CHAPTER 6
GEOLOGICAL RESOURCES AND COASTAL PROCESSES

6.1 AFFECTED ENVIRONMENT

6.1.1 Introduction/Region of Influence

The project area is in the Coast Ranges physiographic province. This province is characterized by low mountain ranges, generally parallel to the coast, with elevations of 1,500 to 3,000 feet, that were formed by plate tectonic forces associated with the San Andreas Fault system. Coastal areas are characterized by step-like marine terraces. The terrace deposits consist of sediments deposited below sea level. The terraces are above sea level now due to a combination of changing sea levels and uplift of the coastal land mass. The same processes that formed the landscape continue to act on it today, although at a nearly imperceptible rate. More noticeable, however, is the rate of coastline erosion, as waves attack and undercut the emergent land and force the nearly vertical bluffs to recede inland. This relentless wave erosion now threatens the integrity of East Cliff Drive and the scenic perspective it provides of the sea.

The region of influence for the proposed projects is determined by and interacts with the geologic environment. It includes East Cliff Drive from Pleasure Point to The Hook, the bluffs and the beach seaward of the road, the wave-cut platform seaward of the beach, adjacent downcoast areas, and the adjacent inland area. In other words, it includes all areas in which project activities are proposed, as well as adjacent areas in which geologic effects may occur.

6.1.2 Regulatory Considerations

Monterey Bay National Marine Sanctuary

The MBNMS overlaps the portion of the project area that lies within the mean high water line. Section 922.132 of the National Marine Sanctuary Program Regulations (15 CFR Part 922) describes activities that are either prohibited or regulated within the boundaries of the MBNMS. With certain exceptions, drilling into, dredging, or otherwise altering the seabed of the sanctuary or constructing, placing, or abandoning any structure, material, or other matter on the seabed of the sanctuary is prohibited without a permit.

Santa Cruz County General Plan

Section 6.1 of the General Plan (Santa Cruz County 1994b) requires a review of geologic hazards for all discretionary development projects in designated fault zones. Such a review could include a geologic hazards assessment. All new public facilities must be designed to withstand the expected ground shaking during an earthquake on the San Andreas Fault.

Sections 6.2.10 through 6.2.21 of the General Plan contain policy and specific guidance regarding coastal bluffs and beaches. Sections 6.2.10 through 6.2.13 require all developments to be sited to avoid coastal geologic hazards, a full geologic report for all new development activities within 100 feet of a coastal bluff, setbacks from coastal bluffs, and exceptions for foundation replacements. Section 6.2.16 sets out structural shoreline protection measures and certain design and study requirements, including monitoring and maintenance programs. Sections 6.2.17 through 6.2.21 set out prohibitions on buildings in coastal hazard areas, requirements regarding public services and density and limitations, and exceptions regarding setbacks of reconstruction of damaged structures on coastal bluffs. Section 6.2 also describes the Santa Cruz County programs for protection management of coastal bluffs and hazard areas.

Section 6.3 sets out the erosion control requirements and includes specific restrictions and management practices, including slope restrictions, grading and drainage requirements, erosion control plans, and land clearing permits.

6.1.3 Geologic Setting

Regional Overview

The San Andreas Fault lies about 10 miles east of the project area and forms the boundary between the North American continental plate and the Pacific oceanic plate. The Salinian Block, which is now part of the Pacific plate, was a piece of the North American continent. Its foundation is granitic rock that has moved northward from its origins in the Southern Sierra Nevada Range over the course of the past 15 million years. Although these rocks are exposed in the mountains south of Monterey Bay and in northern San Mateo County, most of Santa Cruz County is covered by thick deposits of younger sedimentary rocks deposited when the land was below sea level. The active Monterey Bay fault zone, and the Palo Colorado-San Gregorio fault zone further to the west, separate the Salinian Block from the San Simeon Block. The San Simeon Block is moving northward relative to the Salinian Block. For example, it has been estimated that the rock that now underlies Bolinas on the Point Reyes Peninsula was approximately opposite what is now the town of Davenport seven to nine million years ago (Stanley and Lillis 2000). The portion of the Salinian Block south of the Zayante Fault is also known as the Ben Lomond Block (Powell 1998).

About 8,000 feet of rock and sediments overlie the granite basement rock. The oldest sedimentary unit is about 1,800 feet of Monterey Formation. Over it is about 650 feet of the Santa Cruz Mudstone. Overlying the Santa Cruz Mudstone is about 1,200 feet of Santa Margarita sands. Overlying this unit is approximately 700 feet of the Purisima Formation, which in turn is either exposed on the sea floor or in the foothills of the Santa Cruz Mountains or is covered by deltaic and alluvial deposits or shelf deposits that can be up to 2,200 feet thick.

Purisima Formation

The Purisima Formation is the uppermost hard, or indurated, formation beneath the project area. The Purisima Formation supports the sea cliffs, from about Almar Avenue, along West Cliff Drive south, and eastward to Rio Del Mar. The Purisima is pervasively jointed or fractured, which provides weak planes within the bedrock that allow large blocks to fail or collapse. The orientation of the coastline in the East Cliff Drive area is quite linear, and is due to a dominant joint pattern in the Purisima Formation. The joints are evident throughout the project area and determine the slope and configuration of many of the rock outcrops.

The portion of the Purisima Formation exposed in the project area is near the top (youngest portion) of the formation, deposited in shallow waters during the early to late Pliocene Epoch (about two to five million years ago) (Powell 1998). The Purisima consists of interbedded mudstones, siltstones, and very fine-grained sandstones, with abundant shell debris in places, which vary in their hardness or resistance to erosion. The thickness of the beds within the Purisima Formation varies, from several inches to several feet, so that in thick-bedded areas it is difficult to see the layering in the rock. The bedding in the Purisima Formation is not horizontal because it has been subjected to plate tectonic forces that have warped, tilted, and faulted it.

Terrace Deposits

The sediments that were deposited on top of the Purisima are not old enough to have hardened, although they are held together loosely by clay and iron oxide. Groundwater flowing within the loose terrace deposits carried dissolved minerals that precipitated to form a weak cement that binds the sediments together. Nevertheless, if subjected to direct wave action, the terrace deposits tend to erode easily, and because the base of the deposits is particularly weak, the bottom tends to erode fastest. The different degrees of resistance to erosion are reflected in the profile of the bluff face. Stronger, better cemented deposits tend to form steeper slopes than loose poorly cemented deposits.

Terrace deposits are also subject to erosion from terrestrial processes, such as intense rainfall and stormwater runoff, or shaking from a strong earthquake. The rate of erosion of the bluff face also can be increased by human activities, such as by people climbing on the bluffs, or by failure of storm drains. Rodent burrows and plant roots also can weaken the bluffs.

In the project area the terrace deposits are high enough above sea level (about 10 feet or more) that they are subjected to direct wave action relatively infrequently and mainly as a result of major winter storms that approach from the south. This type of storm occurs on average about every three to five years. Most of the time, waves break against the exposed Purisima bedrock. The bedrock becomes scoured and abraded at the base of the bluffs, where the wave action is most intense and persistent and where the waves suspend sand. This scouring and abrasion causes notches or undercuts to form within the mean daily tidal range. Eventually, this undercutting intersects vertical joints in the Purisima bedrock and the bedrock cannot support the weight of the deposits above. The bedrock fails and the terrace deposits that overlie it also collapse. The failure may not occur until five to 10 feet of undercutting has occurred, so that the bluffs collapse from time to time at irregular intervals. This process has been occurring at a rapid enough average rate (estimated to be about one foot per year in the project area) that in spite of the weakness of the terrace deposits, they tend to form relatively steep slopes. It is difficult to find areas in which the terrace deposits are subjected only to erosion from slower terrestrial processes (stormwater runoff, seismic shaking, weathering), and where the slope of the terrace deposits is not a function of the rapid collapse of the underlying Purisima Formation.

Over the long term, the Purisima Formation apparently retreats more rapidly than the terrace deposits and therefore controls the rate of retreat of the whole bluff. However, if the Purisima Formation were more resistant to scouring and undercutting, then bluff-top retreat would be controlled by the rate of erosion of the terrace deposits only. As can be seen in some areas along the shore of the project area, the Purisima bedrock forms ledges that extend out from the base of the bluff. These are points at which the overlying terrace deposits have retreated faster than the rate of retreat of the Purisima bedrock.

6.1.4 Soils

The soil covering the bluffs and terrace, from Pleasure Point to the Opal Cliffs, is classified as Watsonville loam (Bowman and Estrada 1980). The typical surface soil is a very dark, grayish brown, slightly acid loam, about 20 inches thick. The subsoil is pale brown to light gray slightly acid clay, about 21 inches thick. Below this, to a depth of about five feet, is light gray lightly acid sandy clay loam. The soil permeability (ability of water to flow through the pores in the soil) is very slow, and the water retention capacity is 4.5 to 6 inches. The clay acts as a barrier to downward movement of ground water at times, causing water to build up, or "perch" on the clay layers. Roots are restricted to cracks in the clay below a depth of 20 to 40 inches. Engineering limitations of the soil include shrink-swell potential, low strength, and very slow permeability. The soil survey report for Santa Cruz County indicates that special design is needed for building pads, roads, and other urban structures constructed on Watsonville loam soil (Bowman and Estrada 1980).

6.1.5 Seismicity

Regional Faults

The San Andreas Fault system includes the San Andreas Fault and other associated regional faults on which the primary sense of movement is right-lateral strike-slip. A strike-slip fault is one in which the ground movement is mainly horizontal rather than vertical, although there is typically also a vertical component of movement. A right-lateral fault is one in which, when you are facing across the fault trace, the block opposite is moving to the right relative to the block you are standing on. Thus, the Salinian Block, which is on the west side of the San Andreas Fault, moves northward relative to the inland block.

The trace of the San Andreas Fault is about 10 miles east of the project area. However, other active right-lateral strike slip faults that are part of the San Andreas Fault system include the Sargent Fault, about two miles east of the San Andreas Fault, the San Gregorio Fault and the Palo Colorado Fault, about 12 miles west of the project area, and the Monterey Bay Fault zone, about five to seven miles west of the project area. Farther to the east are the Calaveras Fault (about 25 miles) and the Ortigali Fault zone (a little more than 40 miles). In addition, the epicenter of the 1989 Loma Prieta earthquake was near the Zayante Fault, less than eight miles northeast of Pleasure Point. The magnitude of the Loma Prieta earthquake was 7.1 and occurred at a depth of about 11 miles. The San Andreas Fault is capable of generating earthquakes of magnitude 6.8 to 8.0.

Seismic Hazards

The project area does not contain any known active faults and so has no designated Alquist-Priolo fault rupture hazard zones. (Alquist-Priolo fault rupture zones are those on each side of an active fault, as determined by the California Division of Mines and Geology, in which ground rupture is considered to be likely. New construction is generally restricted or prohibited within Alquist-Priolo fault rupture zones.) An active or potentially active fault is defined as one that has been active within the past 11,000 years (Hart 1992). The Purisima Formation does contain ancient faults, but there is no evidence of displacement of the terrace deposits on top of the Purisima, indicating that these faults have probably not been active during the past 80,000 years. The seismic hazards in the project area, therefore, result from the potential effects of ground shaking during earthquakes on active faults some distance from the project area.

The intensity of ground shaking and the amount of damage that occurs at a given location in an earthquake is a function of the magnitude of the earthquake at its source, the distance from the epicenter, the duration of the earthquake, and the nature of the geologic materials beneath the area. In the Loma Prieta earthquake, the peak horizontal component of ground acceleration in the area vicinity was on the order of 0.60 times the acceleration of gravity (g), while the peak vertical component was about 0.54 g (Sydnor et al. 1990). Sydnor et al. (1990) show that the intensity in the projected vicinity of ground shaking from the Loma Prieta earthquake was moderate, about VII on the modified Mercali intensity scale. With a range from I to XII (Roman numerals 1 to 12), the Mercali Scale measures an earthquake according to the observable results or effects the damage caused and the sensations described by people. Mercali numbers do not correspond directly to Richter numbers; for example, V on the Mercali Scale is not equivalent to 5 on the Richter Scale. A reading of VII on the Mercali scale is defined as some people falling over and some walls cracking (UC Regents 1995).

