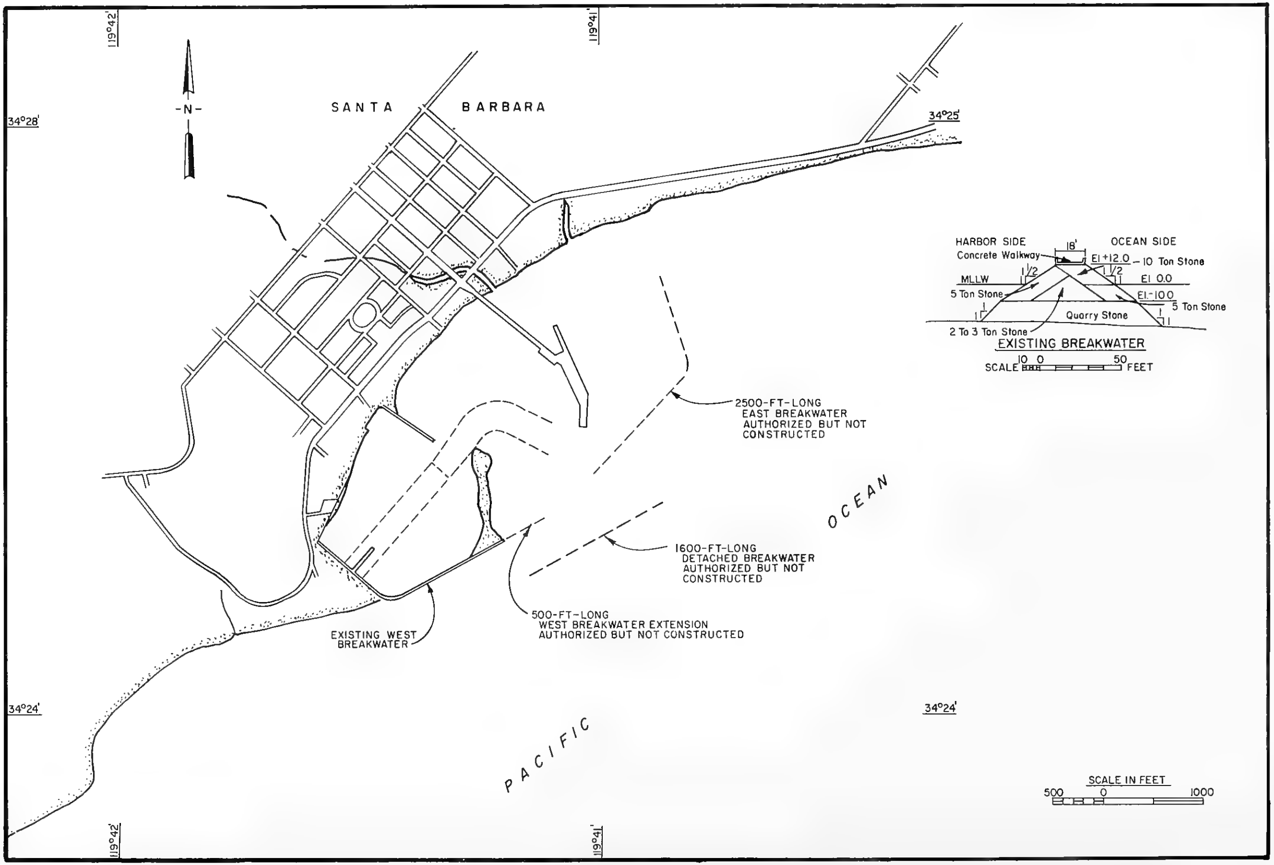

Figure 23. Santa Barbara, California

Table 18

Ventura Marina Structures

Ventura Marina, California

Date(s)	Construction and Rehabilitation History
1963	Construction of the marina was completed by local interests. Structures included a 1,254-ft-long north jetty, a 1,071-ft-long south jetty, and a 250-ft-long middle jetty (Figure 24). The north and south jetties were constructed with a crest el of +20 ft mllw and a crest width of 15 ft with 1V:1.5H side slopes. The ocean side of these jetties was armored with a single, uniform layer of 10.68-ton tribars. The middle jetty had a crest width of 24 ft with varying els and 1V:1.5H side slopes.
1968	A 1,500-ft-long detached rubble-mound breakwater and dredging of a sand trap were authorized. Also, the authorization plan provided for the US to maintain the existing jetties and channels previously constructed by local interests.
1971	Minor repairs were completed at the head of the north jetty. The repairs consisted of resetting displaced and broken tribars on the seaward end of the jetty and reshaping the jetty head with 3-ton stone.
1972	Construction of the 1,500-ft-long offshore rubble-mound breakwater authorized in 1968 was completed (Figure 24). The structure had a 16-ft-wide crest with an el of +20 ft mllw. Side slopes were 1V:1.25H on the harbor side and 1V:2.25H on the ocean side.
1986	The structures currently are in good condition.

