CHAPTER ONE HUNDRED SEVENTY SEVEN

Surveys of Coastal Structures Using Geophysical Techniques

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Coastal engineers have long relied upon bathymetric surveys to determine the extent of underwater damage to jetties and breakwaters. Though such surveys supply important information about variations in water depth around structures, they alone do not show in sufficient detail the nature of the material on the structure, the extent of subbottom features, or the nature of the subbottom upon which the structure sits. However, by conducting bathymetric surveys in conjunction with other remote-sensing techniques and diving observations, it is possible to obtain more complete knowledge of the subaqueous condition of coastal structures.

During the summer of 1983 and the spring and summer of 1984, we conducted side scan sonar and shallow subbottom surveys in conjunction with bathymetric and diving surveys along three northern California coastal structures to determine the condition of the structures before extensive damage occurred. Then, we evaluated the applicability of the data collection techniques for condition surveys in general.

Two of the structures surveyed are the parallel jetties that protect the entrance to Humboldt Bay, California, and the third structure is the outer breakwater at Crescent City, California. Bathymetric records and sonographs from Humboldt Bay show deep holes along much of the inside of the south jetty and off the heads of both jetties. The subbottom record from inside Humboldt Bay shows a subsurface fault, the extension of which would run under the south jetty.

Sonographs from Crescent City show significant bedrock outcrops throughout the area outside the breakwater, making it difficult in places to identify the toe of the structure. The subbottom record shows that pockets of sand exist amidst the bedrock, but they are generally less than 2 m (6 ft) in thickness.

We found that the side scan sonar is an excellent tool for defining the toe of the structure; also, when waves are low, it can be useful in determining armor types and the slope of structures Our subbottom system provided information on fault and bedrock locations; however, other systems need to be tested to see if any of them can locate buried armor near the structures.

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INTRODUCTION

Currently, it is difficult to evaluate the condition of a coastal structure before it fails. Damage from individual waves or storms may slowly undermine structural integrity, eventually causing a seemingly sudden failure and necessitating stop-gap repair measures until more permanent, and usually costly repairs, can be undertaken. Although coastal structures are built to withstand a prespecified wave (usually the significant wave according to the U.S. Army, 1973, p. 7-168), the combination of wave activity, tidal currents, and longshore transport slowly causes structural weakening. When damage becomes severe enough--usually after a visible failure of the structure--engineers inspect the structure above water and conduct a localized bathymetry survey to assess the damage. Prefailure surveys to determine the condition of a structure are rarely, if ever, conducted.

The cost of repairing coastal structures is high; consequently, techniques are needed to determine their integrity. Recently, the Los Angeles District of the Corps of Engineers initiated a program to determine the present condition of man-made structures along the California coast. During the summer of 1983, we conducted geophysical surveys in the vicinity of the jetties at Humboldt Bay, California, and the outer breakwater at Crescent City, California. In the spring of 1984, we repeated some of the Humboldt Bay surveys to document changes produced by winter waves. In the summer of 1984, we dove around the structures to see if we could improve our interpretation of the sonographs. The goals of these surveys were (1) to develop a general survey methodology that could be used to inspect other such structures along the California coast and (2) to test the methodology by ascertaining *in situ* the condition of the structures at the two sites.

LOCATION AND DESCRIPTION

Humboldt Bay, the harbor for the city of Eureka and the largest bay on the northern California coast, is about 400 km (215 nmi) north of San Francisco. Crescent City, located on the south side of Point St. George, is about 120 km (65 nmi) north of Eureka. Figure 1 shows the location of the study area; figure 2 shows the jetties at the entrance to Humboldt Bay, and figure 3 shows the outer breakwater configuration at Crescent City. Both the jetties and the breakwater are rubble-mound structures with large, cast-armor units in selected places.

Stabilizing the entrance to Humboldt Bay commenced in 1881 and has continued sporadically to the present. Repairs have been so extensive that Hagwood (1981, p. 176) stated that the quantity of stone used to repair the Humboldt Bay jetties has been, in total, greater than that used for the original structures. At present, Humboldt Bay has parallel jetties that are 610 m (2,000 ft) apart; each jetty is over 2,000 m (6,560 ft) long. Repeated dredging maintains a navigation channel, 152 m (500 ft) wide by 13 m (43 ft) deep, near the south jetty.