Parks (2001) estimated the horizontal and vertical ground motion coefficients for the Uniform Building Code Design Manual and soil type Sc, to be 0.44 and 0.64 g, respectively, based on the San Andreas Fault being the controlling fault. Sydnor et al. (1990) surveyed the cliffs within the project area and found no evidence of slope failure as a result of the Loma Prieta earthquake, although they did note significant slope failures in the higher bluffs to the east, in the Capitola area, as well as some evidence of collapse of discontinuous sand layers, or lenses, within the terrace deposits. They noted that immediately prior to the earthquake the area was experiencing a drought, and therefore the terrace sediments were relatively dry. They concluded that liquefaction had not been a leading factor in bluff failure during the earthquake, although they noted that if the quake had occurred after a period of wet weather, there may have been more extensive landsliding.

Liquefaction is the sudden loss of strength of soils or sediments as the result of a rapid increase in pore water pressure, usually in water-saturated sandy sediments when subjected to vibration (such as from an earthquake). When sediments liquefy, they no longer can support overlying structures or sediments, which can collapse or sink. Loose sandy layers within the terrace deposits may be susceptible to liquefaction if saturated. However, the open bluff face provides a large surface through which groundwater can drain, which under current conditions prevents groundwater levels from rising. Also, surface drainage systems intercept much of the rainfall, downward vertical movement of this rainwater through the terrace soils is impeded by shallow clays, the permeability of the soils is slow, and a large proportion of the land area in the vicinity of the projects are covered by impervious surfaces, such as streets, houses, and concrete. Each of these factors reduces the potential for groundwater to rise within the terrace deposits. Finally, the terrace deposits are weakly cemented, which resists liquefaction; therefore, under normal conditions, the deposits are not highly susceptible to liquefaction.

6.1.6 Waves and Currents

The ocean surface is rarely calm, and waves are constantly being created as the wind blows across the water surface. The energy from the wind is transmitted to the ocean, initially creating small ripples, but as the wind increases in velocity and blows over a longer distance and for a longer period, the waves get larger. In the middle of a storm at sea, where the wind is blowing hard and transmitting energy to the sea surface and forming waves, the ocean surface and the waves are very irregular, and it is difficult to separate out distinct waves. Such a condition is referred to by oceanographers as *sea*. With time, however, because the longer waves move at higher speeds and tend to move out ahead of the shorter waves, a sorting process takes place and there is a more regular set of waves of similar dimensions. This condition is known as *swell*. Long period swells can move thousands of miles across the ocean; in one experiment, individual groups of waves were tracked by physical oceanographers from their formation, during a storm off New Zealand, completely across the Pacific Ocean, to where they finally broke on a beach in Alaska.

Wave Refraction

As waves approach the shoreline they undergo change as they interact with the bottom. At a water depth equal to about half the wave length, the wave begins to encounter the sea floor (an action sometimes referred to as the wave "feeling bottom"). This begins to reduce the forward speed of the wave. The wave length begins to shorten, and the wave height begins to increase (Photo 6-1).

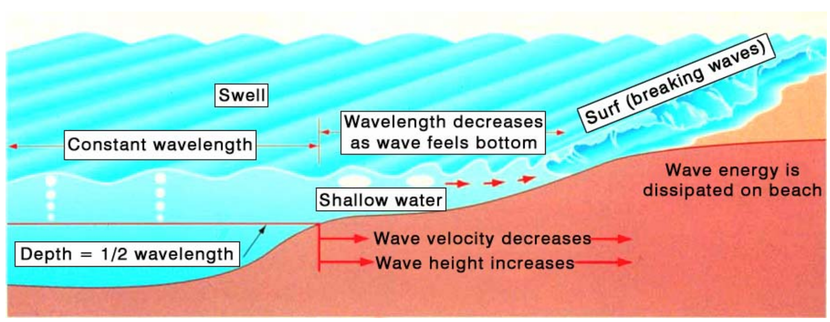


Photo 6-1. Feeling bottom. (Source: G. Griggs)

Approaching the shore, waves undergo *refraction*, or bending, as the wave fronts begin to parallel the bottom contours near the shoreline. This happens because the portion of the wave in shallow water is slowing down sooner than in deeper water. This process of wave refraction tends to focus wave energy on headlands or points and to disperse the energy over submarine canyons or deeper nearshore areas (Photo 6-2). An example of refraction can be seen along the shoreline of northern Monterey Bay where waves typically arrive from the northwest. As the waves approach Lighthouse Point, they begin to feel bottom, slow down and then refract or bend, causing them to wrap around Lighthouse Point (Photo 6-3).

It is the process of wave refraction that makes surfing possible. Waves break when the ratio of wave height to water depth is about three to four; a three-foot wave will break in four feet of water, a six-foot wave will break in about eight feet of water, and so on. As the waves bend around Lighthouse Point, for example, the crest closest to the point breaks first and then the wave breaks progressively toward the wharf as that portion reaches its break point. The combination of sea floor topography and the angle of wave approach is what helps to create an ideal surfing area and long rideable waves.

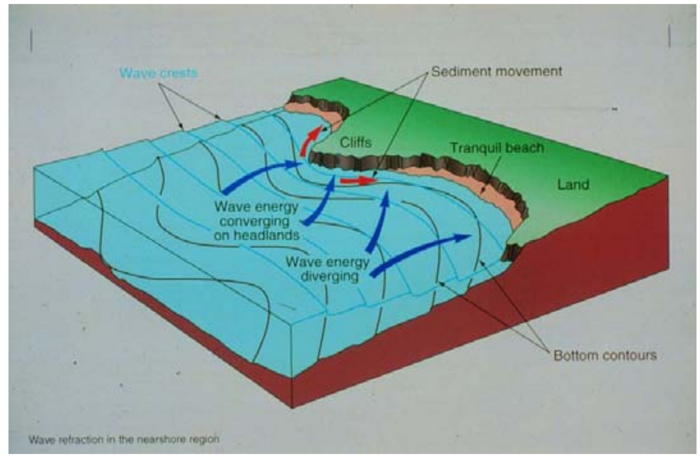


Photo 6-2. Wave refraction. (Source: G. Griggs)

Photo 6-3. Wave refraction near Lighthouse Point. (Source: G. Griggs)

Wave Reflection

Waves also undergo *reflection,* where they strike a vertical or near vertical structure or obstacle. Waves naturally reflect off vertical cliffs along much of West Cliff and East Cliff and send reflected waves offshore to collide with the incoming waves. Reflected waves typically encounter the incoming waves very soon, so their influence doesn't extend very far offshore. Where incoming waves strike vertical seawalls or even sloping revetments at high tide, they also can be reflected. Waves do not discern between a vertical concrete wall and a vertical cliff face, however, and the reflection process is the same.

Wave Interference

Waves vary in size, even over the span of a few minutes. Surfers notice this variation and that waves tend to come in sets or groups of larger waves separated by long periods with smaller waves. The process responsible for this is *wave interference.* At any particular time several different wave fronts will be approaching the nearshore zone from different storm areas. For example, at Lighthouse Point there may be a long period swell arriving from the northeast Pacific, another shorter period swell arriving from a storm off Hawaii, and then smaller waves generated by local winds a few hundred miles offshore. As these wave crests and troughs arrive at the shoreline, they begin to interact with one another. When the crests from two or more wave trains are in phase or arrive at the same time, the waves will be much higher. So the timing of sets and the number and size of the waves in any set is a result of the differences in the various incoming wave fronts. Conversely, when a crest from one wave train meets the trough from another, they tend to cancel out each other and we have a very low wave or none at all.

Recreational Waves

Recreational waves are those with characteristics that make them suitable for surfing. The Pleasure Point break, directly offshore from 33rd and 34th avenues, along with The Hook, off the end of 41st Avenue, are perhaps the most intensively used surf breaks in the Santa Cruz area. Because of the popularity of these areas, there is concern in the surfing community about the effects of coastal engineering projects on recreational wave size and quality.

Wave conditions near the project area are excellent for surfing, and the area is one of the most intensively used surfing locations in the Monterey Bay area. Waves typically break 400 to 600 feet offshore. The proposed project area is affected by both Northern Hemisphere and Southern Hemisphere swells. (A swell is a long wave that moves continuously without breaking).

The winter swell is usually generated by Northern Hemisphere storms. Typically, the swell from these storms comes from the northwest, and the project area is partially protected from these swells. Waves from the west or southwest can be the most damaging to the Pleasure Point area because they approach the shoreline with little refraction or energy loss. These waves are especially common during El Niño years, when significant bluff erosion can take place. Deepwater wave conditions off Monterey Bay can be severe. The largest wave recorded was 30 feet high, with a period of 20 seconds (Corps 1998). More typical deepwater storm conditions consist of wave heights in the 20-foot range, with periods ranging from 10 to 20 seconds. Soquel Point greatly reduces much of the wave energy that reaches the location of the proposed projects from the northwest.

It has been determined through direct observations, along with measurements taken from aerial photographs from 1928, 1943, 1956, 1963, 1975 and 1982, that waves at Pleasure Point usually break from about 400 to 600 feet offshore. As discussed earlier, the location or distance offshore where the waves break is determined by the relationship between wave height and water depths with waves breaking at a height to depth ratio of about three to four. Smaller waves break in shallower water closer to shore, and the larger winter waves break farther offshore in deeper water. The location of the main break at Pleasure Point is thus determined by water depth and, at this particular area, by the presence of Purisima Formation outcrops on the sea floor. The location of the bedrock outcrops is clearly visible on the aerial photographs of the area. Kelp grows only where bedrock is available to provide an anchor for holdfasts and the areas of kelp are clearly visible. These locations have not changed significantly in nearly 75 years.

The direction of wave approach also affects the break with El Niño waves approaching from the west or southwest, in contrast to the typical northwesterly wave approach; this, however, doesn't significantly affect the depth or distance offshore at which the waves break and where surfers can take off.

The break at The Hook is somewhat closer to shore (aerial photos indicate approximately 300 to 400 feet offshore). Otherwise, the conditions are the same as those upcoast at Pleasure Point. The waves continue to break offshore at the same location, closer to shore or in shallower water for lower waves and farther offshore for larger waves. Note that the location where the waves break and the shape of the breaking wave has no relationship to the cliffs but depends on the offshore bathymetry, the angle of wave approach, and the height of the incoming waves. At very high tides, the white water of the broken wave may reach the bluffs and be reflected a short distance offshore until encountering the next broken wave.

Longshore Currents

The downcoast flow of water in the nearshore zone is the longshore current. This current is powered by predominantly northwesterly winds and waves generated in the northern Pacific. These waves bend shoreward as they approach the shallow waters of the coast and refract around points of land so that, although the waves maintain a south-trending component, much of their energy is expended against the coast. The longshore current bends into Monterey Bay as it rounds the coast near Davenport and continues to parallel the shore past the West Cliff area and Santa Cruz Harbor. Additional sand enters the littoral system from the San Lorenzo River, west of the project area.

6.1.7 Bluff Erosion

Long-Term Processes

In the project area, cliff heights range between 25 and 40 feet. The underlying bedrock throughout the entire project area, which is well exposed in the sea cliffs, consists of about 8 to 15 feet of well-consolidated siltstones and mudstones of the Purisima Formation, capped by about 10 to 25 feet of semiconsolidated terrace deposits (Photos 6-4 and 6-5).