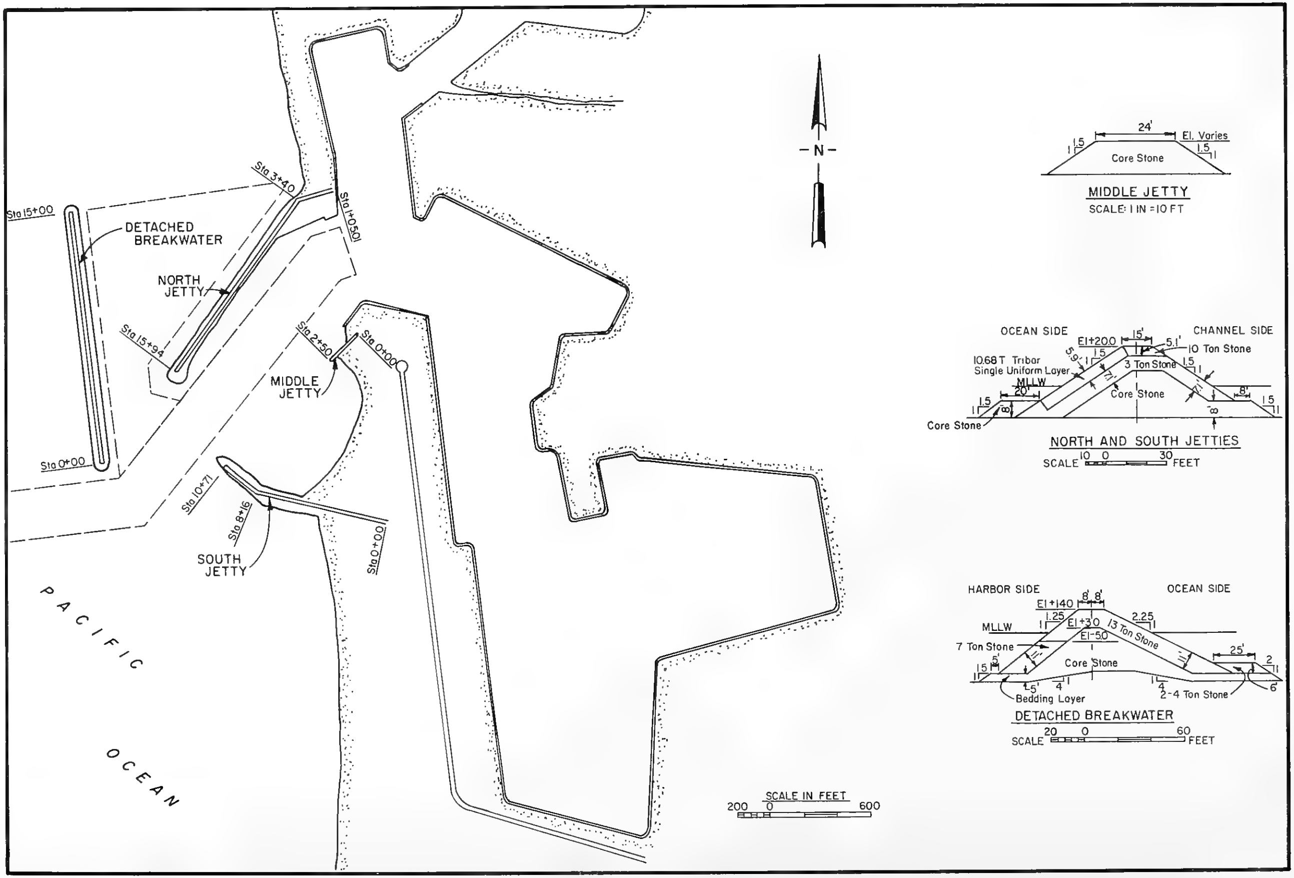

Figure 24. Ventura Marina, California

Table 19

Channel Islands Structures

Channel Islands Harbor, California

Date(s)	Construction and Rehabilitation History
1959	Construction of two rubble-mound jetties was completed at the harbor entrance (Figure 25). The north jetty was 1,270 ft long, and the south jetty was 1,300 ft long. Crest els of the jetties were +14 ft mllw with 16-ft crest widths. Side slopes were 1V:1.5H. Cost of jetty construction was $817,000.
1960	Construction of a 2,300-ft-long detached rubble-mound breakwater was completed for a cost of $2,619,000. The crest el of the breakwater was +14 ft mllw, and it had a 16-ft width. Side slopes were 1V:1.25H on the harbor side and 1V:2H on the ocean side. This structure was constructed to form a sand trap in conjunction with the existing jetties. Initially, 1,600,000 cu yd of material was dredged in the lee of the breakwater and then biennially for deposit south of the harbor entrance for use in restoring and maintaining the downcoast shoreline.
1986	The structures are in good condition.

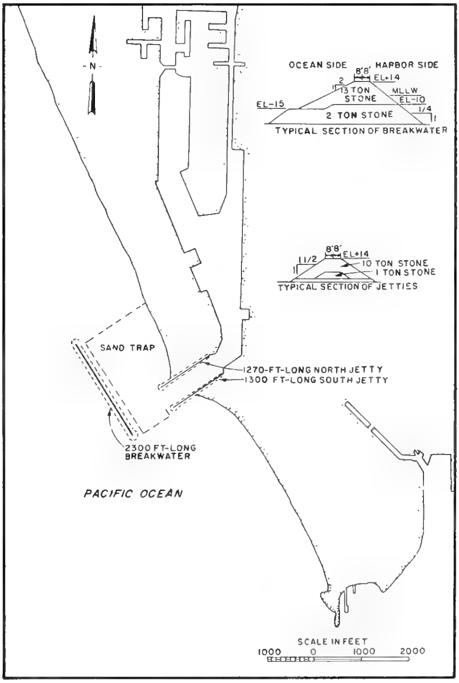

Figure 25. Channel Islands Harbor, California

Table 20

Port Hueneme Jetties

Port Hueneme, California

Date(s)	Construction and Rehabilitation History
1939-1940	Construction of the harbor along with two jetties (Figure 26) was completed by the Oxnard Harbor District for a cost of $1,750,000. The east and west jetties were constructed entirely of stone to lengths of 1,000 ft and 800 ft, respectively.
1968	The existing project (including the jetties) was adopted as a Federal (civil works) project, and deepening and expansion of the harbor was authorized. Therefore, the CE assumed maintenance of the project.
1986	The jetties presently are in satisfactory condition.