Because of strong storm waves in the area, both jetties have experienced repeated damage and repair. Because traditional designs were unable to protect the jetty heads, in 1971 both were widened and

armored with 38- and 39-t (42- and 43-ton) dolosse. This was the first use of these units in the United States (Hagwood, 1981, p. 348). At present, the heads of both jetties have settled, and in one place the inside flank of the south jetty has separated from the cap.

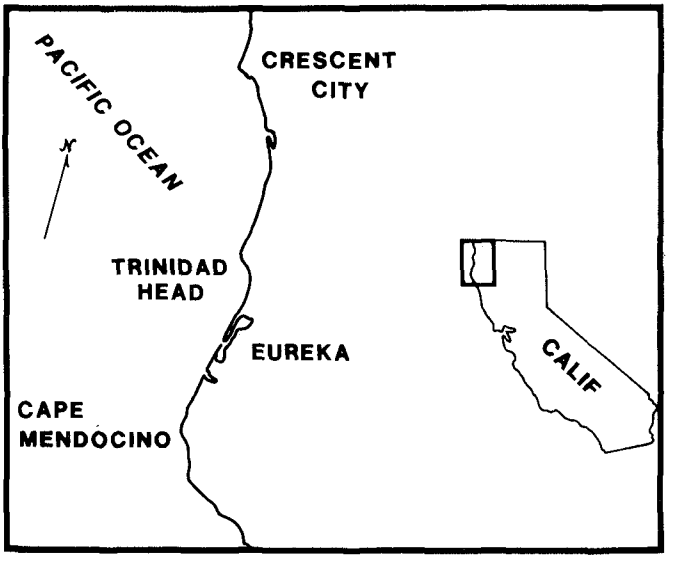

Figure 1: Location of the study sites at Crescent City and Eureka, northwestern California.

The outer breakwater at Crescent City is knee-shaped, extending southeast from the shore for about 1,128 m (3,700 ft) and then turning east for about 305 m (1,000 ft). Construction of the initial breakwater was finished in 1930. That first section extended 914 m (1,000 ft) southeast from the shore toward Round Rock. Later, engineers decided to extend the breakwater to Round Rock, forming a breakwater about 1,740 m (5,700 ft) long. That plan proved to be unfeasible, and the easterly arm was added instead, leaving a submerged rocky reef extending to the southeast.

Model studies at the Waterways Experiment Station, Vicksburg, Mississippi led, in 1956, to the placement of 23-t (25-ton) tetrapods on the easterly arm, the first use of these units in the western hemisphere (Hagwood, 1981, p. 341). Because of further storm damage, 38-t (42-ton) dolosse were added to protect the corner in 1974.

Equipment and Procedures

Although this survey was the first of its kind on the west coast, the various instruments have been used separately in similar

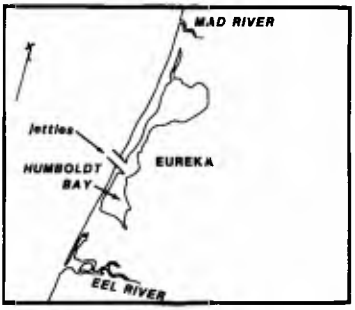

Figure 2: Entrance to Humboldt Bay at Eureka, California.

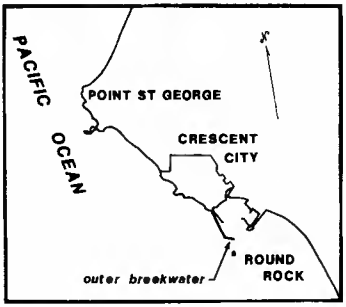

Figure 3: Harbor at Crescent City, California.