Photo 6-4. Example of bluff erosion. (Source: G. Griggs)

The California coast is a geologically active area and has been slowly rising for at least the last million or so years. The series of up to five uplifted marine terraces that underlie most of coastal Santa Cruz County are evidence of this tectonic uplift and a result of the interaction between a slowly rising land mass (~0.4 mm/year) and an oscillating sea level. During warm periods, continental ice sheets and glaciers melt, sea level rises, and waves erode the shoreline and bevel off a wave-cut platform in the underlying Purisima Formation bedrock. When the climate cools, sea level drops, the shoreline moves offshore, and the retreating ocean lays down a sequence of sediments over the platform; these “terrace deposits” typically consist of beach and nearshore sands and gravels, often dune

Photo 6-5. Bluff erosion along East Cliff Drive. (Source: G. Griggs)

sands, and stream sediments (mixtures of clay, silt, sand and gravel); over time a soil sequence gradually develops on top of the terrace deposits.

Erosion of the Purisima Formation

In contrast to the underlying and older Santa Cruz Mudstone, which forms the cliffs from Almar Avenue on West Cliff northward to the Santa Cruz County line near Waddell Bluffs, the Purisima is younger, weaker, and more susceptible to wave attack and bluff failure.

Typically, along the East Cliff Drive, it is the stratigraphic weaknesses, such as the erodible layers exposed in the surf zone at beach level, or the structural weaknesses, such as the orientation and spacing of joint sets, and exposure to wave attack that determine the type and rate of cliff failure and erosion. Faulting also plays a role in the evolution of the shoreline in this area. Faulting in the sea cliffs has offset individual layers or beds of differing resistance within the Purisima. The presence of resistant outcrops of Purisima at beach level that extend out across the beach along the project area, adjacent to softer and more easily eroded layers that form embayments, is due in many cases to fault displacement, which has juxtaposed layers of very different resistance to wave erosion at beach level.

Causes of Bluff Failure

Bluff failure takes place through processes related to the sea (mainly those that affect wave action) and to the land (rainfall and runoff, weathering, earthquakes), although the terrestrial processes are less often appreciated than the marine processes. Wave attack during periods of high tides or otherwise elevated sea level (e.g. El Niño or storm surge) is one of the most common mechanisms of episodic cliff failure in this area (Storlazzi and Griggs 2000). El Niño increases storm frequency and elevates sea levels, wave height and rainfall. Storlazzi and Griggs researched the El Niño, storm frequency, and coastal erosion history from 1910 to 1995 for the central California coast. Fifty-nine storms that caused significant coastal erosion or reported damage to structures were documented in this 85-year period. The storms occurred in 35 different years and all were characterized by larger than normal wave heights. Of the 48 storms that had their direction of origin reported (81 percent), 39 came out of the southwest and generated large southerly to westerly storm waves not commonly observed along the central coast during winter. In all 15 years in which sea cliff erosion was documented, the storms had originated from the southwest. Of these storms that caused significant erosion or structural damage along the central coast, approximately 76 percent (48 storms) occurred during El Niño storms.

The elevated sea levels and waves that arrive from the west or southwest during these El Niño storms are responsible for most of the erosion and wave damage in the project area. This is due not only to a combination of raised water levels and higher waves, but also to the direct wave approach and lack of refraction that reduces the height of the more common northwesterly waves. In addition, intense or prolonged rainfall and runoff or intense seismic shaking are capable of producing cliff failure and have been well documented along the cliffs of northern Monterey Bay (Griggs 1982; Plant and Griggs 1990).

6.1.8 Project Area Bluff Conditions

Many previously surveyed cross-sections through the bluffs of the project area (Foxx, Nielsen & Associates 1999), as well as a field survey at low tide during this study, indicate the significance of surf zone undercutting of the Purisima Formation in the bluff failure process. Undercuts or notches extending from a few feet up to 15 feet at the base of the bluff are common in the project area. This erosion process most likely proceeds by wave attack along weak layers and progressively removes the support for the overlying bedrock. Such activity is evident from the presence of worn and rounded concrete cobbles at the base of the cliff, adjacent to and within the undercut notches. At times of high tides and winter storm waves, the cobbles have served as an effective tool to grind and abrade the base of the bluff and the notches.

Then follows a sequence of events described and clearly depicted by Weber (2000). With the support removed, the overlying bedrock ultimately will fail. There are large blocks of Purisima (up to 6 feet by 7 feet by 13 feet) on the beach in areas where this collapse has recently taken place. These blocks are gradually worn down and abraded but offer some protection to the bluff from wave attack in the interim.

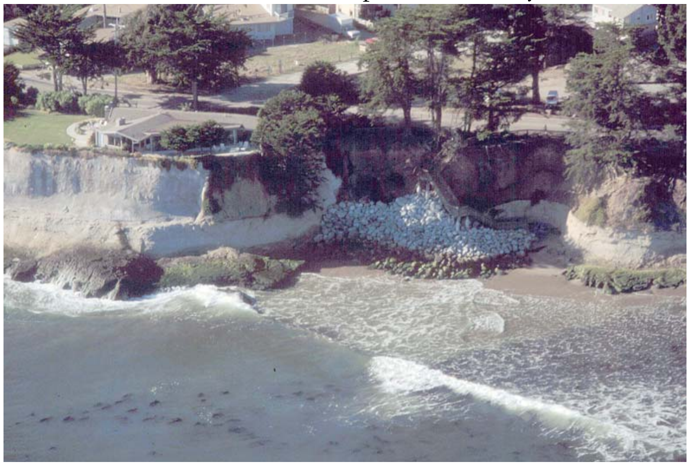


Photo 6-6. 1984 photo near 41st Avenue. (Source: G. Griggs)

Following undercutting and collapse of the Purisima bedrock, the overlying terrace deposits are unsupported and subsequently will fail. Depending on the strength or consolidation and water content of the terrace deposits, they may be able to stand at near vertical slopes for some time, as they do at the end of 41st Avenue (Photo 6-6). In the 33rd to 36th avenue section, the terrace deposits are consolidated enough to stand at 45 to 60 degree slopes in most places (Photo 6-7). In addition to localized slumping and sloughing, the terrace sands and gravels are also subject to rainfall and runoff that lead to sheet wash, gullies, and accelerated erosion. While these are natural processes, they can be accelerated by additional runoff from impervious surfaces (such as East Cliff Drive) or from storm drains that discharge directly onto these materials. During times of elevated sea levels and high tides, particularly during El Niño storms, broken waves can overtop the Purisima platform and reach the terrace deposits, contributing to their erosion.

Photo 6-7. Bluffs near 38th Avenue. (Source: G. Griggs)

The present-day bluff profiles provide the best evidence for the significance of this wave overtopping and erosional process (Foxx, Nielsen & Associates 1999). Throughout much of the 33rd to 36th avenue area, the Purisima rises vertically from beach level for six to 10 feet, and then there is often a narrow bench, wider in places, where the terrace deposits have been removed, and then a 45 to 60 degree slope in the terrace deposits to the bluff-top. It is evident that the degree of wave overtopping of the bedrock platform is limited and this controls how far back the terrace deposits can be eroded. The maximum width of the exposed Purisima platform measured was 24 feet in the 33rd to 36th avenue section although, in most places, this is considerably less. These exposures provide evidence that over time, the Purisima bedrock and the terrace deposits have to be eroding back at the same rate. These field exposures also indicate that while the terrace deposits can continue to erode, even with protection or stabilization of the Purisima, that the extent to which this can take place is limited by how far waves can wash up over the bedrock and erode the terrace materials.

Effects of Sea Level Rise

The five-mile stretch of sea cliffs between Santa Cruz and Capitola is actively being eroded and has been for approximately 15,000 years, ever since the last Ice Age ended. At that time, about 11 million cubic miles of seawater stored on the continents as ice caps and glaciers began to melt, thus starting to raise sea level. This process continues today, although at a slower rate than for much of the past 18,000 years. While at the peak of the warming period sea level rose at an average rate of about half an inch per year, today global sea levels rise on the order of 1.8 millimeters per year, or a little less than a tenth of an inch annually (Peltier and Tushingham 1989). This rate of sea level rise is expected to continue throughout the project period.

Estimating Bluff Erosion Rates

While annual rates of historic bluff retreat along the central coast today are as high as five to 10 feet per year in a few places (Año Nuevo Point and Ft. Ord, for example), more typically, the average long-term annual erosion rates in the Purisima Formation between Santa Cruz Harbor and Capitola are in the range of six inches to a foot or two per year (Griggs and Johnson 1979; Griggs, Patsch, and Savoy 2005; Griggs 1994a; Moore, Benumof, and Griggs 1999; Moore 1998). The placement of riprap along much of the East Cliff Drive area, however, has significantly reduced these rates over the past 20 to 25 years.

Based on both historic aerial photographs (that extend back to 1928) and also parcel maps, long-term average annual erosion rates in the 33rd to 41st avenue area range from about six inches to a foot annually. Calculated erosion rates may vary over time for different historic periods (due to variations in storm frequency and El Niño occurrences) and with location due to alongshore differences in rock resistance. Over time, however, the relatively uniform northeast-southwest alongshore trend of the shoreline from Pleasure Point to New Brighton Beach indicates that the entire area of approximately 2.5 miles of coastal bluffs is retreating in a relatively uniform fashion and is controlled by the orientation of joints in the rock.

Average annual bluff erosion rates are based on careful measurements taken from historic aerial photographs and maps. While these rates can be calculated, they are only an average. In reality, failure tends to occur in episodes, with large blocks or masses falling from the bluff as the strength of the material is exceeded by the forces producing failure. The size of the failed blocks within the Purisima bedrock in the project area is typically determined by the spacing of the master joints, as it is elsewhere along East Cliff Drive. The very large block of Purisima at the base of the bluffs opposite the end of 35th Avenue is good evidence for this process.

6.1.9 Sand Movement (Sources and Transport)

Littoral Drift

Along most of the California coast, the great majority of beach sand (75 to 95 percent in most littoral cells) is derived from rivers and streams, with most of the remaining sand coming from bluff erosion. Once the sand arrives at the shoreline, it moves alongshore under the influence of prevailing wave conditions and ultimately is lost downcoast, either to a submarine canyon or to a dune field (Inman and Frautschy 1966).

Pleasure Point lies within the Santa Cruz littoral cell, which has been considerably studied over the past four decades. It extends from south of San Francisco at San Pedro Point downcoast to Monterey Submarine Canyon in the central portion of Monterey Bay (Inman 1976; Best and Griggs 1991a, 1991b; Limber 2005). Waves from the northwest dominate this portion of the California coast and drive littoral drift from north to south. In the Pleasure Point area, because of the shape of the coastline, littoral drift actually moves from southwest to northeast. The major sources of sand for the Santa Cruz littoral cell are the coastal streams draining the mountains of San Francisco, San Mateo, and Santa Cruz counties, and erosion of the coastal cliffs, bluffs, and dunes throughout the 106 miles of the Santa Cruz littoral cell. Although sediment input to the littoral cell is highly episodic in response to large storms that both erode the coastal bluffs and also produce high stream discharges, the rate at which sand moves alongshore as littoral drift tends to be more uniform over time.

Littoral Drift Rates

The construction of the Santa Cruz Small Craft Harbor in 1963-1965 had an impact on littoral drift and on upcoast and downcoast beaches, and the County of Santa Cruz realized that regular dredging would be needed to maintain the entrance channel. A number of studies have been undertaken over the years in an effort to quantify the littoral drift rate at the harbor. Potential littoral transport rates have been calculated in the vicinity of the harbor from both wave hindcast data (Anderson 1971; Walker et al. 1978) and from wave data measured directly offshore, near the one-mile buoy (Seymour et al. 1980).