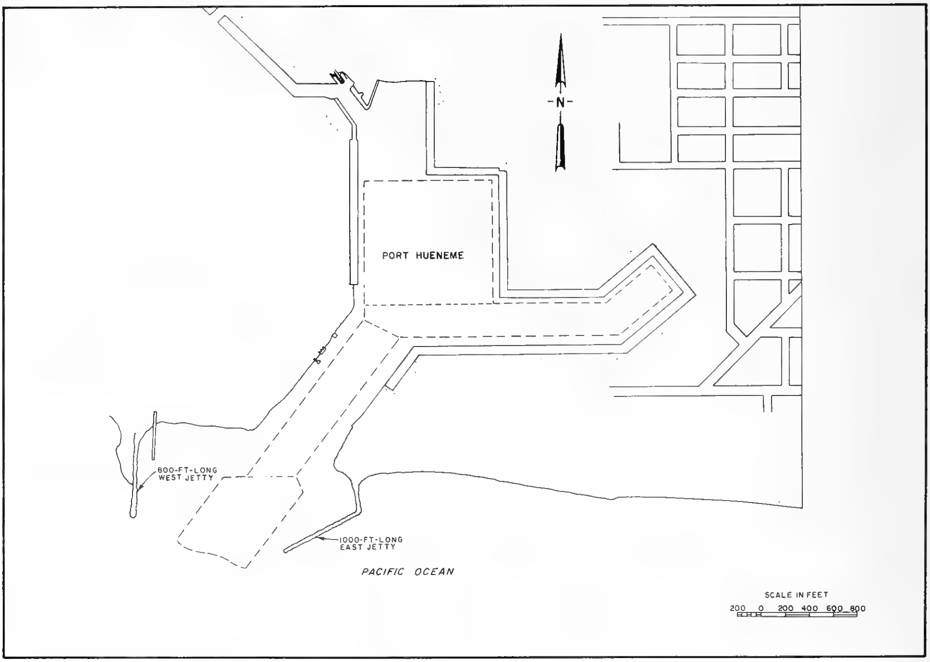

Figure 26. Port Hueneme, California

Table 21

Marina Del Rey Structures

Marina Del Rey, California

Date(s)	Construction and Rehabilitation History
1965	Construction of a rubble-mound breakwater and two rubble-mound jetties was completed at the site (Figure 27). The breakwater was 2,330 ft long with a crest el varying from +17 to +22 ft mllw. The crest was 16 ft wide, and side slopes were 1V:2H on the ocean side and 1V:1.25H on the harbor side. The existing Ballona Creek north jetty was extended 760 ft in length and became the marina south jetty, and a 2,000-ft-long north jetty was constructed. The crest els of the jetties were +14 ft mllw with a width of 16 ft. Side slopes were constructed 1V:2H. The breakwater was model tested (Brasfeild 1965) and was necessary to reduce waves entering the wide entrance channel and reflecting off the vertical concrete perimeter walls to an acceptable level.
1986	The structures presently are in satisfactory condition.

