The Effects of Armoring Shorelines—The California Experience

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Introduction

Washington's Puget Sound shoreline varies significantly in its geologic make up and many areas of the shoreline are both developed and undergoing erosion. Increasing concern has recently been expressed regarding the impacts of armoring this coastline. This paper reviews what has been learned from the experience of armoring the more intensively developed coastline of California with the objective of providing insight to guide future decision making regarding armoring of the shorelines of Puget Sound.

While coastal zones globally have always been sites of human habitation, populations in these areas over the past 50 years have grown faster than in other regions (Crossett and others, 2004). In the United States in particular, coastal land has become increasingly more valuable as oceanfront communities and cities have expanded, recreational activities and tourism have grown, and people have chosen to build or purchase residences or vacation homes along the shoreline. At the same time, sea level has continued to rise, and hurricanes and El Niño Southern Oscillation (ENSO) events have taken their tolls as coastlines have continued to retreat.

The exposed outer coast of California is different in many ways from the protected shoreline of Puget Sound. In fact, about the only things the two areas may have in common are an adjacent body of salt water and a widespread desire of residents in both states to live as close to that water as their bank accounts will allow. California has an 1,100-mi long, roughly linear shoreline that experiences a maximum tidal range of about 6 ft to perhaps as much as 9 ft, and is directly exposed to the large swells of the Pacific Ocean. Puget Sound, on the other hand, has a 2,600-mi long, crenulated shoreline, a maximum tidal range of about 12 to 13 ft, and is sheltered from open ocean waves.

More than one-half (59 percent, or 650 mi) of the coastline of California consists of low relief cliffs and bluffs commonly eroded into marine terraces; 140 mi (13 percent) consists of high-relief cliffs and coastal mountains; and the remaining 310 mi (28 percent) is characterized by lowlands with beaches, dunes and lagoons or estuaries (Griggs and others, 2005). The coastline of Puget Sound is dominated by low to moderate height bluffs that have been eroded into mixed glacial deposits left behind by the glaciers that covered the Sound during the last Ice Age. The typical California beach is wide and sandy, whereas most Puget Sound beaches tend to be relatively narrow and commonly consist of gravel or a mix of sand and gravel.

In California, the state owns and has jurisdiction over all land below the mean high tide line. In the state of Washington, however, about half of the property owners have title to the land down to the mean lower low water line; in other words, they own or have control over the intertidal zone. California is crowded with a population of 38 million people; Washington is relatively uncrowded with 6.5 million people.

Coastal Erosion and Protection in California

Over the past 50 years, the typical response to coastal erosion in the United States has been the construction of a seawall, revetment, bulkhead or other "hard" structure, intended to protect wave-impacted development or infrastructure. In California, an astonishing 110 mi, or 10 percent, of the state's entire 1,100 mi of coast, has now been protected or armored. In southern California's four most urbanized counties (Ventura, Los Angeles, Orange, and San Diego), 33 percent of the entire 224 mi of shoreline has now been armored (Griggs, 2005). Most of California's shoreline development took place during the cool or less storm Pacific Decadal Oscillation (PDO) cycle that extended from 1945 to 1977. The warmer 1978–2000 PDO cycle was characterized by a number of strong ENSO winters, bringing shoreline-damaging events that led to large increases in requests for new armoring permits.

In contrast to the oceanfront homeowner's concern for the cost, lifespan, and effectiveness of a coastal protection structure, considerable public opposition has risen in recent years to proposals for new seawalls or revetments because of the potential impacts of these structures. Many of the concerns in California revolve around the issue of whether private property owners should be allowed to impact public beaches as they attempt to protect their own property, or in the case of government funded projects, how much taxpayers money should be spent in efforts to stabilize the position of an otherwise eroding coastline? With an increasing public awareness of global warming and a rising sea level, the issues of coastal erosion and protection are being viewed more critically than they were a decade or two ago.