Estimates by Moore (1972), Walker and Dunham (1978), and Walker and Williams (1980) put the net annual longshore transport rates at 250,000 and 300,000 cubic yards. These figures are based on rates of deposition against the upcoast jetty of Santa Cruz Harbor following its construction. Walker and Williams (1980) suggest that 175,000 to 375,000 cubic yards of sand annually bypasses the harbor mouth. Alternatively, Seymour, Domurat, and Pirie (1980) concluded that the amount of sand bypassing was minimal. An analysis of aerial photographs from the harbor mouth and the beach shape on opposite sides of the harbor suggest some bypassing is taking place, although the volume is unknown (Photo 6-8).

Photo 6-8. Santa Cruz Harbor entrance. (Source: G. Griggs)

Griggs and Johnson (1976), Walker and Williams (1980), and Griggs (1987) used dredging data from Santa Cruz Harbor to obtain minimum values for rates of littoral drift. Dredging has now been carried out at the harbor for 40 years so there is an extensive database available. This relatively recent data is more representative of long-term littoral drift rates because significant volumes of sand were impounded against the west jetty from when construction began to approximately 1977. During this period, Seabright Beach widened until equilibrium was reached, and then most of the sand began to bypass the beach and enter the harbor.

Patsch (2005) recently completed an investigation of the sand budgets for all of California's major littoral cells. In the Santa Cruz cell, she built on the earlier studies, as well as the dredging history of the Santa Cruz Small Craft Harbor, and concluded that the average annual littoral drift rate at the harbor from 1977 to 2004 was approximately 200,000 cubic yards (approximately 153,000 cubic meters). In 1977, Seabright Beach was believed to be fully charged, such that all littoral drift had to move into the harbor entrance or across it to Twin Lakes Beach. However, more recent aerial photographs indicate that the west jetty may have continued to impound additional sand after 1977, widening Seabright and Main Beach in some summers, beyond or seaward of San Lorenzo Point, the previous natural groin for Main Beach. Dredging volumes from 1995 to 2004 average 235,000 cubic yards (180,000 cubic meters) per year, provide additional support for this observation. Dredge figures are probably minimums because they do not account for any sand bypassing the harbor entrance naturally.

The estimate for averaging annual littoral drift in the Santa Cruz littoral cell is based on the following:

- Evaluation of all previous calculations of rates of littoral transport and potential littoral transport at Santa Cruz Harbor;
- 40 years of annual dredging volumes; and
- The belief that a significant volume of sand bypasses the entrance.

Therefore, the best estimate for average annual littoral drift at this point in the Santa Cruz littoral cell is in the range of 250,000 to 325,000 cubic yards annually. This figure will vary somewhat from year to year, based on wave climate and sediment availability. For the Santa Cruz littoral cell, the most recent assessment of source volumes indicates that rivers and smaller streams contribute 66 percent of the total sand, coastal gullies and sand dunes contribute 22 percent, and cliff and bluff retreat contributes 12 percent (Patsch 2005).

The sand is regularly dredged out of the harbor mouth and is placed on Twin Lakes Beach where it reenters the littoral system. It then is transported downcoast or southeastward by the prevailing waves toward Pleasure Point. Black Point and Pleasure Point form natural groins or obstructions to littoral drift, allowing upcoast beaches to form (Photo 6-9). Because much of the shoreline between the harbor and Pleasure Point has been armored, there is little erosion in this area, and thus no significant additional littoral sand is added from bluff erosion. Stream sediment contributions in this reach are also insignificant such that the littoral drift rate calculated at the harbor is a reasonable value for the annual littoral drift volume in Pleasure Point.

Photo 6-9. Purisima outcrop in front of O'Neill house that serves as a natural groin, which traps littoral drift. (Source: G. Griggs)

Hicks first developed the concept of littoral cutoff diameter in 1985 for a study of the Santa Cruz beaches. Best and Griggs (1991a, 1991b) used the littoral cutoff diameter for the Santa Cruz littoral cell budget, and Runyan and Griggs (2003) used it for two large littoral cells in southern California. The assumption had been made for years that any material of sand size or larger (greater than 0.002 inch [0.062 millimeter] in diameter) delivered to the shoreline from any source (from river discharge or cliff erosion, for example) would become part of the beach or the littoral system. However, a careful look at the grain size of the material on the beaches of California indicates that, depending on the grain size of the available material and wave energy prevalent on any particular area of shoreline, the beach material may be considerably coarser; that is, the beach may consist of medium-grained or coarse-grained sand, or in some cases, pebbles or larger material. In other words, beaches are not made up of only small particles of sand, and in fact smaller grains of sand may be more likely to be transported by offshore wave action.

The littoral cutoff diameter is defined as a grain size D_{10} (sediment diameter for which 10 percent of the material is finer grained and 90 percent is coarser) plus one standard deviation (Hicks 1985; Best and Griggs 1991a, 1991b). Littoral cutoff diameter is positively correlated with wave energy in that sediment smaller than the cutoff will be carried offshore under lower energy conditions. In determining how important some specific source of sand is to a littoral cell or to the littoral budget, it is important to first determine what the littoral cutoff diameter is for the beaches of the cell. Material delivered by any sand source that is finer grained than this size will not remain on the beach and will not become part of the beach system or littoral budget.

Sand Contribution from Bluff Erosion

The contribution of sand from coastal bluff or cliff erosion to the littoral drift system can be relatively straightforward to calculate and can be considerably more accurate than measurements of other inputs, river sediment discharge, for example (Best and Griggs 1991a, 1991b; Patsch 2005; Willis and Griggs 2003). The average annual production of littoral sand from a segment of coastline through sea cliff erosion (Qs) is equal to the product of the cross-sectional area of sea cliff (A, equal to cliff length times cliff height), the average annual rate of cliff retreat (R), and the percentage of the cliff material greater than the littoral cutoff diameter (percent littoral sand), or :

$$Qs = (A)(R)\ (\%\ \text{littoral sand})$$

Each of these components needs to be assessed at the Pleasure Point project site in order to develop as accurate a measurement as possible of the contributions of bluff erosion to the littoral cell so that any possible impacts of bluff stabilization can be determined.

Rates of Cliff Retreat

Rates of sea cliff retreat are governed by the ability of large storm waves to attack the base of the cliff, and the relative ease with which cliff material can be dislodged, either directly by wave attack, or through subaerial processes such as runoff, gullying, or soil slumps. Episodic and locally variable rates of cliff retreat result from a combination of the following:

- Differences in the strength of cliff materials (Griggs and Johnson 1979);
- The infrequent occurrence of high tides and extreme storm waves capable of producing significant erosion and removing debris from the base of the cliff (conditions common during El Niño events);
- Concentration of wave energy due to local bathymetry;
- The presence or absence of a protective beach; and
- Other episodes that may affect bluff or cliff failure, such as earthquakes, prolonged and intense rainstorms, or bluff saturation followed by slumping.

The 7.0 magnitude 1989 Loma Prieta earthquake was the largest earthquake to affect the central coast since the 1906 San Francisco earthquake, and it produced cliff failures from Marin County to central Monterey Bay (Plant and Griggs 1990a, 1990b, 1991). For the most part these seismically induced failures consisted of isolated rockfalls, soil slips, or slumps, resulting in up to three feet of bluff retreat. Similar cliff failures were noted during the 1906 San Francisco earthquake in the Santa Cruz area (Lawson 1908). Plant and Griggs (1990a, 1990b, 1991) documented the earthquake-induced slope failures in the sea cliffs of northern Monterey Bay following the Loma Prieta earthquake. While there were no mapped failures between Pleasure Point and 36th Avenue, there were two failures of terrace deposits onto the beach at Larch Lane, and another failure of terrace deposits near the end of 41st Avenue.

A comprehensive discussion of the issues related to quantifying bluff erosion rates in general, and the retreat rates in the project area more specifically, was provided in Section 2. The following is a summary of the reported data on bluff erosion rates for the project area:

- Griggs and Johnson (1979) completed the earliest cliff erosion measurements for the area using a combination of old maps and historic aerial photographs that spanned the period from 1850 to 1975. They used an optical comparator and determined average annual cliff erosion rates ranging from 0.75 to 1.0 foot (23 to 30 centimeters) in the project area.
- Griggs (1994b) used an extensive set of aerial photographs dating from 1928 to 1993, and again using an optical comparator, to calculate average annual erosion rates between Pleasure Point and 41st Avenue, ranging from 0 to 0.75 foot (0 to 23 centimeters).
- Foxx, Nielsen, and Associates (1998b) in their engineering geology study of the proposed coastal bluff stabilization project between 33rd and 36th avenues calculated average annual bluff erosion rates using aerial photographs from 1943 and 1986 that ranged from 0.75 to 0.93 foot (23 to 28 centimeters). This same report included a cross-check using assessor's parcel maps from the 1950s and present day topography. Results

showed rates ranging from 0.37 foot (11 centimeters) per year to 1.1 feet (34 centimeters) per year. Foxx, Nielsen's conclusion was that the best long-term estimate of the average retreat rate for the bluff edge was 1 foot (30 centimeters) per year, which is in the high range of the values measured over the years, so it provides a worst-case condition.

- Moore (1998) and Moore, Benumof, and Griggs (1999) used soft-copy photogrammetry, the most precise technique available, to measure coastal bluff retreat from 1953 to 1994. While there are some small areas where no erosion was documented over this 41-year interval, most of the erosion rate values fell into the 0.2 to 0.65 foot (6 to 20 centimeter) per year range. This is a shorter interval than was used in some of the previous studies, but it does include both La Niña (1953-1978) and El Niño (1978-1994) periods, so it is a representative and a reasonably long period for bluff erosion data. Based on cross-sections spaced about 16 feet (five meters) apart, the average rate from this recent and most precise work is .33 foot (10 centimeters) per year.

What is reassuring is that, spanning 20 years of research, using over 100 years of maps and aerial photographs and a variety of methods, all of the cliff erosion rates for this site calculate consistently in the 0.3 to 1 foot (9 to 30 centimeters) per year range. Based on all of the studies to date, and weighing the most recent data from Moore (1998) and Moore, Benumof, and Griggs (1999), who used the most accurate and precise methods available, it is prudent to use an average annual bluff erosion rate of six inches (18 centimeters) in calculating the potential production of sand from bluff erosion. This is slightly higher than the average rate (0.3 foot year [9 centimeters]) but is a more conservative approach. While the bluff could be broken up or segmented into smaller areas for analysis, with slightly different long-term erosion rates, the linear pattern of the bluff along the Pleasure Point project area and the uniformity of the bluff-forming materials throughout the 1,400 feet (427meters) of project area indicate that over time, these rates would average out and this effort would not improve the reliability or value of the results.

Area Providing Sediment to Littoral Cell

The area of sea cliff or coastal bluff that potentially provides sand to the littoral budget was determined from accurate measurements of cliff length and height. Throughout the approximately 1,100 feet (334 meters) of project area from 33rd Avenue to 36th Avenue, the cliff section to be protected averages 33.7 feet (10.3 meters) in height, based on 23 surveyed cross-sections by Foxx, Nielsen, and Associates (1998b), and extending from 0 foot msl to the top of bluff, with the lower 13.5 feet (4.1 meters) on average consisting of fine-grained sandstones, siltstones, and mudstones of the Purisima Formation and the upper 20.2 feet (6.2 meters) consisting of marine and nonmarine terrace deposits. However, of the 1,400 feet (334 meters) of the total project area, 290 feet (88 meters) of the terrace deposits have already been stabilized, and are not subject to additional protection. Thus the total area of bluff that will be armored in the remaining portion of the project is 1,110 feet (338 meters) long and averages 33.7 feet (10.3

meters) in height, totaling 37,407 square feet (3,481 square meters) (47,180square feet [4,398 square meters] if the unprotected area is included).[1]

Grain Size

An inspection of the sea cliffs of the project area and the bluffs for several miles upcoast or downcoast indicates that both the terrace deposits and the Purisima Formation vary in composition and grain size. This is a result of the range in the original environment of deposition for both the terrace deposits (which include sediments deposited on ancient beaches, dunes, streams, and finally the soils that cap this heterogeneous sequence) and the Purisima Formation (which was deposited in a shallow marine, estuarine-type environment, probably much like Elkhorn Slough or San Francisco Bay, and therefore includes sandy shell-rich deposits, as well as siltstones and mudstones).