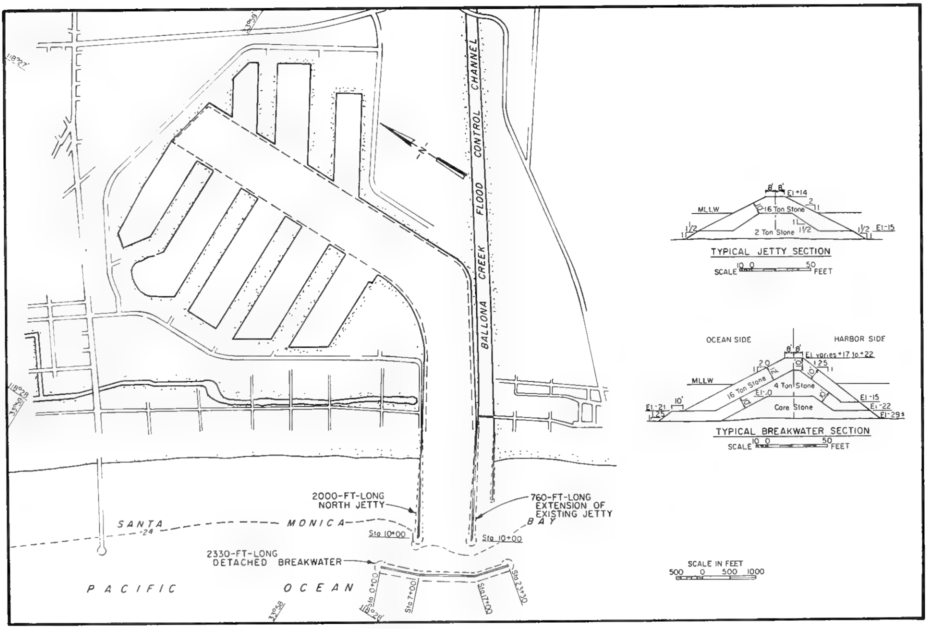

Figure 27. Marina Del Rey, California

Table 22

Redondo Beach Breakwaters

Redondo Beach King Harbor, California

Date(s)	Construction and Rehabilitation History
1938	Construction of a 4,285-ft-long permeable, rubble-mound breakwater (Figure 28) was completed.
1950	The breakwater became a Federal project, and improvements were authorized.
1958	Ten-ton capstones were placed on the ocean side of the breakwater on a 1V:2H slope, and the crest was raised to +14 ft mllw and increased to 16 ft in width. Thirteen-ton capstones were used on the breakwater between sta 36+00 and 52+00. A 600-ft-long south breakwater with a crest el of +14 ft was constructed. The structure has a 16-ft crest width, and side slopes were 1V:2H on the sea side and 1V:1.5H on the harbor side.
1960	Minor repairs to the north breakwater (from a storm in 1959) were completed.
1963	Storms demonstrated the inadequacy of the north breakwater for protecting small craft within the Harbor. While doing only minor damage to the breakwater, damage to small boats and Harbor facilities amounted to $431,000.
1964	The north breakwater (between sta 15+50 and 36+00) was modified. The structure crest el was raised to +22 ft mllw at this location. Stones, ranging from 2.5 to 10 tons, were placed on the harbor side of the breakwater on a slope of 1V:1.5H (Figure 28).
1978-1980	Storms of 1978 and 1980 resulted in damage to the north breakwater in nine areas with major voids occurring at sta 16+00 and 22+00.
1982	As a result of the damages in 1978 and 1980, the north breakwater was repaired at a cost of $304,000.
1983	Storms resulted in significant damage at several locations along the north breakwater. The most significant was a breach 70 ft long, just south of the curved portion. Repair work was completed, and approximately 5,300 tons of new capstone and 1,700 tons of corestone were utilized. At seven additional locations, about 4,000 tons of capstone were replaced. The repair work cost approximately $400,000.
1986	The breakwaters presently are in satisfactory condition.