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A number of potential impacts of coastal armoring have been identified and are the issues typically evaluated before any new seawall permit is approved. The following discussion focuses on each of the types of impacts or effects that are usually identified with the emplacement of coastal armor. These include: visual impacts, impoundment or placement losses, reduction of beach access, loss of sand supply from eroding bluffs/cliffs, and what have been termed passive erosion and active erosion. For a more complete discussion of these impacts, see Griggs (2005) as well as Krauss (1988) and Kraus and McDougal (1996).

Armoring

Visual Impacts

Any armoring structure built to protect either cliff, bluff, dune or back beach development will have some aesthetic impacts (fig. 1). Whether a seawall, bulkhead, revetment or some other form of stabilization or protection, there is a visual impact that can be much greater to the beach user or general public than to the owner of the property being protected, who may not even see the structure. In California, the visual impact of coastal armor is probably the issue that most concerns the public. This is something they can observe directly that does not require a scientific explanation or debate among experts. Prior to the requirements of Environmental Impact Statements or Reports, armoring projects were completed without any environmental review. Some of these very early projects consisted of dumping concrete rubble onto the beach or a variety of other non-engineered solutions. We are still living with some of these protection efforts. Because of these visual impacts, and general concern with covering over natural cliffs and bluffs with rocks or gunnite or seawalls, far more attention than ever before is being focused on reducing visual impacts.

One relatively recent approach in California has been the use of soil nail walls or sprayed concrete, which is colored and textured to match the native rock in the cliffs. Colored and textured gunnite or soil-nail walls have been used to stabilize highway road cuts, but only recently has this approach been applied to coastal protection projects as a way to mitigate the visual impacts. These structures involve anchoring soil nails or tie backs into the bluff materials, and then constructing a steel-reinforcing frame that mimics the shape of the existing bluff. This mesh is then covered with about a foot of gunnite, followed by a second 6- to 12-in. thick layer, which is textured and colored to match the adjacent rock as closely as possible (fig. 2). Weep or drain holes must be built into the structure in order to avoid the buildup of water behind it.

Figure 1. These cliffs in Capitola, California have been protected by a home-made seawall with visual impacts for beach users.

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Figure 2. Bluff reconstruction and stabilization along the Pebble Beach area of the Monterey Peninsula, where the exact textures and colors of the existing granitic rock were duplicated to minimize visual impacts.

Concrete, if it is well mixed and prepared, and if the reinforcing rods are protected from exposure to seawater, can be very resistant to wave impact and erosion. While the color and texture of natural cliffs and bluffs can be duplicated, this is more problematic when beachfront or dune development is being armored or protected.

Placement Loss

When any protective structure is built at the base of a bluff, cliff, or dune, or well out on the beach profile, a predictable amount of beach will be covered by the structure. The effect is immediate beach loss, the extent of the loss being a function of how far seaward and alongshore the structure extends. Where a relatively thin vertical seawall or soil nail wall is built, there is usually very little beach loss because the structure has a very small cross-shore width, perhaps only several feet. Some very large concrete seawalls, however, such as the O'Shaughnessy seawall along San Francisco's Ocean Beach (fig. 3), or the Galveston seawall, do have an appreciable width and will cover over more beach area.

On the other hand, where riprap or a revetment is placed to protect a bluff, it may reach a height of 15 to 25 ft or more, and extend seaward at a 1.5:1 or 2:1 slope, covering 30 to 50 ft of beach (fig. 4). This placement loss can easily be calculated for any proposed revetment knowing the cross-sectional area and alongshore length, and this impact can then be quantified in relation to how much adjacent or surrounding beach area would still be available. In other words, if the existing beach is very narrow, say 30 ft on average, the riprap may cover the entire beach. Where the beach is wider, riprap may cover only one-third to one-half of the available beach area.

Figure 3. The massive and carefully engineered O'Shaughnessy Seawall in San Francisco was built in 1928 and has stood the test of time.

Figure 4. This revetment in the city of Santa Cruz has eliminated the entire beach through placement loss.