The preparers of many studies simply assume that any material derived from streams or cliff erosion that is sand-sized or larger (greater than [0.062 millimeter (0.002 inch)] in diameter) will contribute to the beach sand budget. However, grain-size analysis of beach sands along the coast of Santa Cruz County have determined that very little sand finer grained than 0.18 millimeter (0.007 inch) is usually found on the beaches (Hicks 1985; Best and Griggs 1991a, 1991b). In other words, very fine and fine-grained sand is not stable on the relatively high-energy beaches of central California. This was confirmed by Benumof (1999) with an analysis of beach sand samples from below Depot Hill and New Brighton Beach where, on average, 96 percent of the sand was greater than 0.18 millimeter (0.007 inch) in diameter.

Foxx, Nielsen, and Associates' (1998b), engineering geologic study on the proposed Pleasure Point bluff stabilization, used estimates based on field examination of 50 percent sand greater than 0.18 millimeter (0.007 inch) for the terrace deposits and concluded that the Purisima Formation is too fine grained to provide significant sand to the beach. In order to verify these estimates, two samples of the Purisima Formation, one from the 41st Avenue site and one from the bluff near 35th Avenue, were collected in 2003, crushed, , and analyzed by sieving to obtain a grain size breakdown. The sample from the 41st Avenue site was a silty mudstone and typical of the Purisima Formation in this area. It contained only two percent beach size sand. The second sample was selected from a sandy unit within the Purisima Formation near 35th Avenue, and it contained 18 percent beach compatible sand.

In order to provide a more comprehensive analysis of the littoral sand contained in the bluffs, three additional samples were collected in September 2005. Each of the three samples was a composite of two or three subsamples taken from the different units of the Purisima Formation exposed in the project reach. Because the Purisima is essentially flat or horizontal in this area, the same stratigraphic or sedimentary units are exposed in the 13.5 feet (4.1 meters) of cliff throughout the 1,400 feet (427 meters) of project area. Therefore, these composite samples are believed to be reasonably representative of the material being eroded throughout the 1,400 feet (427 meters) of exposed bluff. The amount of littoral-size material in these samples (larger than .005 inch [.118 millimeter] and smaller than .08 inch [2 millimeters] in diameter) and ranges from 30.9 to 68.5 percent. Averaging these five samples

[1]For purposes of analysis by the California Coastal Commission, the area providing sediment to the littoral cell would be somewhat larger because calculations would be based on the cliff face prior to the 2004 emergency repairs (i.e., 290 feet).

produces an average percentage of littoral sand that would be derived from erosion of the Purisima Formation in this area of 33.9 percent.

Although many of the terrace deposits in the project area consist of a sandy cobble deposit, a grain size analysis of this material would be meaningless, so a single sandy unit was sampled in 2003; it contained 46 percent beach-size material. This is consistent with the value of 50 percent used by Foxx, Nielsen, and Associates and the 60 percent estimated by Benumof (1999) for the terrace sands. Samples collected in September 2005 were also examined and each of these was a composite of two or three subsamples from throughout the 20.5 feet (6.2 meters) of exposed terrace deposits. There was a high degree of uniformity in the grain size distribution from these samples, with 42.3 to 49.5 percent of each of these samples falling between .005 and .08 inch (0.118 and 2.0 millimeters). Averaging these three and the previously collected sample produce an average of 45.5 percent of littoral material derived from the terrace deposits of the project area.

The estimated maximum amount of sand contributed annually from the entire bluff area based on the above data is as follows (the entire bluff area is used in the calculation to produce a more conservative value, although 290 feet [88 meters], or 21 percent, has already been protected):

Qs =(A)(R) (% littoral sand)

Qs terrace deposits = Area (1,110[2] ft. X 20.2 ft) X Erosion Rate (0.5X ft/yr) X 45.5% littoral sand

= 5,101 ft^3/yr = 189 yd^3/yr of littoral sand

Qs Purisima = Area (1,400[3] ft. X 13.5 ft) X Erosion Rate (0.5 ft/yr) X 33.9 % littoral sand

= 3,203 ft^3/yr = 119 yd^3/yr of littoral sand

The average estimated beach sand contribution from 1,400 feet (427 meters) of bluff erosion equals 308 cubic yards (235 cubic meters) per year (or 0.22 cubic yards per foot of coastline each year). This value compares very favorably with the 350 cubic yards (268 cubic meters) per year estimated by Foxx, Nielsen, and Associates (1998a), for the 1,200 feet (366 meters) of shoreline used in their calculation (or 0.29 cubic yards per foot of coastline each year).

The sand contribution from the horizontal bedrock under the base of the wall has also been calculated. The footprint of the proposed wall and apron would be about five feet wide. Using the same formula as above but with the smaller surface area and lower rate of erosion of the bedrock, the additional sand contribution from the bedrock under the base of the bluff protection structure would total an estimated 20.72 cubic yards/year. (The calculation is as

[2]The linear distance of 1,110 feet for the terrace deposits corresponds to 810 feet between 33rd and 36th avenues plus 300 feet at the Hook.

[3]The linear distance of 1,400 feet for the Purisima formation corresponds to the total length of the bluff: 1,100 plus 300 feet for the Hook.

follows: Qs Purisima = [1,100 feet X 6 feet] X [0.25 feet/year] X [33.9 percent littoral sand] = 559 cubic feet/year = 20.72 cubic yards/year.)

Total Sand Contribution

At this point in the Santa Cruz littoral cell, based on all available data, it appears that 300,000 cubic yards (229,367 cubic meters) per year is the best estimate for long-term littoral drift rate. Using this rate, the 329 cubic yards (430 cubic meters) per year supplied by bluff erosion in the project area amounts to 0.1 percent of the total littoral drift, well below the error bars of the measurements and year-to-year variations in drift.

6.1.10 Beach Formation

Visitors to a beach in Santa Cruz will notice a striking difference between the winter and summer beaches (Photos 6-10 and 6-11). The steep, shorter period, high-energy waves of winter are more closely spaced and stir up a lot of sand, which stays in suspension, often discoloring the water. The sand from the beach moves offshore where it settles out and is reworked by the waves into a series of bars and troughs. As a result, the beach is eroded each fall and winter, leaving a narrow, coarser-grained, often cobble beach, as the sand is moved offshore. In some locations the beach may be removed altogether. This seasonal beach erosion often allows the more energetic winter waves to break closer to shore, thereby having a greater impact on the weakening or erosion of the cliffs.

Photo 6-10. Summer beaches-May 1984. (Source: G. Griggs)

Photo 6-11. Winter beaches-January 1982. (Source: G. Griggs)

As the winter storms wind down, the lower, less energetic waves of spring and summer begin to arrive at the coastline. These longer period waves tend to gradually transport the sand that was deposited offshore back onto the shoreface. As a result, the beaches begin to build up as the sand settles out between waves. Through the spring and summer, the berm will be built higher and the beach will gradually expand outwards.

While there are many areas along the shoreline of Santa Cruz County where the beaches are very wide, this is not the case in the project area. During a field survey in July 2001, there was no significant usable dry beach between Pleasure Point and 36th Avenue, or the westernmost 1,100 feet of shoreline proposed for bluff stabilization. There are several reasons for this finding.

Photo 6-12. Arial view of East Cliff Drive project area. (Source: G. Griggs)

The shoreline in the project area trends southwest-northeast. With the waves refracting around Pleasure Point from the northwest, there is a strong west to east littoral drift (Photo 6-12). Thus the sand is carried through this area quickly and there is little accumulation. There are also very limited barriers to littoral transport that would trap sand to form beaches.

Most beaches in California have formed where there are natural or artificial obstructions to littoral drift (Everts and Eldon 2000). The project area historically has had only two moderate sized beaches, both formed upcoast of small promontories or projections. In aerial photographs of the area taken in 1928, 1943, 1956, and 1963, there are moderately wide summer beaches immediately upcoast from the short promontory or natural groin fronting the O'Neill house (Photo 6-9) and also upcoast from the promontory at the Clanton house just upcoast from 41st Avenue (Photo 6-4). These beaches typically are eroded each winter and then rebuilt in spring and summer. The gradual erosion of the short bedrock groin fronting the O'Neill house over the past 25 or so years, which previously impounded sand upcoast, led to the loss of this beach. The beach that fills the embayment fronting Larch Lane (upcoast from Clanton House) and that extends upcoast a few hundred feet to the access stairway, still forms in spring and summer due to the short bench of Purisima at the east end of this beach. Without this natural groin, there would be much less available beach at this location.

6.1.11 Issues That May Affect Bluff Protection Structures

Scouring/Active Erosion

Undermining or scouring at the base of a coastal protection structure can be a common failure mechanism. Scouring can affect sediment or bedrock. Scouring of sediment, in any environment, whether the beach or a river, is the result of current velocities that are high enough to move or erode the material in any particular location. Winter waves generate enough energy and have short enough periods that they erode or scour the beach. Longer period and less energetic summer waves move the sand back up the shoreface and rebuild the beach.

As the coastline erodes from scouring and wave impacts, the entire shoreface and cliff profile retreats together. This includes the intertidal or wave cut bedrock platform, as well as the bedrock and terrace deposits making up the sea cliff. The cliff itself cannot be eroded too far back without also lowering the bedrock platform in front of the cliff, or else more energy would be lost on the bedrock platform and less would be available to erode the cliff. These balance out over time such that the profiles move back more or less uniformly.

A key design objective to protect a coastal protection structure from such erosion of the anchoring bedrock is to extend the base of a protection structure below any maximum expected scour depth and, if possible, anchor or embed the toe of the structure into bedrock, which is not always possible. There are many locations where wave scour has undermined a structure followed by loss of fill behind the structure and collapse or failure. The geotechnical engineer and the engineering geologist for the proposed projects have recommended extending the toe of the structure downward to an elevation of at least –three feet NGVD, embedment of the toe at least three feet into dense bedrock, and constructing a concrete apron that would extend four feet seaward of the base of the wall. This is particularly critical for the 33rd to 36th avenue section of bluff protection (Photo 6-9).

Cross-shore profiles surveyed by Foxx, Nielsen and Associates (1997) indicate that Purisima bedrock outcrops offshore are at an elevation of -1.5 to –3.0 feet NGVD, at about 60 to 100 feet from the base of the bluff. The sea floor between the offshore exposure and the bluff, however, is covered with loose rock, worn concrete rubble and sand although there were no probes to determine the actual depth to bedrock at the base of the bluff. Foxx, Nielsen and Associate's cross-sections all predict a very low sloping platform such that the bedrock at the base of the bluff is essentially the same elevation as the offshore outcrop or slightly higher (e.g. –1.5 to –3.0 feet NGVD). The bedrock elevation at the base of the bluff should be a good indication of maximum scour depth, as the bedrock has not been eroded any deeper in recent time. A large number of coastal protection structures have been designed and built along the central coast, and while there are differences in scour depth used depending upon the specific area and the particular structure, a scour depth of –3.0 feet NGVD is a reasonable value to use.