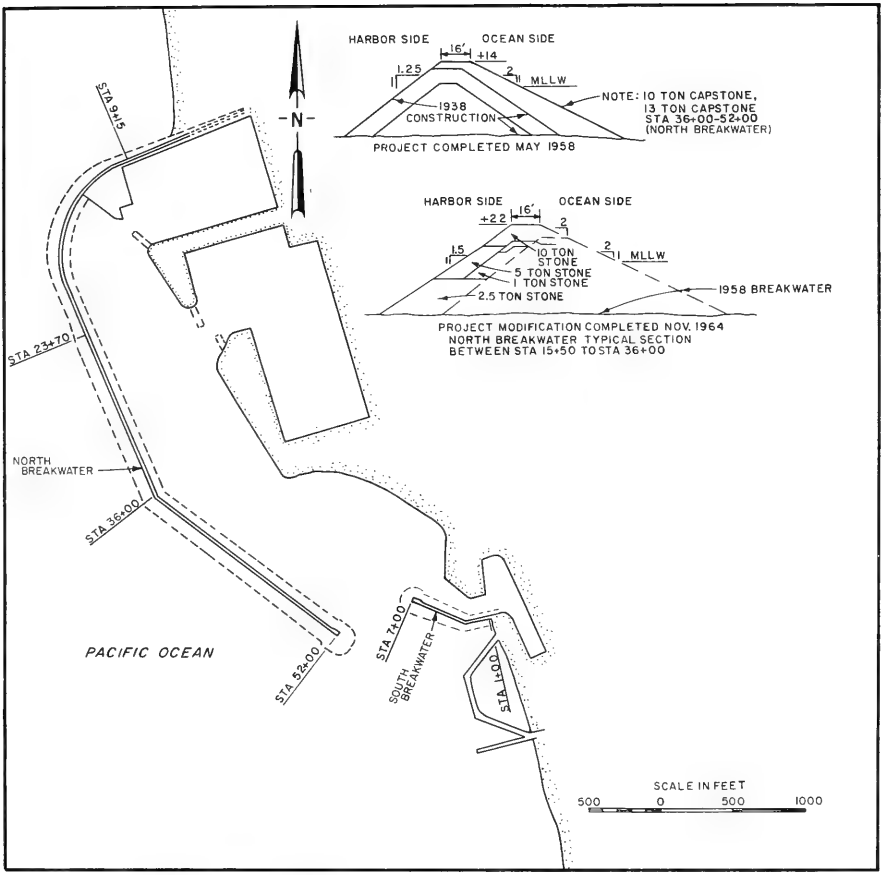

Figure 28. Redondo Beach King Harbor, California

Table 23

Los Angeles and Long Beach Breakwaters

Los Angeles and Long Beach Harbors, California

Date(s)	Construction and Rehabilitation History
1898-1910	Construction of the 11,152-ft-long San Pedro Breakwater occurred at the site (Figure 29). The harbor side of the structure was built with 1V:1.2H side slopes, while the ocean side consisted of 1V:1.2H slopes from the bottom up to an el of -12 ft mllw. At this point the slope changed to 1V:3H to an el of 0.0 ft mllw. The rubble-mound portion of the structure (Figure 30) was 47 ft wide at el 0.0 ft mllw. Granite blocks (up to 20 ton) were laid in courses to an el of +14 ft with a crest width of 20 ft. The rubble-mound portion of the structure was constructed with 8- to 10-ton stone and was permeable. Other structures, which are now incorporated into the inner harbor works, were constructed as early as 1871.
1930-1938	Construction of the 18,500-ft-long rubble-mound middle breakwater (Figure 29) was in progress. The breakwater had a 16-ft crest width at el +14 ft mllw. Side slopes on the ocean side were 1V:2H and on the harbor side ranged from 1V:1.25H to 1V:1.5H (Figure 30). An impermeable core was installed from the bottom (approximately -50 ft mllw) to el -26 ft mllw.
1942-1960	Construction of the 13,350-ft-long rubble-mound Long Beach Breakwater (Figure 29) occurred during this period. With the exception of the breakwater core el (Figure 30) the cross section of this structure was similar to that of the middle breakwater.
1947	Repairs to the middle breakwater were accomplished for a cost of $786,700.
1983	Winter storms resulted in extensive damage to the San Pedro Breakwater. The structure was breached in an area immediately seaward of the curved portion of the breakwater. Model tests were conducted after the damage (Carver 1984, Baumgartner, et al. 1986), and restoration of the San Pedro Breakwater was subsequently completed. Work consisted of the placement of approximately 25,000 tons of salvage stone and new angular stones ranging from 15 to 25 tons each. Where voids occurred on the crest after this stone placement, concrete was pumped into flexible temporary forms to complete the repair.
1986	The breakwaters presently are in good condition.

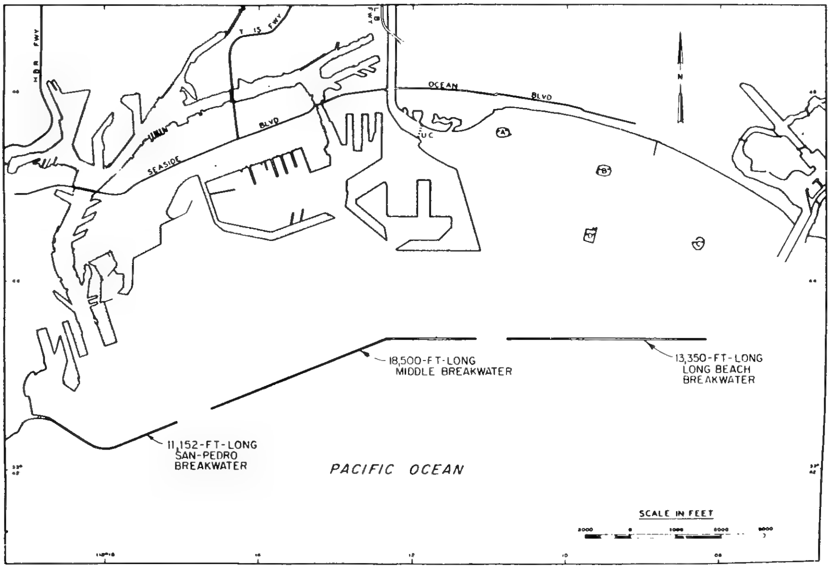

Figure 29. Los Angeles and Long Beach Harbors, California

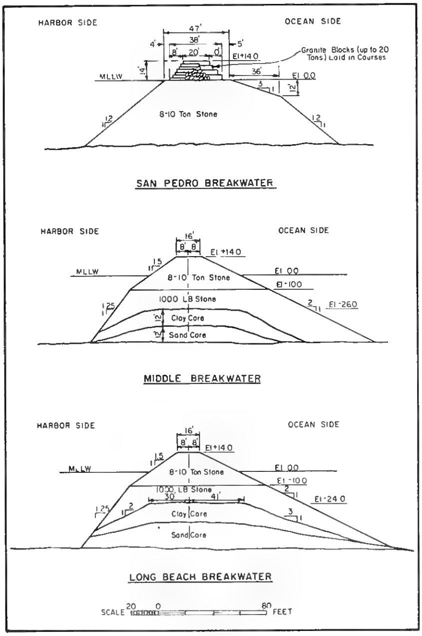

Figure 30. Breakwater cross sections, Los Angeles and Long Beach Harbors, California

Table 24

Newport Bay Jetties

Newport Bay Harbor, California

Date(s)	Construction and Rehabilitation History
1934	Construction of two rubble-mound jetties at the site (Figure 31) was completed. The west and east jetties were 2,860 ft long and 1,620 ft long, respectively. The el of the structures was +15 ft mllw, and the crest width was 15 ft. Side slopes of 1V:1.5H on both ocean and harbor sides were used.
1986	Throughout the years, local interests have provided minor maintenance to the jetties, the extent of which is unknown. The jetties presently are in satisfactory condition.