Reduction of Beach Access-Vertical or Lateral

In California, a major driving force for the passage of the original Coastal Act in 1976 was public access to the shoreline that was increasingly being threatened or restricted by oceanfront development. Depending upon the coastline being considered for armoring, and the nature of the protective structure being proposed, the potential exists to reduce or restrict access either to the beach (vertical access) or along the beach (horizontal lateral access). Depending upon the width of the beach and the typical tidal range, lateral access may be lost for differing amounts of time throughout the year (fig. 5). Loss of lateral access will be greater in the winter months, when the beach has been lowered and narrowed, than in the summer months, when a wide berm usually exists. A continuing rise in sea level, however, will increase the amount of time when lateral access becomes restricted.

While a seawall normally extends a lesser distance seaward than a revetment, both structures can restrict lateral access if the beach is narrow or present only seasonally. Knowing tidal ranges and wave run-up at a particular site, as well as typical beach widths or elevations during differing times of the year, a reasonable prediction of the amount of time that lateral access would be lost can be made. At some locations, stairways and elevated walkways have been built over these structures to help mitigate this impact.

Loss of vertical access is a somewhat different issue. Seawalls or bulkheads can restrict or eliminate access to the beach from the cliff or bluff top, but in steep cliffed areas, vertical access is limited to begin with. Access stairs can be built into most coastal armoring structure, however, so that this impact can be mitigated, although such stairs may also be damaged or destroyed by the wave action that led to the need for armoring to begin with.

Figure 5. Under winter beach conditions, lateral access is significantly reduced due to the encroachment of these temporary protection structures onto the beach at Malibu.

Impoundment or Loss of Sand Supply from Eroding Bluffs/Cliffs

Coastal armoring has also become an issue as it affects sand supplied to beaches on a regional basis. In California, the great majority (70 to more than 95 percent) of the beach sand delivered to individual littoral cells comes from rivers and streams, with most of the rest coming from eroding cliffs or bluffs (Runyan and Griggs, 2003; Griggs and others, 2005). With a significant reduction in sand transport and delivery due to the construction of more than 500 dams on coastal streams in California (Willis and Griggs, 2003), there is increased concern about the cumulative impacts of additional sand supply reduction.

Assessing the impact of any proposed coastline armoring on sand supply involves determining how much beach-compatible sand is supplied by the retreat of the particular coastline being armored. The alongshore length and height of the bluff, the percentage of sand or littoral-size material, and also the average annual erosion rate are the factors that need to be included in a sand reduction calculation. Determining the amount of littoral-sized material is straightforward in unconsolidated materials, but is more difficult for consolidated rock types. In addition, many cliffs or bluffs consist of several different types of materials with differing sand contents (bedrock and terrace deposits for example), or vary alongshore, which further complicates any calculations. The assumption is commonly made that particles of sand size or larger (>0.062 mm) will contribute to a beach, but because beach sediment size varies in response to local wave energy, this assumption is usually not a valid one (Limber and others, 2007). In some areas along California's coast, where because of the grain sizes of the cliff or bluff materials they contribute significantly to adjacent beaches, armoring will significantly reduce littoral sand supply, but in other areas this will not be an issue.

Passive Erosion

Whenever a hard structure is built along an eroding coastline, the shoreline will eventually migrate landward on either side of the structure (fig. 6). The effect will be gradual loss of the beach in front of the seawall or revetment as the water deepens and the shoreface profile migrates landward. This process is designated as *passive erosion* and has been well documented along many different shorelines (Griggs, 2005). Passive erosion takes place regardless of the type of protective structure emplaced. This process is perhaps the most significant long-term effect of shoreline armoring.

Active Erosion

The potential for a seawall or revetment to induce or accelerate beach erosion has been the source of considerable controversy over the past two decades. A common assertion is that seawalls cause beach erosion. Although differing opinions have been put forward on these issues, until fairly recently there had been a noticeable lack of sustained or repeated field observations and measurements with which to resolve the conflicting claims. Two major compilations of existing studies and references related to the issue of seawalls and their effects on beaches have now been completed (Kraus, 1988; Kraus and McDougal, 1996).