Wave Overtopping

Overtopping is defined as the transport of significant quantities of ocean water over the top of a seawall, either as greenwater, splash, or spray. Overtopping can cause damage by exerting direct vertical and horizontal forces, and also by eroding materials from behind walls (Photo 6-13). In most coastal environments it is not practical or economical to build a protection structure that will not be overtopped during severe storm conditions. Standard run-up calculations for seawalls typically consider only the frequency of overtopping by greenwater. The height of the run-up is usually calculated using empirical or theoretical formulas based on specified water depth, beach slope and grain size, wave height, wave period, maximum expected sea level and the type of slope of structure involved.

Photo 6-13. Result of wave overtopping. (Source: G. Griggs)

One of the limitations of run-up calculations is that they don't accommodate the local variations in the bluff profile, or the irregularities of the shoreline. A single value is picked for each parameter for each computer run, and although the computer model can be run multiple times with different values, this still may not represent actual field conditions. For example, in the Haro and Kasunich (1998) wave run-up analysis, a single offshore slope of 1:50 is used and it is assumed that all sediment is stripped off so that a uniform bedrock platform results. Haro and Kasunich also assumed a bluff profile having a slope of about one and two-thirds foot of vertical rise per foot of horizontal run (after bluff armoring). They concluded that the chance of overtopping the armored bluff (with elevation of 34 feet NGVD) in 100 years was "very small." They noted that previous wave run-up calculations by the Army Corps of Engineers had predicted wave run-up of 30 feet (Haro and Kasunich 1998).

While wave run-up calculations are based on simplifying assumptions, in reality, most of the 33rd to 36th avenue area has an extensive covering of riprap and concrete rubble, which helps disperse wave energy (Photo 6-7), and would reduce run-up somewhat. The natural bluff profile varies along its length, and in some areas is less vertical than assumed in the calculations. The presence of riprap at the foot of the bluff would also reduce the effective slope of the bluff. Both of these would serve to increase run-up.

Outflanking

Outflanking occurs when material to either side of a seawall or protection structure erodes to a point where it threatens or damages the wall itself, or property behind it (Photo 6-14). Along a progressively eroding coast, all successful, isolated protection structures would be gradually outflanked, because the coastline on either side would erode more rapidly than that behind the wall. This is a relatively predictable process and should be anticipated in the design of any isolated wall in a rapidly eroding area. Often outflanking of one wall leads to construction of additional walls adjacent to the first. As the amount of continuously protected coastline increases, outflanking becomes a problem in the unprotected gaps.

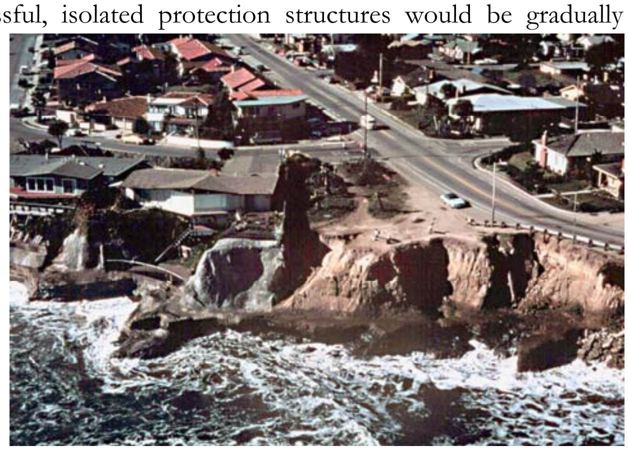


Photo 6-14. Example of outflanking. (Source: G. Griggs)

Battering/Failure

A number of poorly engineered protection structures or timber bulkheads around northern Monterey Bay have been seriously damaged or destroyed by battering, either by waves or by debris, primarily large logs. At Sea Cliff State Beach, the timber bulkhead either suffered major damage or was destroyed 10 times in 58 years (Griggs and Fulton-Bennett 1987). In each case, large logs brought down in local rivers and streams were thrown by waves against and over the timber seawall. The lagging was damaged and the fill was washed out from behind the wall. In this case the two- to three-inch (5- to 8-centimeter) thick planks were not strong enough to withstand battering by large logs.

Photo 6-15. Failure of protection structure near Monterey Bay. (Source: G. Griggs)

A concrete panel seawall constructed along Beach Drive in Rio del Mar was damaged within a few months of completion by wave impact when the fill behind the wall was washed out. The wall was only eight inches (20 centimeters) thick, had only minimal reinforcing steel and with the fill that provided the resistance gone, waves began to crack the wall (Photo 6-15). The proposed reinforced shotcrete, backed by the Purisima at the base of the bluff and the terrace deposits at the bluff top, should not be susceptible to significant battering by waves or debris because it will be at least 10 to 12 inches (25 to 30 centimeters) thick and, in most cases, 12 to 18 inches (30 to 46 centimeters) thick.

6.2 ENVIRONMENTAL CONSEQUENCES

Impact Methodology

Geologic impacts include all of the effects that result from the interaction between the projects and the geologic environment. For example, impacts from the projects could include changes in erosion rates or changes in the level of exposure of people and structures to earthquakes or unstable slopes.

The ROI for the geologic impact analysis includes the immediate project area in which construction would take place and adjacent areas. The boundaries of the ROI may vary for different types of impacts, but for geological resources the ROI is the location of the origin of the impact, the region in which its effect is greatest, and the distance from the origin at which the impact is expected to be observable.

Thresholds of Significance

The significance of the impacts from the projects is defined in both relativistic and absolute terms. Relativistic criteria base significance on context and tend to be subjective, while absolute criteria are defined in terms of objective standards. For CEQA, significance threshold criteria are developed in order to determine which impacts require the adoption of mitigation measures and which impacts cannot be mitigated. In this analysis, an alternative is considered to have a significant impact on geological resources if it were to result in any of the following:

- Increase the exposure of people or structures to geologic hazards that could result in injury or loss of life or major economic loss;
- Adversely alter existing geologic conditions or processes such that the existing or potential benefits of the geologic resource are reduced; or

- Permanently damage or alter a unique or recognized geologic feature or landmark.

6.2.1 Full Bluff Armoring (Alternative 1)

Alternative 1 is designed to fully protect the bluff from failure due to wave impacts and erosion. As described in Section 6.1, no bluff protection structure can be guaranteed to be fully protective forever. The bluff protection structure could develop fractures or fail under some extreme conditions, although the structure would be designed to be very robust. Monitoring and maintaining the bluff protection structure would help to maximize its life. Figure 6-1 illustrates the expected condition of the bluff over the first 50 years after construction. For purposes of comparison, similar illustrations are provided for each of the alternatives below.

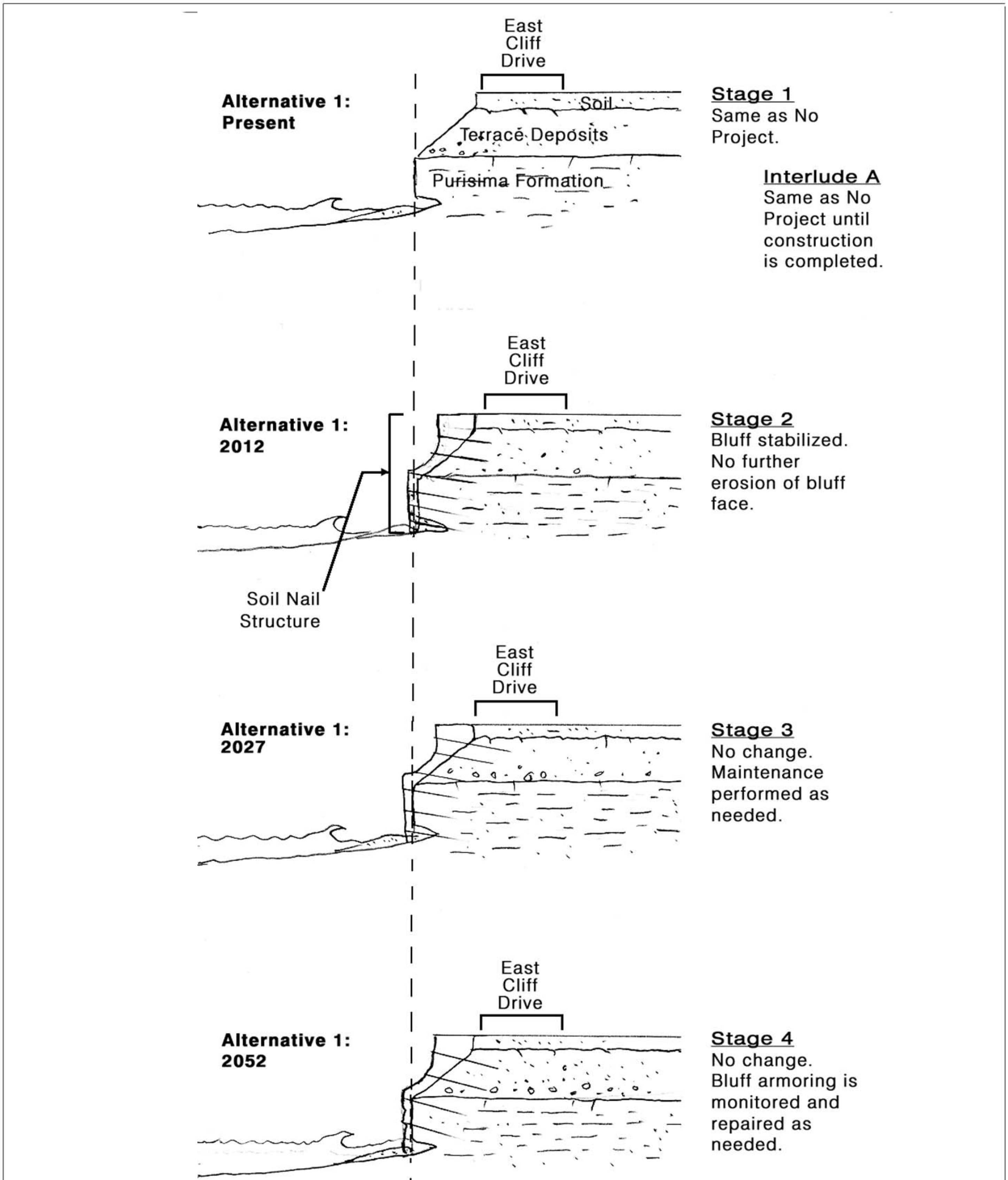
Significant Impacts

Impact 6.1 Enhanced Bluff or Beach Erosion Adjacent to the Project Area and Other End Effects of the Bluff Protection Structures

The ends of the proposed bluff protection structures are a potential focus of continued or enhanced erosion (outflanking). The ability to design against and control these effects would be limited in areas where the proposed structure abuts an existing structure, for example on private property. The failure of an existing adjacent bluff protection structure could make the proposed bluff protection structure more vulnerable to wave attack. If improperly designed, a bluff protection structure could direct wave energy toward an adjacent bluff protection structure. The effects of outflanking would be significant because they could either render the proposed structure less effective over time or result in damage to neighboring properties.

The geotechnical engineering report (Haro, Kasunich & Associates 1997) recommends that the seawall be terminated at its east and west end points with a tapered catenary (a type of smooth curve). This would prevent negative effects to the adjoining properties by preventing wave deflections from being focused onto the adjacent bluff face. By tapering the seawall ends as a catenary curve, the natural geometry of the existing coastal bluff would be maintained and changes in wave deflection due to seawall structure would not occur.

Upcoast and downcoast terminations must be considered for both the 33rd Avenue to 36th Avenue and 41st Avenue sections of the proposed bluff protection structure. At the 33rd Avenue, or west end, the adjacent bluff is already armored with shotcrete, which extends all the way around Pleasure Point. At this location there is no concern with wave deflection onto unprotected bedrock or terrace deposits. The proposed and existing structures would be joined at the location of the existing path down the bluff. Because the proposed bluff protection would follow the existing shape of the bluff, there should be no significant change in the interaction of waves with the bluff, and therefore no significant outflanking effects at this area.