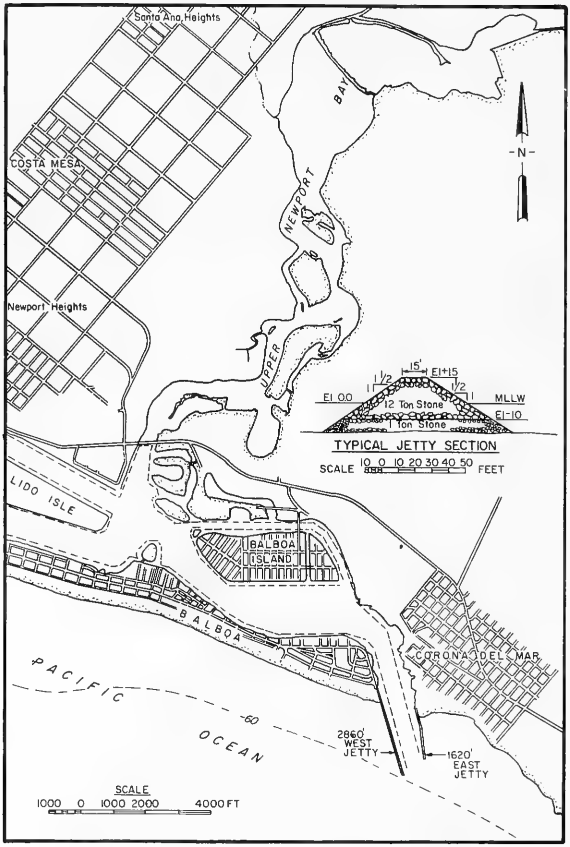

Figure 31. Newport Bay Harbor, California

Table 25

Dana Point Breakwaters

Dana Point Harbor, California

Date(s)	Construction and Rehabilitation History
1968	Construction of two rubble-mound breakwaters at the site (Figure 32) was completed. The west breakwater was 5,500 ft long with a 16-ft-wide crest at el of +18 ft mllw. The ocean side slope of the structure was 1V:2H, and the harbor side was 1V:1.25H. The east breakwater was 2,250 ft long with a 14-ft-wide crest width and a +14-ft el mllw. The ocean-side slope was 1V:1.5H, and the harbor-side slope was 1V:1.25H. Model tests were conducted for the project (Dai and Jackson 1966, Wilson 1966).
1983	Major storms resulted in approximately $610,000 in damages to the breakwater.
1984	Restoration of the west breakwater in nine locations was completed. About 5,800 tons of capstone were used for this maintenance repair.
1986	The breakwaters are in satisfactory condition.

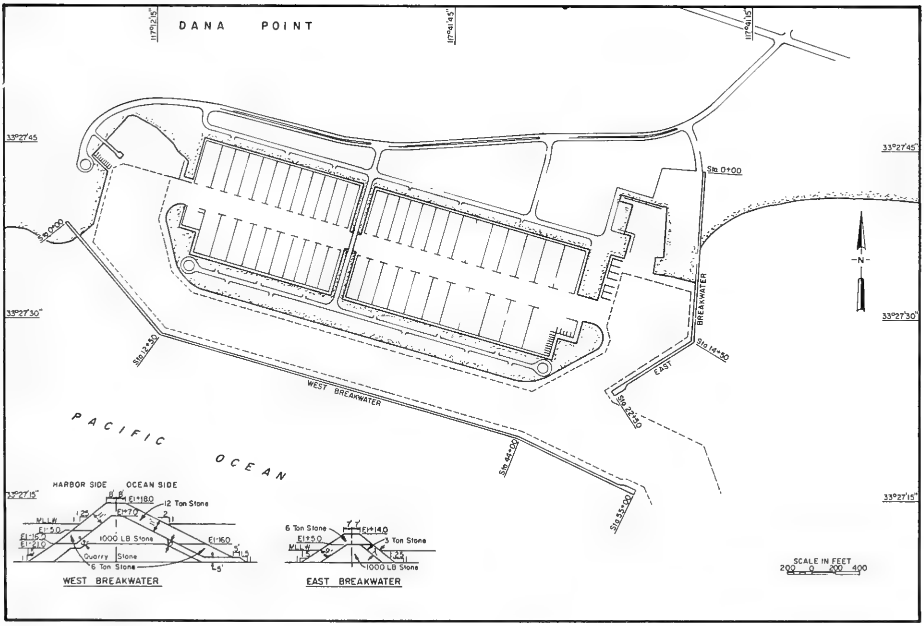

Figure 32. Dana Point Harbor, California

Table 26

Oceanside Jetties

Oceanside Harbor, California

Date(s)	Construction and Rehabilitation History
1958	Construction of the Del Mar Boat Basin (formerly Camp Pendleton Harbor) was completed by the US Navy. The north and south jetties at the basin entrance also were constructed and are maintained by the Navy.
1961	The construction of a 1,000-ft-long rubble-mound south jetty at the entrance to Oceanside Harbor (south of Del Mar Boat Basin) was completed (Figure 33). The jetty had a crest el of +14 ft mllw and a width of 18 ft. Side slopes were 1V:1.5H.
1968	Construction of a 350-ft-long rubble-mound extension to the south jetty was completed. In addition, the existing jetty was sealed from sta 3+70 to 12+10 in an effort to minimize shoaling of the entrance channel. Grout holes were drilled through the armor stone and penetrated the core by 1 to 2 ft. Grout then was pumped in the holes under pressure to seal the structure.
1986	The jetty is in satisfactory condition.