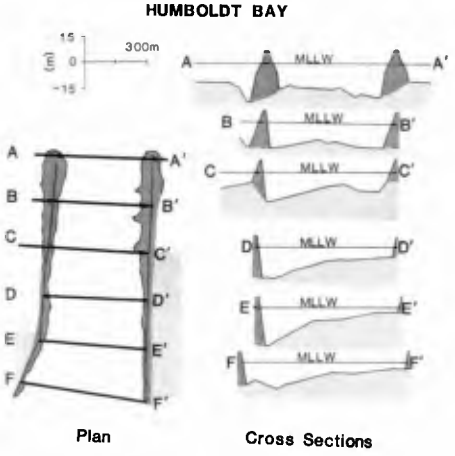

Figure 4: Plan view (left) of the jetties at Humboldt Bay, California showing the location of cross sections plotted on the right.

situations. Bathymetric surveys are commonly conducted around coastal structures. Patterson and Pope (1983) used side scan sonar to inspect structures in quiet waters; Mazel (1984) described how to use side scan sonar to inspect vertical surfaces; and surface-towed seismic transducers are often used to study surficial sand bodies.

Equipment used during this study included precision depth recorders, 100- and 500-kHz side-scan sonars, and a surface-towed 3.5-kHz subbottom profiler. The instruments were deployed from the (43 ft) R/V David Johnston or from a small (21 ft) boat. Instruments were chosen to fulfill specific objectives: the precision depth recorders were used to survey the bottom in the vicinity of the structures and to determine structure slopes; the side-scan sonar provided images of the toes of the structures and of surficial features on the adjacent sandy bottom; and the subbottom profiler determined the depth to bedrock and type of near-surface internal structure.

During the summer of 1984, scuba divers swam along the toes of, and occasionally onto, the three structures, and their direct observations were used to clarify the sonographs.

RESULTS

The 1983 and 1984 geophysical surveys and the 1984 scuba dives produced accurate data on the toes of the three structures, detailed bathymetric maps and slope profiles, and a rough picture of the subsurface. These surveys failed to produce detailed information on the distribution of armor on the structures or the location of buried armor. Sub- bottom techniques capable of accurately locating objects as large as the armor units failed to do so because of adverse conditions.

Humboldt Bay

Water depth varies considerably and systematically throughout the inlet and adjacent nearshore zone, as shown in figure 4. Whereas water is deep on the southwest side of both jetties, only along the south jetty is the water deep adjacent to the inlet-side (inside) flank. Figure 5, a plot of additional profiles run perpendicular to the south jetty, shows the disparity in depth between its outside and inside flanks. Near the head of the south jetty, the water is deeper on the south (outside) flank; however, landward from the back of the head, the water is deeper on the inside.

The seismic profiles showed that the shallow subsurface is sandy. Transects in the bay that crossed the center lines of both jetties show subsurface faulting that would lie under the south jetty when extended (fig. 6). However, over 20 m (66 ft) of unfaulted sediment overlies the faults. Waves distorted the offshore records to the extent that subbottom features could not be discerned. Attempts to locate buried armor were not successful.

The sonographs delineate the toes of the jetties and large subaqueous dunes in shallow parts of the inlet; slope changes and individual armor upon the jetties were identified. The location of the

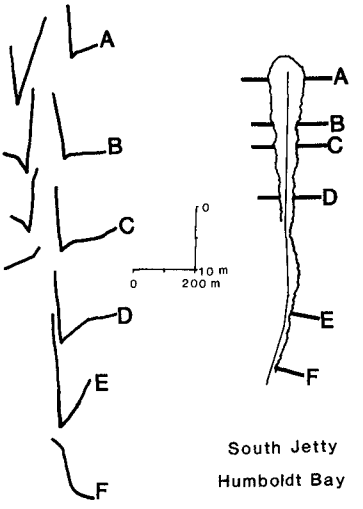

Figure 5: Profiles along the south jetty at Humboldt Bay, California. Zero on the abscissa is at the centerline of the jetty. Station numbers represent distances in hundreds of feet, with the largest value being at the jetty head.

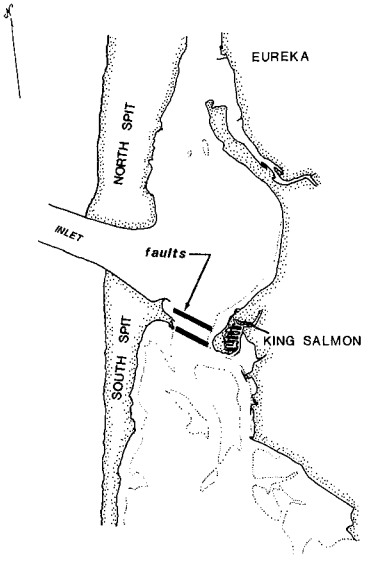

Figure 6: Location and trend of subsurface faults inshore of the south jetty at Humboldt Bay, California.

jetty toes, as calculated from the sonographs, are shown in figure 4.