Source: Griggs 2001

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Alternative 1 Erosion Estimate
Full Bluff Protecerion

Santa Cruz, Claifornia

Figure 6-1

At the 36th Avenue end, adjacent to the west side of the O'Neill property, the County property extends to within about eight feet of the home. The riprap protecting the O'Neill home presently extends about 30 feet upcoast from the house and to the top of the bench on an outcrop of Purisima bedrock. The end of the bluff protection structure at this termination would be 13 feet (4 meters) back from the property line and would be configured as a catenary curve, as recommended by Haro, Kasunich and Associates. Existing rip rap might have to be rearranged at this end of the wall. This leaves the possibility that end effects could still occur, which would be a significant impact.

The west end of the 41st Avenue bluff protection structure would abut an existing bluff protection structure consisting of a shotcrete seawall covering the terrace deposits and keyed approximately four feet into the Purisima Formation. The existing structure was built in 1984 and had a projected life expectancy of 17 to 50 years. The structure was expected ultimately to fail when undercutting of the Purisima Formation intersected the keyway foundation of the structure. Based on observed rates of scouring, the structure is near the end of its expected life. At some point, an apron of shotcrete was placed over the Purisima bedrock below the terrace deposits, which appears to protect the Purisima from further undercutting. The structure is not tied to the terrace deposits with soil nails and would be subject to collapse if and when its foundation is undermined. The portion of the shotcrete structure nearest the proposed bluff protection structure appears to be in poor condition, with a piece missing at its base. The top of the bluff at this location is The Hook Overlook. The outcrop presents a wedge-shaped edge in the direction of approaching storm waves. Incident waves hitting this outcrop would be split, with part of the incident wave energy directed to the west, at the masonry structure below the private property, and part of the wave energy directed to the east. Should the existing structure to the west fail, it would allow wave action to continue to erode the bluff face, eventually outflanking the bluff protection structure and eroding the bluff behind the structure. This would result in a significant impact.

The steep slope of the terrace deposits at the 41st Avenue area results from the presence of a resistant bed of cobble conglomerate (a deposit consisting of cobbles in a matrix of finer sediments) that is able to hold a steep slope, as there is little evidence of undercutting in the Purisima here. The roots of large trees protrude from the bluff top in this area, indicating that the bluff is indeed retreating. The bluff protection structure would be terminated on the east at the outer end of the outcrop. The adjacent bluff to the east is not currently protected; however, the property owner has submitted plans to the County for a structure to protect the terrace deposits below the residence (see Chapter 15). Although the presence of a projecting outcrop of Purisima Formation indicates that the formation is resistant to wave attack here, the Purisima would probably retreat to some extent. Protecting the overlying terrace deposits would not prevent the retreat of the Purisima. Retreat of the Purisima could lead to the proposed bluff protection structure being outflanked. This would result in a significant impact.

Each of the potential outflanking areas described above represents a point of potential failure of the structure within the 100-year design life of the structure. This is considered to be a significant impact because it would prevent the structure from stabilizing the bluff for the required period.

Mitigation 6.1a

To mitigate potential end effects associated with the termination of the bluff protection structure adjacent to the O'Neill property, the bluff protection structure shall be extended as close as is feasible to the edge of the O'Neill property. To protect this termination, the riprap shall be removed, the bluff protection structure shall be completed to the property line, and then the riprap shall be replaced only as necessary to arm the transition area. This would provide a high degree of protection to the bluff in the transition area and should reduce the potential impacts of outflanking to less than significant levels. Removing and replacing the riprap would require coordinating with the property owner.

Mitigation 6.1b

To minimize bluff or beach erosion problems adjacent to the project area and associated outflanking of the bluff protection structures, the County Department of Public Works shall implement an annual program of inspection, maintenance, and repair (as needed) of the bluff protection structures, with particular emphasis on the ends of the structures.

Implementing this mitigation measure would reduce this potential significant impact to a less than significant level.

Nonsignificant Impacts

Wave Overtopping

As discussed in Section 6.1.11, the potential for wave overtopping in the project area is difficult to quantify due to limitations of modeling and the need to make simplifying assumptions. Haro and Kasunich (1998) concluded that the chance of waves overtopping the bluff protection structure (elevation 34-foot NGVD) in the next 100 years is "very small." Their calculations assumed that there was no riprap present at the foot of the bluff, and they used conservative estimates of incident wave heights, tides, and sea levels that may have overestimated wave run-up. Even if some large waves do infrequently overtop the bluff, the bluff protection structure would resist wave erosion better than the existing unprotected bluff. Also, improved drainage in the parkway area should reduce the potential for erosion impacts at the top of the bluff. Therefore, the impacts of wave overtopping are expected to be less than significant for the Full Bluff Armoring Alterative.

Impact of Vehicle Traffic on Slope Stability

The bluff protection structure would be designed to resist ground shaking from a major earthquake on the San Andreas Fault. The chronic vibration associated with vehicle traffic would have far less impact than a large earthquake on the integrity of the bluff protection structure. Engineered fill would be compacted, and the terrace deposits and fill material would be drained to prevent settlement or liquefaction. A monitoring and inspection program (see Mitigation 6.1) would be implemented to identify and repair any structural flaws that may develop in the bluff protection structure. Therefore, the effects of vehicle traffic on the structural integrity of the structure would be less than significant.

Effects of Construction Activity and Use of Heavy Equipment on the Beaches Fronting the Project Area

As described in Section 2.3.8, heavy equipment needed to construct the bluff protection structure would be lowered from the top of the cliff to the working height. Therefore, there would be no need to construct ramps from the bluff top to the beach for access. Use of heavy equipment to remove concrete rubble and rock riprap would disturb the beach. Removing these materials could expose the beach and the foot of the bluffs to wave action. This activity is not expected to affect the stability of beach sand and would have negligible impacts on bluff stability during the short period of summer construction. As discussed previously, the concrete rubble does not effectively protect the bluff. The removal of this material would actually reduce some of the abrasion that occurs when the rubble is tossed against the bluffs in heavy surf. Sand movement and beach formation is controlled by wave energy, and riprap has little effect on sand retention. These effects are expected to be less than significant.

Reduction in Sand Contribution to Local Beaches

Armoring the bluff face would prevent its erosion over a total distance of about 1,400 feet, reducing the annual volume of sand transported by longshore currents and the availability of the sand to form beaches downcoast of the project area. The amount of sand generated by bluff erosion, within the size range found on beaches in the area, is estimated to be approximately 329 cubic yards per year on average, or about 0.1 percent of the total annual volume of sand transported by littoral drift past the project area. Such a small percentage decrease in the sand contribution from the project area would have no observable effect on the size of downcoast beaches.

Reduction in Sand Contribution to Project Area Beaches

Armoring the bluffs would reduce the local contribution of sand, as described above. However, the amount of sand contributed to the beach fronting the project area is small, compared to the amount of sand carried alongshore by wave action. Therefore, the projects are not expected to alter the rate of beach formation or the size of the beaches in the project area. The winnowing action of waves separates and removes fine-grained material from the sand that forms the beach.

The removal of concrete rubble and riprap from the beaches fronting the project area could increase the amount of wave energy reflected from the bluffs and could slightly alter the pattern of deposition of sand on the beach. Removal of riprap would increase the width of the sand beach. Areas adjacent to riprap that currently collect mats of dead kelp and other debris would no longer trap this material and would adjust to the profile of the adjacent beach. The overall effect would be to make the beach appear more uniform along its length than it is now.

Bluff Erosion Contribution to Littoral Drift

The contribution of bluff erosion to total littoral drift is estimated at 0.1 percent. This is well below the error bars of measurements and year-to-year variations in drift. Therefore, the full-bluff armoring alternative would have less than significant impact on the total littoral drift.

Passive Erosion

Wherever a hard structure is built along a shoreline undergoing net long-term erosion, the shoreline will eventually migrate landward behind the structure in adjacent areas. The effect of this migration will be the gradual loss of beach in front of the structure, as to either side the water deepens and the shoreface moves landward. This is called passive erosion. This has been a contentious issue along the Atlantic coast where the offshore barrier islands are migrating landward as sea level rises, except where the coastline has been fixed with seawalls. Passive erosion has also been recently documented in California, Oregon, Washington, and Hawaii. The process of passive erosion appears to be a generally agreed upon result of fixing the position of the shoreline on an otherwise eroding stretch of coast and is independent of the type of structure. Though passive erosion can occur on rocky coasts, it is most apparent on sandy coastlines where the shoreline can recede very rapidly. Because of the way the soil nail wall would tie into pre-existing structures on adjacent properties, and to adjacent rock (such as at the Hook), no substantial passive erosion is likely to occur as a result of the project, and this impact would be less than significant.

Beach or Shore Loss

The possibility exists that the proposed action, in fixing the location of the bluff where it is and preventing further landward erosion, would result in a loss of the area between the bluff and the water line because of sea level rise and the ongoing erosion of the bedrock underlying the beach in front of the bluff.

Although there remains much uncertainty in the estimation and prediction of global sea level rise, long-term historical data from areas that are not influenced by changes in land elevation suggest that sea levels have been rising at a rate of about +1.8 mm/year (Peltier and Tushingham 1989). This is equivalent to about 3.5 inches over a period of 50 years. Sea level rise is difficult to measure partly because the land elevation rises or falls locally in response to a variety of factors. In the Santa Cruz area, this rate of land elevation rise, which is independent of global sea level rise, has been estimated at approximately 0.4 mm/year, as noted above. The net long-term rise in sea level relative to shoreline in the Santa Cruz area would therefore be 1.4 mm/year, or roughly 2.8 inches in 50 years. It should be noted that while sea level rise occurs incrementally, land rise can be more episodic, so that average annual values or even values over a period of 50 years may not accurately reflect what happens over those short timeframes. However, in general, in the Santa Cruz area, it is expected that sea level rise will be partially offset, in the long-term, by a rise in land elevation.

While the bluff as a whole is estimated to migrate inland at an average rate of approximately one foot per year, with local variations in the rate due to local variations in geology and the strength of wave attack, there are fewer data available for estimating the rate of downward erosion of the intertidal platform at the base of the bluff. Despite this uncertainty, erosion of this platform is understood to occur at a substantially slower rate than erosion of the bluff, because of the slope and nature of the rock composing the platform (Griggs 2003b). For purposes of analysis, the Corps of Engineers has estimated the erosion rate of the platform at approximately 0.0005 feet/year, which is equivalent to about 0.15 mm/year, or about 0.3 inch in 50 years (Conner 2003). Compared to the estimated rate of sea level rise and even land elevation rise, this would not be a substantial factor in estimation of beach or shoreline loss.

Based on this erosion rate and the water level increase expected from sea level rise, it has been estimated that the distance between the bluff and the mean low low water line (MLLW) would decrease between 10 and 20 feet during the 50-year project period (Conner 2003). (Note that it is assumed here that there is very little sand deposited near the MLLW mark, where the surface of the Purisima bedrock forms tidepools). However, the encroachment of higher sea levels would not necessarily result in the loss of 10 to 20 feet of beach width because the beach is formed by deposition of sand under a dynamic set of conditions that involve the adjacent shoreline geometry, average wave height, sand supply, and other factors. The slope of the beach (the slope of the sand deposits on the shore) is determined largely by the sand particle size and the average wave conditions at a given time. Normally, summer deposition of sand on the shore results in a steeper slope and higher ground level compared to the slope of the underlying bedrock surface exposed during winter months, because sand is piled higher on the back of the beach than at the front. This sand originates primarily from the sand carried down the coast by currents that run parallel to the shore, which is then pushed onto the shore by relatively gentle summer waves. The project will have no substantial effect on the supply of sand that contributes to formation of the beach. Therefore, rising sea level would reduce the summer beach width less than it would reduce the amount of rocky shoreline platform that is exposed during the winter. Additionally, the distance between the bluff and the water line varies greatly both seasonally and during the course of the day, and can change from 150 feet wide to almost nothing in the course of one tidal cycle. Because of this wide variation and the tiny increments by which sea level would rise, it is unlikely that the shoreline reduction would be noticeable to most users on a year-to-year basis.