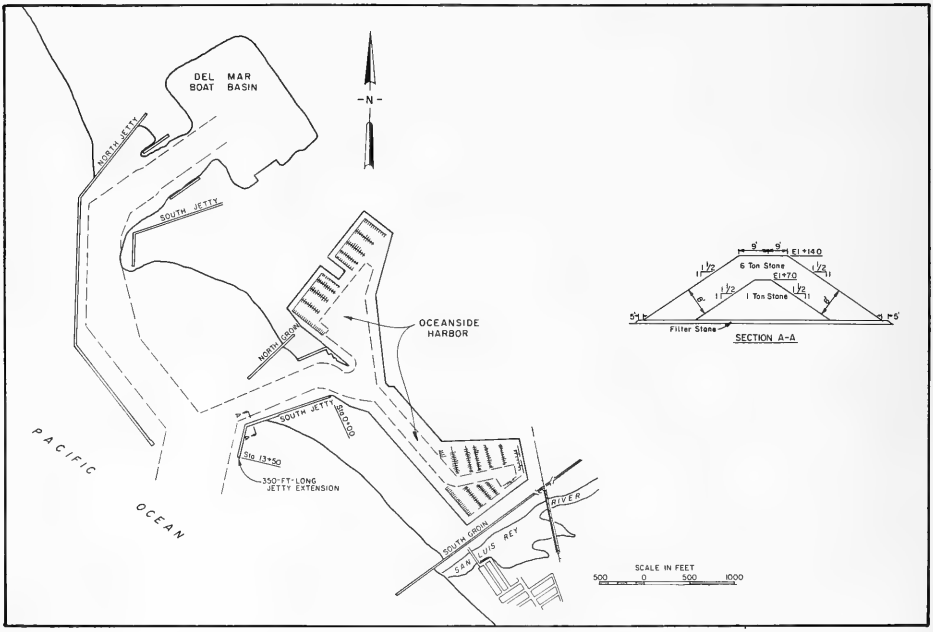

Figure 33. Oceanside Harbor, California

Table 27

Mission Bay Jetties

Mission Bay Harbor, California

Date(s)	Construction and Rehabilitation History
1949	Construction of three rubble-mound jetties at the site (Figure 34) was completed. These structures included a 3,300-ft-long north jetty, a 4,270-ft-long middle jetty, and a 950-ft-long south jetty. Typically, the jetties were built with a 16-ft-wide crest at an el of +14 ft mllw with side slopes of 1V:1.5H.
1955	Sediment from the littoral zone was noted passing through the north jetty into the entrance channel. Sealing stones (3,000 tons) were placed on the seaward slope of the jetty. This measure retarded the movement of sand but did not entirely stop infiltration.
1959	Approximately 1,300 ft of the middle jetty and 1,000 ft of the north jetty were sealed with grout to prevent the movement of sediment through the structures. The original core stone of the jetties was constructed at el 0.0 ft mllw. The intruded grout barrier was installed to el +6 ft mllw. The cost of this work was $78,900.
1970	A 1,100-ft-long extension and sealing of the south jetty were completed. Jetty sealing was accomplished by installing a 3-ft layer of sealing stone in the littoral zone. The head of the middle jetty also was repaired in that the cover stone (12-ton) at the head of the jetty was restored. Total cost of the work was about $566,000.
1986	The existing jetties currently are in satisfactory condition. Design has been completed for an offshore breakwater located seaward of the north and middle jetties that will provide additional wave protection for Mission Bay Harbor. The proposed offshore breakwater has been model tested (Curren 1983, Markle 1983, Bottin and Acuff 1985) but not yet constructed in the prototype.