The scuba dives, although conducted when water visibility was poor, led to the discovery that the jetty toes have different makeups. As shown on figure 7, the toe of the south jetty varies from large rock, to dolosse, to large rock with extensive sand that forms ramps up the flank, whereas the toe of the north jetty varies from large rock, to dolosse, to large areas covered with gravel and small rock.

Crescent City

Surveys at Crescent City covered the area between the outer breakwater and Round Rock to the south and Steamboat Rock to the west and the area adjacent to the inside of the arm (see fig. 3). Outside the Crescent City breakwater, the bottom is irregular because of extensive bedrock outcrops, is gently sloping, and is punctuated by rocky pinnacles that occasionally reach the sea surface. Depths along the outside of the shore-attached breakwater are as much as 9 m (30 ft) at the corner of the breakwater, maintaining that depth along the east-trending arm. The bottom shallows over the rocky reef, which nearly reaches the surface in places. One notable difference from the Humboldt Bay bathymetry data is the absence of depressions along the breakwater toe.

The sonographs showed extensive bedrock outcrops. On many records, such as the one shown in figure 8, it was hard to separate the breakwater toe from the naturally outcropping material. Figure 9 shows the location of the toe of the breakwater and of features thought to be outcrops rather than the breakwater itself. At one site just west of the corner of the breakwater, divers noted that the bulge is actually bedrock and that the toe is straight.

Seismic profiling confirmed that bedrock lies at or near the surface throughout the region. Typically, sand is restricted to depressions, forming patches less than 2 m (6 ft) thick. The only areas where sand completely covers the bedrock are east of the breakwater head and along the inside of the arm.

DISCUSSION

At Humboldt Bay, the bottom is sandy, and depth varies with location such that the greatest depths occur between the entrance channel and the south jetty and adjacent to the south sides of both jetty heads. The flanks of the south jetty slope as much as 42°, and the adjacent bottom drops off from the channel to the jetty without forming a channel wall (fig. 5). Continuing that profile to the ocean side of the jetty revealed highly unequal water depths on the two sides of the jetty--the outside being much shallower. That discrepancy is typical except at the head where, it reverses so that the deep scour appears on the outside. For interpretative purposes we divided the sea floor around and between the jetties into five parts: (1) the areas southwest of both heads, (2) elsewhere along the outside of the jetties, (3) the inside of the south jetty, (4) the entrance channel, and (5) elsewhere in the inlet.

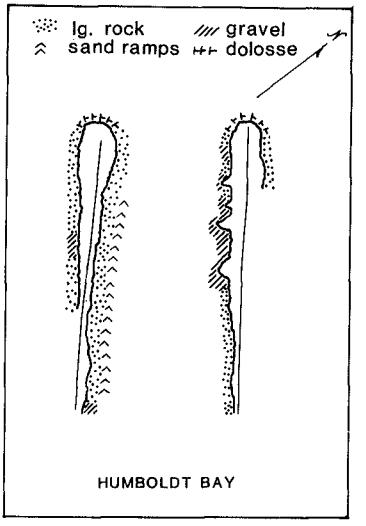

Figure 7: Location of armor types and sand ramps along the jetties at Humboldt Bay, California.

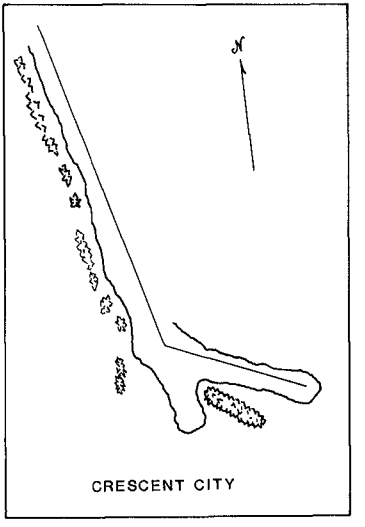

Figure 9: Location of the toe of the outer breakwater at Crescent City, California, as interpreted from sonographs. Also shown are bedrock outcrops near the breakwater.

