CHAPTER 182

LONC TERM EXPERIENCE WITH SEAWALLS ON AN EXPOSED COAST

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Appropriately designed, constructed, and maintained rubble mound seawalls are an efficient and cost-effective means of protecting erodible sections of exposed coastline. This conclusion is supported by more than 25 years of satisfactory seawall performance along the Pacific Ocean coast of Santa Cruz County, California, U.S.A. Important factors in satisfactory seawall performance include a clear understanding of the oceanographic and geologic design parameters, a vigorous inspection program during construction, and continued observation and maintenance of the structures.

INTRODUCTION

The coastal city of Santa Cruz, in Santa Cruz County, California, U.S.A., is located about 75 miles south of San Francisco, along the northern shore of Monterey Bay (Figure 1). For more than a century, the beaches and shores in this area have served as a major recreational resource (Figure 2) for residents of the San Francisco Bay Area and the California Central Valley.

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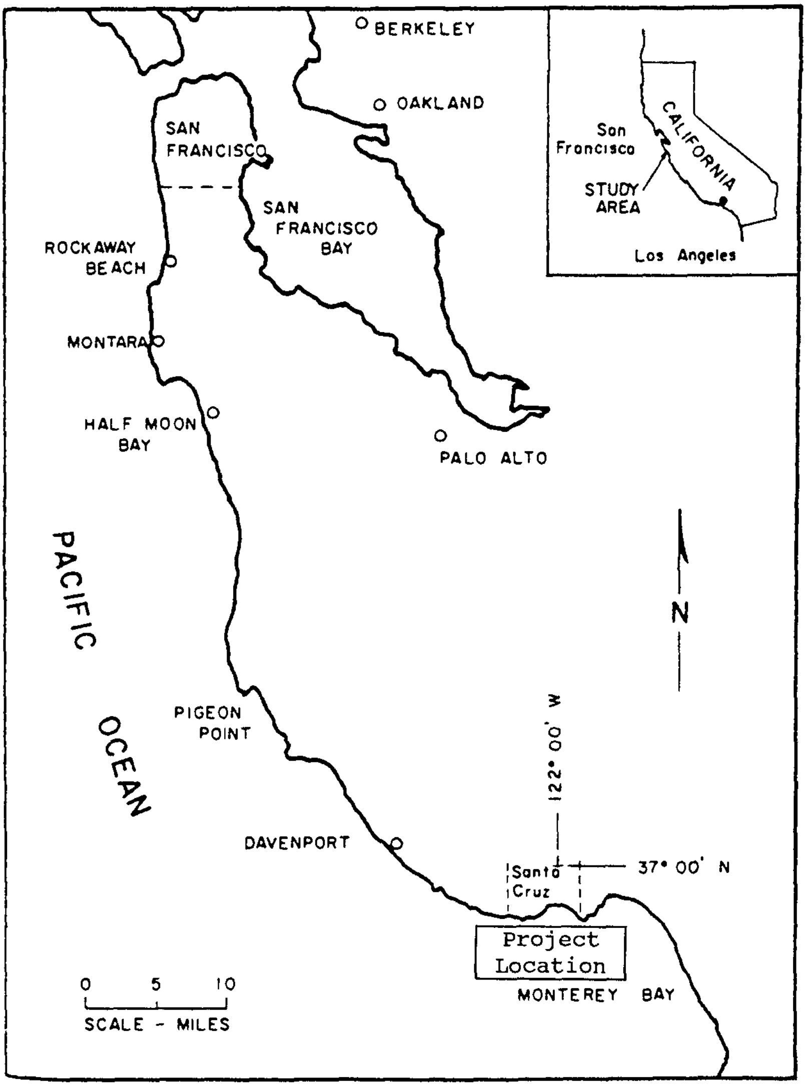

Figure 1 - Project Location

Figure 2 - Using the Beach at Capitola

The California coast in the Santa Cruz area is subject to very high waves, with maximum deep water waves often exceeding 50 feet in height. The water depths immediately seaward of the toe of the bluffs are sufficiently shallow to cause large waves to break well seaward of any protective structures under most conditions. The resulting waves at the shoreline are affected by both the depth of water as well as the complex bathymetry and topography immediately offshore.

The erosion of the beaches and cliffs on the northern side of Monterey Bay between the west limits of the City of Santa Cruz and New Brighton Beach State Park had been progressive for many years (Figure 3). The recession of the cliffs had cut through public streets, destroyed both public and private land, and threatened to destroy residences and other buildings. Individual efforts by local interests to combat the erosion problem were historically insufficient in scope or failed in their intended purpose.