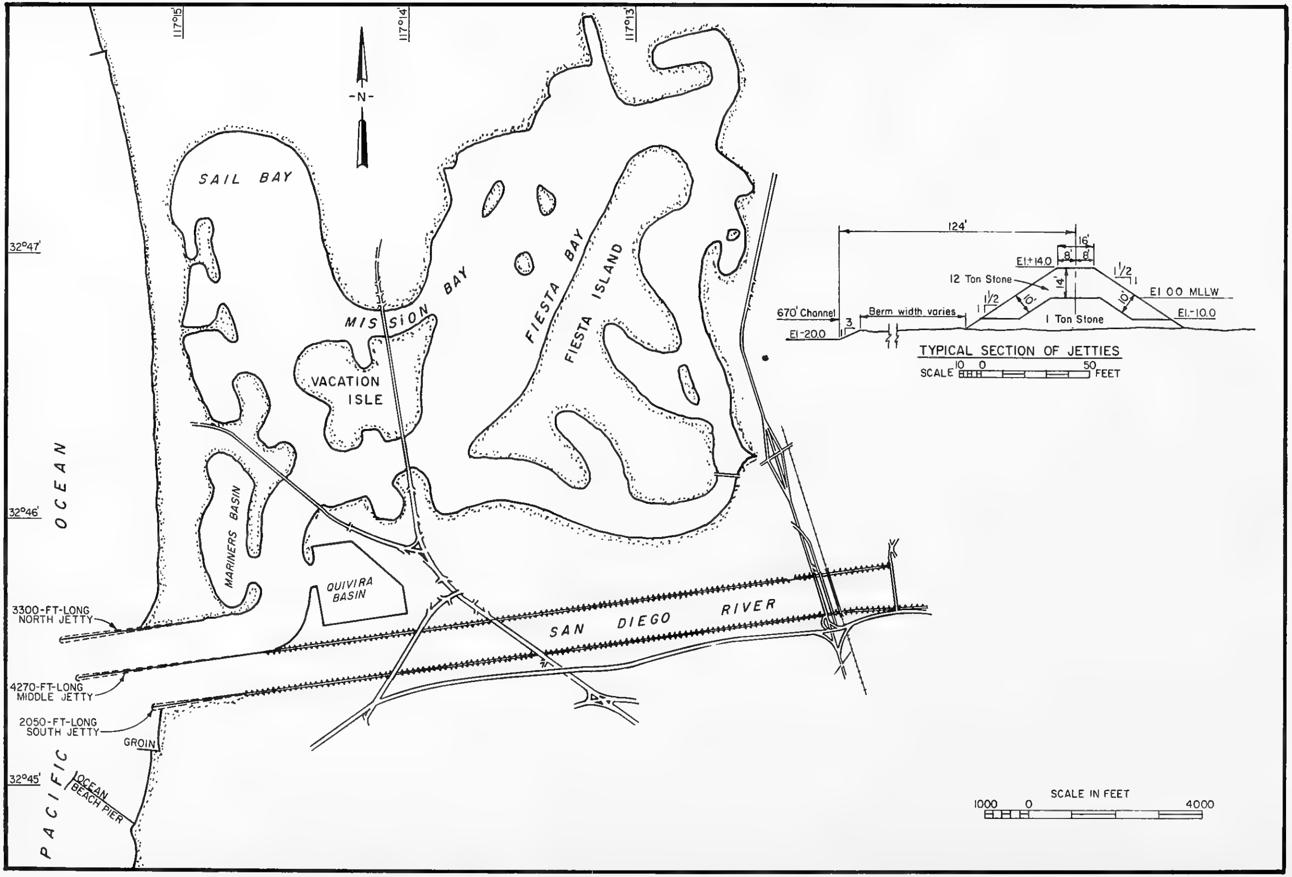

Figure 34. Mission Bay Harbor, California

Table 28

Zuniga Jetty

San Diego Harbor, California

Date(s)	Construction and Rehabilitation History
1894-1902	Construction of a 7,500-ft-long rubble-mound jetty (Zuniga Jetty) was completed (Figure 35) during this time frame. The design height of the jetty was +14 ft mllw with a 14-ft-wide crest. Side slopes were 1V:1.25H. It is indicated, however, that the jetty was not constructed to the full design height.
1942	Rehabilitation work was performed by the US Navy from the shoreward end to a point about 1,400 ft seaward.
1943-1969	Settlement and flattening of the slopes occurred, particularly in the outermost third of the jetty. As a result, parts of the jetty were awash or submerged at most tide stages, creating hazards to navigation.
1970	Maintenance repair of the jetty was accomplished for a cost of approximately $127,000. This work consisted of the construction of platforms on the jetty for navigation lights which were installed by the US Coast Guard to alleviate hazards to navigation.
1984	Maintenance repair of the jetty was completed, the extent of which is unknown.
1986	Even though the jetty was not constructed to full design height, it functions satisfactorily as a training wall which concentrates tidal flows and keeps the entrance channel scoured to project depth.

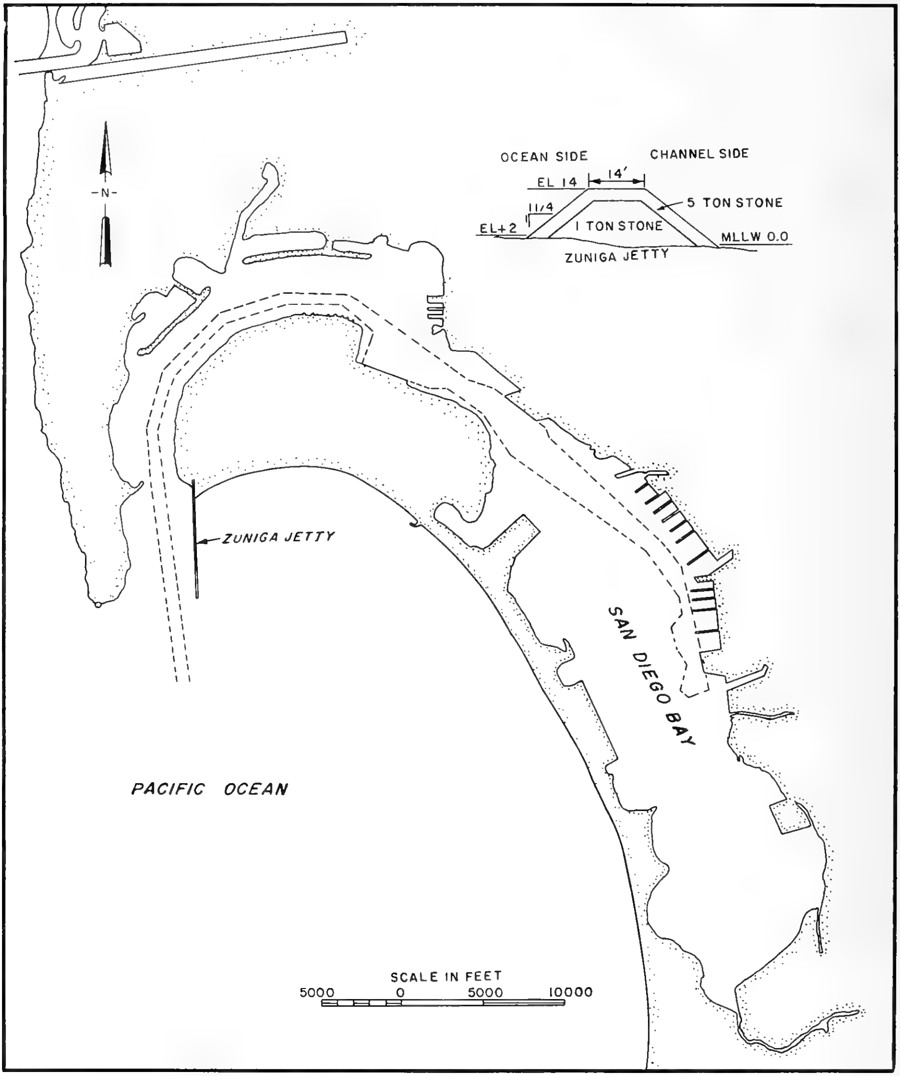

Figure 35. San Diego Harbor, California

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