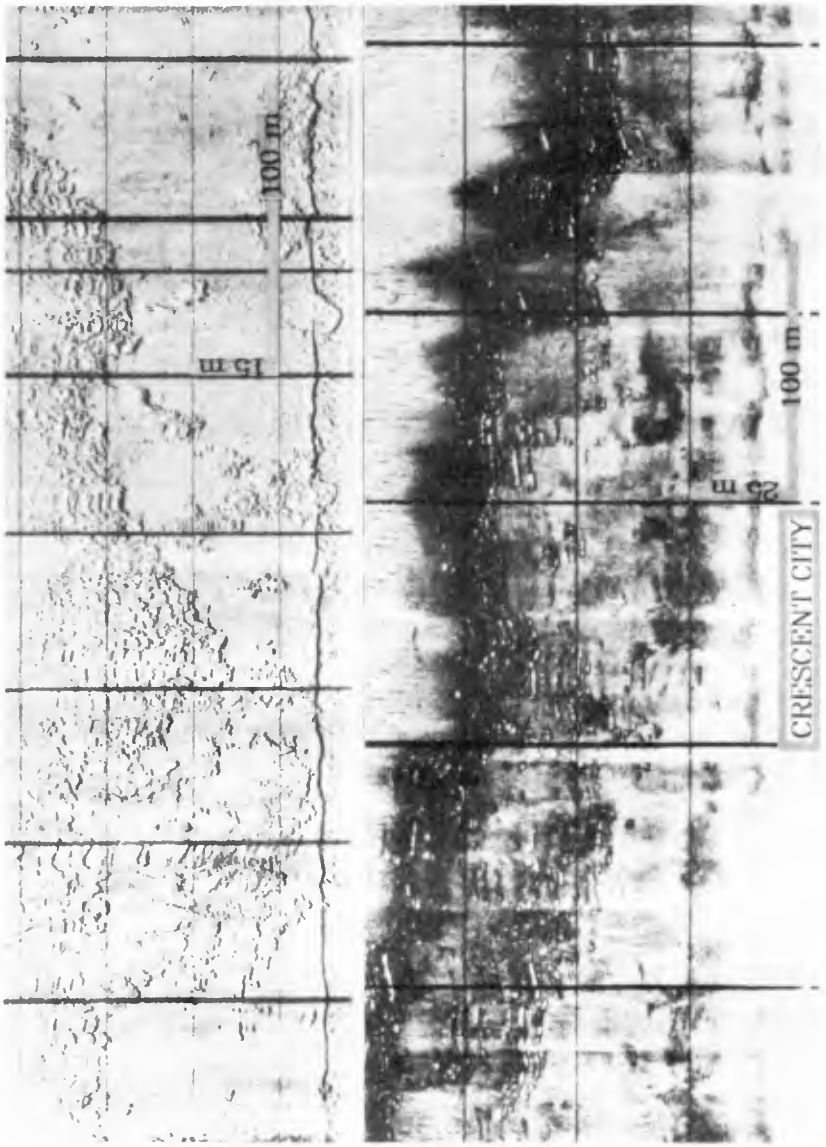

Figure 8: Sonographs of the bottom adjacent to the corner of the outer breakwater at Crescent City, California. Strong reflectors are bedrock outcrops. A 500-kHz sonograph is to the left, and a 100-kHz sonograph to the right.

Southwest of both heads, storm waves produce large, year-round, scour holes along the heads that are slightly deeper in the winter. Perhaps tidal flows or shelf currents contribute to the extensive erosion in this area. Overlaying the bathymetry on the construction drawings shows that the jetty toes have been extensively undermined in this area (Doug Pirie, oral commun., 1984).

Farther onshore, the waves have not created large depressions along the outsides of the jetties. Instead, the bathymetric data show a shallowing shoreward trend. Going from north to south there is about a 610-m (2,000-ft) shoreward offset of the shoreline.

Along the inside of the south jetty, strong tidal currents appear to have eroded the bottom, creating a continuous depression. Here, the divers found sand that formed ramps from the floor up the flank. The location and orientation of these sand ramps--abutting the east side of large armor and whose axes are tilted slightly shoreward-- suggest either flood-tide control or control by the distribution of armor. The entrance channel is periodically dredged to 13 m (43 ft). Its proximity to the inside of the south jetty may contribute to the extreme scour along that stretch of the toe.