GEOLOGIC SETTING

Coastal cliffs are a common landform along large sections of the geologically young California coast (Figure 4). The cliffs are the result of active erosion, being subject to periodic retreat during stormy periods. Many of the cliffs consist of relatively soft sandstones, siltstones, and shales, which are highly susceptible to erosion from wave action and surface runoff. The problem of coastal cliff erosion and retreat is well understood qualitatively and described in the literature. However, because the episodes of retreat are relatively infrequent and the overall rate is deceptively slow, property owners tend to develop a false sense of permanency and security.

The actual process and rate of cliff erosion and slope retreat depend to a large extent on the type of material involved. The weathering and erosion of the predominantly sandy rocks in California lead to the accumulation of talus and the formation of sandy beaches. The talus and the beach protect the toe of the slope from wave erosion between major storms. In areas underlain by stronger, more cohesive rocks, there is often not enough sandy material to form the beaches and the waves tend to lap directly at the toes of the cliffs. In both cases, however, the rates of cliff retreat tend to be relatively slow in the periods between large storms.

Failures, when they occur, tend to be the result of large episodic events such as major storms. For slopes protected by sandy beaches, the storm waves and tides must be sufficiently large to remove the protective sand before the waves can attach the slopes themselves. Once this occurs, the rate of cliff erosion can be very rapid. Cliffs that are not protected by beaches will obviously be exposed to significant wave action more often. Even

Figure 3 - Beaches and Cliffs near West Cliff Drive

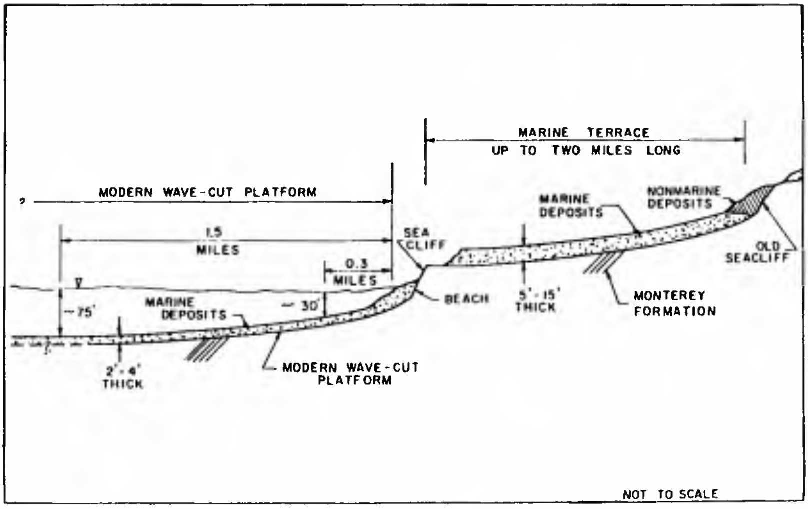

Figure 4 - Typical Profile Normal to Coastline

then, major failures will be relatively infrequent and more likely to occur during large storms. Overall, these infrequent failures result in a slow but steady average retreat of coastal cliffs, often at a rate of less than one foot per year. More important, a lack of erosion over a period of a few years is not evidence that the retreat of coastal cliffs has been halted.

Santa Cruz County lies along the northern coast of Monterey Bay in central California. Uplifted marine terraces flank most of the northern bay and also the open coast farther to the north. The seacliff varies in height from about 20 to 90 feet and is generally composed of Santa Cruz Mudstone and the Purisima Formation (siltstone and sandstone). These sedimentary rocks usually lie almost horizontal or dip gently seaward and are often capped by 6 to 20 feet of unconsolidated marine and non-marine terrace deposits.

The Santa Cruz Mudstone is predominantly a diatomaceous siliceous mudstone. It is thin-to-thick-bedded and individual beds vary from several centimeters to a meter in thickness. Joints and fractures give most outcrops a blocky appearance. The large number of rockfalls and block landslides which occur in the mudstone indicate its susceptibility to failure on steep slopes such as canyon walls and seacliffs. The Purisima Formation consists of thick bedded, poorly to moderately indurated siltstones and sandstones with occasional interbeds or lenses composed almost entirely of mollusk shells. This formation is jointed, faulted, and warped. The influence of individual stratigraphic units within the Santa Cruz Mudstone and in the Purisima Formation on local geomorphology and erosion rates is significant.