An 8-year field study was carried out along the central coast of California to resolve some of the seawall/beach impact questions (Griggs and others, 1994; Griggs and others, 1997). This is still the only long-term beach-seawall monitoring research that has been reported on in California. The project involved monthly cross-shore surveys of beaches fronting and both up and down coast from several different seawalls and revetments along the shoreline of northern Monterey Bay. The seawall that was monitored for the entire 8-year period was built 75 m seaward of the base of the coastal bluff and is exposed to wave impact every winter. Twelve cross-shore profiles at 60 m spacing were surveyed. These beaches undergo significant seasonal erosion and accretion, but are not experiencing long-term retreat. An additional factor in this area, which may be significant, is the average annual littoral drift rate of about 230,000 m^3/yr (Best and Griggs, 1991; Patsch and Griggs, 2006).

Figure 6. Passive erosion in southern Monterey Bay, California, has eliminated the beach in front of this riprap as the bluffs on either side continue to erode at more than 6 feet per year.

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A number of consistent beach changes related to seawalls were recognized during this monitoring. During the transition from summer to winter, the berm was cut back slightly sooner in front of the seawalls relative to adjacent unarmored beaches. Once the berm retreated landward of the seawall, however, there were no significant alongshore difference in the beach profile. Repeated surveys and comparisons at a vertical concrete seawall and a rock revetment indicate little consistent difference in profile response due to differences in permeability or reflectivity. Either the apparent differences in permeability of the two types of structures are not significant to wave reflection, or the importance of reflected wave energy to beach scour needs reconsideration.

Local scour was often observed at the downdrift end of each structure as a result of wave reflection from the angled end section of a seawall. The extent of this scour (which was usually only a few to perhaps several tens of meters in downcoast length, appears to be controlled by end-section or wing wall configuration, the angle of wave approach, and wave height and period.

Surveys of the spring and summer accretionary phase indicate that the berm advances seaward on the adjacent control beach until it reaches the seawall. At that point, a berm begins to form in front of the seawall and subsequent accretion occurs uniformly along shore. Thus while the winter erosional phase is influenced to some degree by the presence of a seawall, this is not the case for the berm rebuilding phase. Comparison of data from 8 years of surveys reveals no distinguishable differences between the winter or the summer profiles for the seawall and the adjacent control beaches. Since the completion of this study, there have been no other long- or short-term studies in California of the impacts of shoreline armor on adjacent beaches.

Conclusions

Few issues in coastal areas are more complex and more divisive or controversial than shoreline armoring practices or projects. The extent of seawalls and revetments along the shoreline suggests that such projects are necessary to protect property, but the numerous issues associated with them suggest much disagreement or differences of opinion about this necessity. The fact that armoring now protects 110 mi, or 10 percent, of the entire coastline of California is indicative of the magnitude of development in hazardous areas prone to severe to damaging erosion.

In recent years, considerable opposition has often arisen when new seawalls or revetments have been proposed because of the potential effects of these structures. These potential effects include visual impacts, restrictions on beach access, placement losses, the reduction of sand supply from previously eroding coastal bluffs following armoring, and passive erosion, or loss of the beach fronting a seawall as sea level continues to rise. An additional issue, which has arisen with the proliferation of coastal armoring, has been that of the direct impacts of a seawall on the beach itself, or active erosion. Long-term field investigations of seawalls and adjacent beaches along the coastline of Monterey Bay, California, where littoral drift rates are high, indicate that seawall induced erosion is not a significant issue at this location.

Well-designed and constructed soil nail walls can effectively mitigate visual impacts, access restriction, and placement losses. Passive erosion will likely have the greatest impacts on California's beaches as sea level continues to rise in the decades ahead.

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