Waves and tides interact to control the rest of the inlet. The traces of old groins, which were built to inhibit erosion along the north jetty (Chuck Orvis, oral commun., 1984), on both summer and winter sonographs suggest that tidal flows limit the depositional depth of the wave- driven sand in that area. Large bedforms in the central part of the inlet also suggest strong wave and tidal currents.

At the Crescent City study area bedrock dominates. Because the breakwater sits on bedrock, scour at the toe is minimal. Divers found, in places where sand or gravel abutted the breakwater, that the slope is gentle up to approximately 1 m (3 ft) of the armor and then steep down to the base of the armor; wave activity probably causes this pattern. Tidal currents appear to be relatively unimportant around the breakwater. Outside, waves attack the breakwater; inside, the water is often quiescent.

Wave action reduced the quality of the various records. Records collected on the (rare) calm days showed much more detail; furthermore, records could be collected over the structures only on such days. Most of the records, however, were affected by wave activity to the extent that details were missing. Each of the aspects of the study--bathymetry, seismic profiling, side scanning, and diving--could have contributed more information under better conditions.

Wave activity affected the bathymetric surveys by introducing large offsets to the bottom traces and by preventing us from surveying over the steep slopes of the structures. To a great extent, wave noise can be visually removed from the bathymetric records, but fine detail is lost. However, not being able to survey over the structures made it difficult to accurately locate the toes of the structures.

Side scan sonar helped in determining toe location when working

over the structure was not possible. However, if, as in the case of the south jetty at Humboldt Bay, the bottom depth was much different at the toe than at the point where the side scan fish was being towed, the distance measured from the sonograph would not be the horizontal distance from the ship's track to the toe. To obtain that distance a correction had to be made that depended on the depth at the toe, which necessitated knowing the location of the toe. Nevertheless, the error in toe location could be satisfactorily minimized by towing the fish near the bottom and knowing the approximate depth of the toe.

Patterson and Pope (1983) showed that side scan sonar can be used to recognize individual armor units and perhaps to recognize slope changes and missing armor. However, such detailed work requires ideal conditions, which, in many areas, occur only a few days per year. Those who plan surveys must, therefore, decide on whether or not it is economically feasible to wait for the right conditions. Although during this study wave conditions precluded our identifying individual armor or slope changes, variations in armor size between areas showed on the sonographs. Divers found that the groins along the north jetty at Humboldt Bay contain small rock, whereas the rest of that jetty has large rock or dolosse at the toe. Figure 10 shows how these differences appear on a sonograph.

Although the 500-kHz side scan sonar produced records with much more detail on them than did the 100-kHz sonar, both provided enough detail to determine toe location in most cases. However, the 500-kHz unit should be used when searching for small features.

Boat speed must be considered when looking for small features. If, for example, one wants to identify the sand ramps, which sit in 2- to 3-m (6- to 10-ft) gaps between large armor, boat speeds must be less than 1 m/s (2 kt). Otherwise, that section of the sonograph will be too narrow, making it impossible to resolve the feature.

Seismic profiling requires calm conditions to obtain interpretable records. This is especially true of a surface-towed unit. Again, detail is lost during wavy conditions. We attempted to find buried armor, which would show up on the record as point-source parabolas, but saw none. Although there may not have been any to find, excessive motion of the sled would have masked their presence.

Diving also requires calm conditions, both to improve visibility and to permit swimming around the structure. We were able to follow the toe, but unable to see far enough to assess large-scale irregularities.

CONCLUSIONS AND RECOMMENDATIONS

1. At Humboldt Bay extensive scour has taken place on the south sides of the heads of both jetties and along the south jetty between the inside flank and the entrance channel.