Coastal erosion or seacliff retreat is caused by both marine and terrestrial processes. Surf action is usually the dominant agent, producing both wave impact and abrasion. The rate of seacliff retreat is dependent upon the following natural factors: (1) available wave energy and exposure (including the presence or absence of a protective beach at the base of the cliff); (2) the lithology of seacliffs and their resistance to erosion; (3) geologic structure including joints, faults, and folding; and (4) the height and slope of the seacliff. Runoff and human activities are factors that can also add significantly to the rate of cliff retreat.

Within Monterey Bay, the seacliffs are generally protected from direct wave attack. The predominant waves from the west-northwest are refracted almost 90 degrees before striking the coast, and wide sandy protective beaches begin to appear. The coastal cliffs throughout most of the city of Santa Cruz are composed of erodible sediments of the Purisima Formation. Rapid erosion has cut back the cliffs, changing the trend of the coastline and creating the embayment known as northern Monterey Bay (Figure 5). Although the bay configuration protects this area from

Figure 5 - Monterey Bay (looking East)

direct wave attack, erosion rates in these sandstone and siltstone beds (Purisima Formation) are still greater than the rates in the Santa Cruz Mudstone along the open coast to the north. The erosion rate of the Purisima Formation is influenced by the varying hardness of different lithologic units within the formation, the orientation of well developed joint sets, and the presence of faults.

Cliff height sometimes exerts an indirect control on erosion rates. The quantity of material produced by a given amount of coastal retreat is a direct function of cliff height. For example, cliffs have been undercut and have subsequently failed, and large blocks have broken out along joint sets and fallen to the beach below. To the extent that this material remains in place at the foot of the cliff, it serves as temporary riprap to buffer the cliffs from direct wave attack. However, the large sandstone and siltstone blocks produced by breakdown of the Purisima Formation last only a few years in the surf zone.

PROJECT HISTORY

Studies of the beach and cliff erosion problem in Santa Cruz County were conducted in the mid to late 1950's by the U.S. Army Corps of Engineers in cooperation with the State of California, Santa Cruz County, and the City of Santa Cruz. These studies concluded that the most practicable plan for protection of the West Cliff Drive and Opal Cliffs-Capitola reaches would be rubble mound seawalls with top elevations ranging from 14.0 to 17.5 feet above Mean Lower Low Water (MLLW). It was further concluded that the irregular alignment and rocky nature of the shoreline would make placement of beach fill economically infeasible. The numerous projecting points or minor headlands that function as groins do not impound sand in sufficient quantity to protect the cliffs, indicating that groins, either with or without fill, would not correct the problem.

In order to reconstruct and restore West Cliff Drive to serve the large public demand at this important resort, the City of Santa Cruz, the City of Capitola, the County of Santa Cruz, the State of California, and the U.S. Army Corps of Engineers cooperated in planning, designing, and constructing more than 4,000 feet of rubble-mound seawalls in about twenty sections. In their studies, they found that the cliffs in the area had been progressively eroded for many years.

Further south, the Opal Cliffs-Capitola reach, also about 2.5 miles long, is characterized by an irregular shoreline backed by cliffs ranging from 35 to 75 feet in height. Except for narrow beaches found during the summer in shallow embayments and at the mouth of Soquel Creek, the greater length of this section is devoid of beach material and the cliffs are exposed to wave attack all year. During the winter months, wave action strips the beaches of sand leaving the underlying bedrock exposed.

The beach erosion control project for these two reaches that evolved from the Federal studies was authorized by the River and Harbor Act of 1958. This act provided, in part, for Federal participation by contribution of funds toward the cost of construction of: (1) rubble mound seawall units with an aggregate length of 4,700 feet, along West Cliff Drive; and (2) rubble mound seawalls about 870 feet in length at Cliff Drive in the Opal Cliffs area of the City of Capitola, about 10 miles to the southeast.

The plan of protection for West Cliff Drive provided for rubble-mound, or riprap seawalls and/or revetments at critical reaches, totaling about 4,150 feet in length (Figures 6 and 7). These seawalls have a maximum width of 10 feet at an elevation of 17.5 feet above mean lower low water, and a seaward slope of 1 on 1-1/2 after anticipated settlement. The individual face or cap stones have a minimum weight of 4.5 tons so as to resist an anticipated wave 9.5 feet high. In accordance with then current design practices, the core of the seawalls consisted of quarry run stone from 10 to 1,000 pounds with 50 percent greater than 500 pounds. A stone filter blanket was placed prior to placement of larger stone when the thickness of the sand layer at the seaward toe of the seawalls exceeded one foot. The design was predicated on the premise that the (Federal) project could only protect the bluffs from that component of the erosion caused by direct wave action, and that erosion caused by other causes (i.e., surface runoff, wave splash erosion due to geologic causes, etc.) could not be a part

Figure 6 - Seawall during Construction (April 1962)

Figure 7 - Seawall Construction (May 1961)

of the Federal project. Erosion due to causes other than waves, currents and tides would thus be a non-Federal responsibility and were not included in these designs.