2. On all three structures, large rock is the predominant material found along the toes. At Crescent City, there are a few dolosse at the corner and tetrapods along much of the easterly extension. At

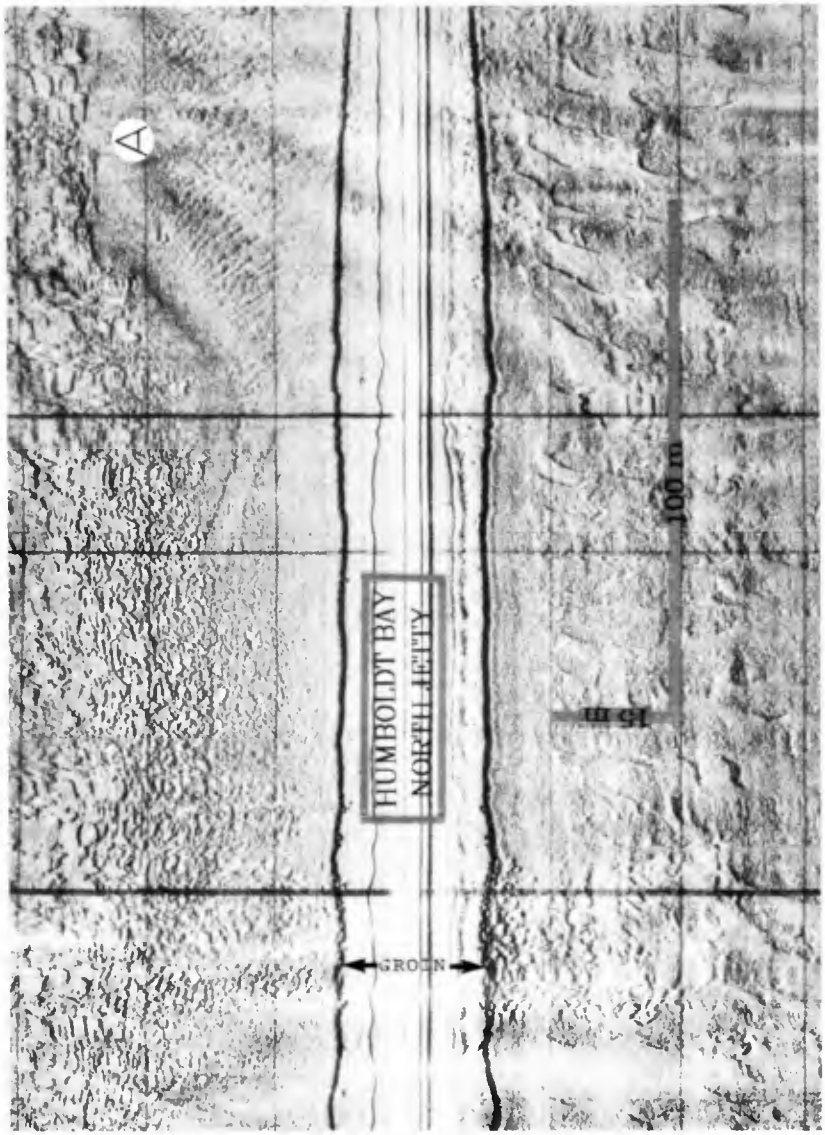

Figure 10: Sonograph of a groin along the inside of the north jetty at Humboldt Bay, California. The patterns on the sonograph indicate that the size of the material composing the groin and adjacent toe is smaller than the size of the material farther shoreward (A).

Humboldt Bay, there are dolosse on the bottom around both heads and smaller rock in a few places, primarily around the groins.

3. At Humboldt Bay, the subsurface is sandy; faulting extends under the south jetty but does not break the surface. At Crescent City, bedrock is present at or near the bottom throughout the study area.

The surveys showed that some techniques have general applicability and that others are more specialized. Also, they showed the extent to which such surveys depend on calm seas. On the basis of our work around these structures, we make the following recommendations:

1. Bathymetric surveys are fundamental to conducting condition surveys on coastal structures. They can be used under more severe conditions than the other techniques, and most wave noise can be filtered from the records.

2. Side scan sonar is an important adjunct to bathymetry in determining the location of the toe of the structure and the position of bottom features. It also can be used to look for features on the structures, but only when seas are calm.

3. Seismic profiling is useful when large-scale features are to be resolved. More work with different devices, however, must be done before it will be known if seismic techniques can locate buried armor.

4. Diving is a useful tool when visibility and wave climate permit. It can provide information on small features that often cannot be resolved with the geophysical tools.

ACKNOWLEDGMENTS

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