Because of funding considerations, the City of Santa Cruz chose to construct the shore protection improvements in stages over a three-year period. Stage one, accomplished in 1961, consisted of the construction of thirteen small units or sections totaling 1,950 feet in length. Stage two was completed in 1962 and consisted of seven units of a total length of 1,050 feet. Stage three was completed in 1964 and consisted of three sections aggregating 1,150 feet in length, a total of 4,150 feet.

RECENT OBSERVATIONS

An inspection of these rubble mound seawalls and revetments in early 1988 indicated that over ninety percent of them are in a very serviceable or nearly as-built condition (Figures 8 and 9). Damage or potential damage to the remaining five to ten percent appears to be caused by the following: (1) erosion and/or collapse of the bluff material landward of the seawalls with subsequent loss of backing or support which allowed rubble to be displaced; (2) erosion of the bluffs at the terminal ends of the seawall, allowing lateral movement, loss of core material, and subsequent damage; (3) erosion of material under the toe or foundation and subsequent settlement of wall (for relatively small displacements of the toe, remedial action of placing relatively minor quantities of additional armor stone appeared satisfactory); and (4) inadequate design wave height, related to difficulties in determining wave

Figure 8 - Seawall near Santa Cruz (May 1988)

Figure 9 - Seawall near Capitola (May 1988)

heights at the structure due to highly irregular bathymetry and topography immediately offshore.

The large majority of the Santa Cruz West Cliff seawalls were built as single armor layer revetments. Single armor layer structures have very little tolerance to any shifting or movement of the armor cover. The cover is not a "flexible" layer in the same manner as a multi-layer armor cover. Minor movement of the armor layer as the structure settles is not fatal in a two-layer armor where the shifting units can fall into the structure to heal gaps and still provide cover to the underlayer. With single layer construction any shifting or settling of the armor (even if there is no initial unit loss) may expose the underlayer to erosion.

Three distinctive modes of failure or structure unraveling were noted in those West Cliff sections where damage was observed. Even though the foundation material is bedrock, it is susceptible to erosion.

Flanking of the individual revetment sections can occur if the adjacent bluff continues to retreat; in these cases, the armor may slide toward the unsupported flank, exposing the core; minor losses of core material cause additional shifting of the armor layer and the revetment continues to unravel until enough of the crest armor collapses down to form a multiple layer flank which effectively seals off the core from wave action.

The toe of the seawall may not in all cases have been keyed down to the bedrock. Some of the revetments are built at the back of coves where a local pocket beach covers the bedrock with a thin veneer of sand; erosion of the pocket beach or possibly even some abrasion and scour of the bedrock may undermine the toe, causing stone to shift. In a multiple layer revetment, damage caused by the down-slope migration of the toe stone is usually minimized as an upper layer unit collapses into the lower layer. This may cause an apparent steepening of the toe but shifted units will often seal the cover without exposing underlayer further up slope. The multiple layer cover heals itself as it collapses. Not so with a single layer cover, where the displaced toe exposes the core and the downward migration of the cover continues without healing. Units can only migrate down slope by sliding on the core until there is enough loss of core to allow collapsing. In these cases, the revetment is reduced to a pile of armor which has collapsed into the void left as the core was eroded.

Erosion of the back bluff was observed in several cases. Runup and overtopping of the revetment or surface water runoff may have caused further retreat of the bluff behind the revetment and loss of support to the structure. Backward sliding crest stones again exposed the underlayer or core resulting in an unraveling of the structure from the top down. Sections exhibiting this type of damage usually experienced only minor loss of the structure's integrity unless the retreat of the supporting bluff was significant.

Although several design limitations with single layer armor construction could be identified at this site, the satisfactory performance exhibited by most of the sections illustrates the acceptability of single layer construction in certain geologic settings. Single layer construction can be used in areas of a stable foundation where bedrock or erosion-resistant soil limits toe scour or retreat of the back support. However, if this shore protection system were to be designed and built today, advances in design standards and the information gathered from years of observation would lead to some differences in approach. These would include a more comprehensive investigation of foundation conditions, erosion rates, and the effects of extreme water levels and storm conditions. A formal operation and maintenance plan would also be prepared and implemented. And, double-layer construction with a filter fabric backing would probably be selected as the final design.

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