Recreational uses of the shoreline in front of the bluff are generally confined to walking the shore and access for surfing; the beach is not commonly used for sunbathing or other stationary uses requiring a wide sandy area. The project would include removal of rubble and riprap that currently litters the back beach. This would provide somewhat better access to the beach, and would increase the useable beach surface area. Because of the limited effect on recreational uses and the wide chronological and geographical variations in shoreline width already occurring at the project site, the proposed action would result in a less than significant impact from beach or shore loss.

Offshore Scouring

Whether the cliff along the Pleasure Point bluff stabilization project area consists of Purisima Formation sandstone or mudstone or shotcrete will not affect the velocity of the water movement along the shoreline. At the maximum, the coastal cliff will be built out with shotcrete about two feet farther seaward than where it is at present. With a cliff that is eroding at an average rate of one foot per year, this means the cliff face would be about where it was two or three years before the project began, or about two feet farther seaward. This would not have any different effect on beach or bedrock scour in the intertidal zone than the natural cliff did two years ago. It is important to remember that what is planned for construction is nearly identical in shape, reflectivity, and location to the existing cliff face, or the cliff from two years ago. This is very different than building a massive concrete curve faced seawall, such as at Aptos Seascape, on what was formerly a wide sandy beach. There would be no substantial changes to offshore water velocity or scouring compared to existing conditions.

Impacts on Recreational Wave Breaks

Several factors are key to producing good surfing waves. Of primary importance are the characteristics of the waves themselves—the direction of approach, period, and height. The dominant waves that reach the Pleasure Point area and that provide for the best surfing conditions arrive from the northwest from storms generated in the North Pacific Ocean. Equally important to the waves themselves are the geological conditions in any particular coastal or shoreline area. These include the orientation of the coastline relative to the approaching waves, the bottom topography or bathymetry, location of “reefs” or rock outcrops and sand bars, and also the tidal conditions or tidal range. A discussion of the processes in forming waves and how they break is found above in Section 6.1.6.

If successful, the proposed project would halt the retreat of the coastal bluff for the near future, but no area of coastline remains the same for very long, either over the short term or the long term. A coastline is one of the most dynamic physical environments on Earth and undergoes constant change. Wind, waves, tidal variations, sea level change, El Niño events, and the erosion of the seafloor and transport of sand in the nearshore zone all provide for an extremely active geologic environment. Each of these factors have an effect on either the waves that approach the shoreline at Pleasure Point or how those waves will break and, therefore, on surfing conditions.

Tidal Elevations. One of these variables is fairly predictable, that of the tidal conditions or tidal height that can be expected at any particular time in the future. This component of sea level is based primarily on the gravitational influence of the moon and sun and therefore the positions of the moon and sun relative to Earth. We know with considerable precision what tidal heights we should expect, hours, days, years and decades in advance. In the Monterey Bay area, we experience a mixed semidiurnal tide with two high and two low tides each 24 hours and 50 minutes that are unequal in magnitude or height. Extreme high and low tides range between about 6.9 feet and -1.6 feet (2.1 and -.48 meter), respectively, or a maximum range of about 8.5 feet (2.6 meters), with an average range between high and low tide of about 3.5 feet (1.1 meters). Because of the astronomical motions involved, tidal oscillations occur twice daily, twice monthly, twice yearly, and every 4.4 years, with a smaller 18.6-year cycle as well.

However, during major El Niño events, the sea surface elevation may increase as much as 1.5 or 2 feet (.5 to .6 meter) above the predicted tidal level due to a combination of atmospheric pressure differences, thermal expansion of seawater, wave setup, and wind direction. These events and their future impacts on sea level are completely uncertain and cannot be predicted in advance.

Because water depth is a primary factor influencing how waves of a particular length and height will break, the condition of the tide is important in determining surfing conditions. There are some surfing areas that break better at high tides and others at low tides. Therefore, tidal elevation is a major, but mostly predictable, variable in surfing conditions. However, for perspective, the 8.5 feet (2.6 meters) of water surface elevation difference between extreme high and low tides in this area that can occur during a single 24-hour period, is equivalent to 102 inches (2,590 millimeters), or 1,295 years of .08 inch (2 millimeters) per year of sea level rise.

Sea Level Increase. A lengthy discussion of changing sea level is presented in Section 2. Based on available data, Pleasure Point is probably experiencing an overall sea level rise rate not too different from that of Earth as a whole, about .08 inch (2 millimeters) a year. There is also some uplift taking place, as witnessed by the elevated marine terraces that form the coast of the

Pleasure Point area, but this indicates that the relative sea level rise rate is somewhat lower here than the global average. Again, however, this is an area of some uncertainty in terms of exact uplift rate and therefore precise sea level rise rates and, subsequently, effects of sea level rise on the shoreline.

It is important to place this sea level rise in context with the daily or monthly changes in sea level at Pleasure Point due to tidal fluctuations. At .08 inch (2 millimeters) a year, it would take 1,295 years of sea level rise to raise sea level as much as the present difference between low and high tide levels. If the future sea level rise rate doubled to .16 inch (4 millimeters) a year, it would take 648 years. An extreme El Niño-elevated sea level condition of two feet (.6 meter), such as that experienced at the San Francisco tide gage in 1983, is equivalent to 305 years of sea level rise at the current rate of .08 inch (2 millimeters) a year.

Waves break today in the Pleasure Point area at both high and at low tides, although they provide different surfing conditions. Over the next hundred years, sea level is estimated to rise between one and three feet above today's sea level.

At the present time waves break at a number of different locations depending upon the specific wave heights and tidal conditions. The offshore water depths and bottom topography, which affect how and where the waves will break, would be the same whether or not the bluff is allowed to retreat. At low tide or high tide, water depths would most likely be somewhere between one and three feet (30 and 91 centimeters) deeper than at present by 2100. Everything else being equal, these waves would break closer to the shoreline. However, the bottom conditions (rock outcrops, or reefs, and the location of sand bars or sand deposits) that produce the wave breaks are variable across the nearshore zone and would change gradually with a rising sea level. Whether or not there is a beach along the shoreline or how wide that beach is, or whether it is covered with rocks or sand, would not affect the waves breaking several hundreds of feet offshore. The presence or absence of a beach doesn't affect the wave break now and it would not affect it in the next 100 years. The tidal conditions and waves themselves are the critical factors.

Bathymetry or Seafloor Topography. Pleasure Point is a popular surfing spot, primarily because of the refraction of waves around Pleasure Point and the bottom topography. The distribution of rock outcrops and sand bars or areas of sand on the seafloor affect where waves break. However, the location of sand bars changes weekly and seasonally and from year to year, and the rock outcrops are gradually worn down or eroded slowly over time due to a combination of wave impact, sand abrasion, and also bio-erosion. These bottom conditions change over time in unpredictable ways, and, while waves will always break along this coast, there is no way to determine how the bottom conditions and, therefore, the surfing conditions, will change in the future. What is certain, however, is that they will change.

While access to the shoreline is a consideration in getting into the water to surf, the presence or absence of a beach in many of Santa Cruz's surfing spots is not a consideration. Virtually all of the surfing locations between Steamer Lane and Natural Bridges are at locations where there are no or very narrow beaches. At Steamer Lane, there is no beach but rather a 30-foot (nine-meter) high vertical cliff, armored in part with riprap, that surfers navigate in order to get into and out of the water. Surfers take off heading right for the cliff at times. At Cowell's Beach, a classic surfing spot due to wave refraction around Point Santa Cruz, the lack of a beach and ongoing cliff erosion led to the placement of riprap in the early 1960s; the waves continue to form an ideal and gentle break, and hundreds of surfers of all ages continue to surf and enjoy the waves there. The Steamer Lane and Cowell's Beach area is similar in many ways to the Pleasure Point area. They both have rocky outer points with larger waves (the Lane is a vertical cliff with riprap, and outer Pleasure Point has been armored with shotcrete, concrete seawalls, and riprap for nearly 50 years). Both locations also have somewhat lower wave heights farther to the northeast (Cowell's and then the area fronting East Cliff Drive, east of Pleasure Point). Both areas, as discussed earlier, are oriented northeast-southwest and have no significant beach. The bluff at Cowell's Beach was armored, but the armoring has not affected the refracted breaking waves offshore, which depend on the sandy bottom conditions offshore, not the riprap along West Cliff Drive.

Wave Climate. The waves breaking along any particular area of shoreline constantly change in unpredictable ways. Day to day, week to week, one winter to the next, the waves approaching the Pleasure Point area change because the forces that create the waves are constantly changing. Oceanographers now understand that the storm and wave climate, as well as water surface temperature and elevation, change over decadal cycles (now known as the Pacific Decadal Oscillation) and produce periods dominated alternately by El Niño conditions and La Niña conditions. For example, from the late 1920s to about 1945 was one of more frequent El Niño events, which translates to heavier rainfall, more frequent and severe coastal storms, elevated sea levels, larger waves, and more coastal erosion and storm damage (Griggs and Brown 1998; Griggs and UCSC/USGS Coop 1998; Storlazzi and Griggs 1998, 2000). From 1945 to 1978, the central coast experienced milder or more benign conditions overall. Conditions changed again in 1978, as we again entered an El Niño-dominated period, which produced widespread coastal storm damage and beach and bluff erosion.

However, there is no way to predict when the climate cycle will shift and when associated wave conditions will change. The Pleasure Point shoreline, like all other surfing locations along the coastline of California, experiences a changing wave climate that varies on hourly to decadal scales, and there is no way to predict what may come, beyond a few days or weeks in advance. Wave conditions are not the same from year to year, and there is no reason to believe that they will stay the same over the years and decades ahead.

In conclusion, there is a set of conditions that exists on any particular day at Pleasure Point, but it is the overall wave climate along the central coast, the orientation of the coastline, and the offshore bottom conditions, or bathymetry, that produce the excellent surfing conditions in this area. Sea level, tidal height, wave conditions, and the distribution of sand and rocky bottom are all constantly changing, some more rapidly than others. While stabilizing the position of the bluff at East Cliff Drive for perhaps the next 50 years would fix the position of the shoreline, and the gradually rising sea will progressively cover more of the beach at high tide conditions, for the next 100 years it is the wave climate and offshore bottom conditions that will have the greatest influence on surfing conditions. The conditions that create ideal surfing waves at Pleasure Point will gradually change over time and will not be significantly affected over this period by a small change in water level at the shoreline. As is evidenced in the Steamer Lane, Cowell's Beach, and

West Cliff Drive area, many of Santa Cruz's prime surfing areas do not depend on sandy beaches at the coastline.

Seismic Effects

The bluff protection structure would be designed to resist forces of ground shaking expected in a 7.9-magnitude earthquake on the San Andreas Fault, 10 miles from the project area. As a result, the risk of a failure of the bluff protection structure in an earthquake is low. The structure would be designed to allow passive drainage of groundwater, especially water that may be perched within the well-sorted sand deposits at the base of the terrace deposits. Where terrace deposits drain freely, the liquefaction potential is considered low. Additionally, the shaking accompanying each earthquake tends to further compact and consolidate the terrace deposits, thus reducing the potential for liquefaction. Failure of the armored bluff during a large earthquake, if it were to occur, would not be likely to present any greater safety hazard than failure of the unarmored bluff, although it would represent an economic loss. The bluff protection structure may actually reduce safety risks by better retaining the road and other bluff top features than if there were no structure.

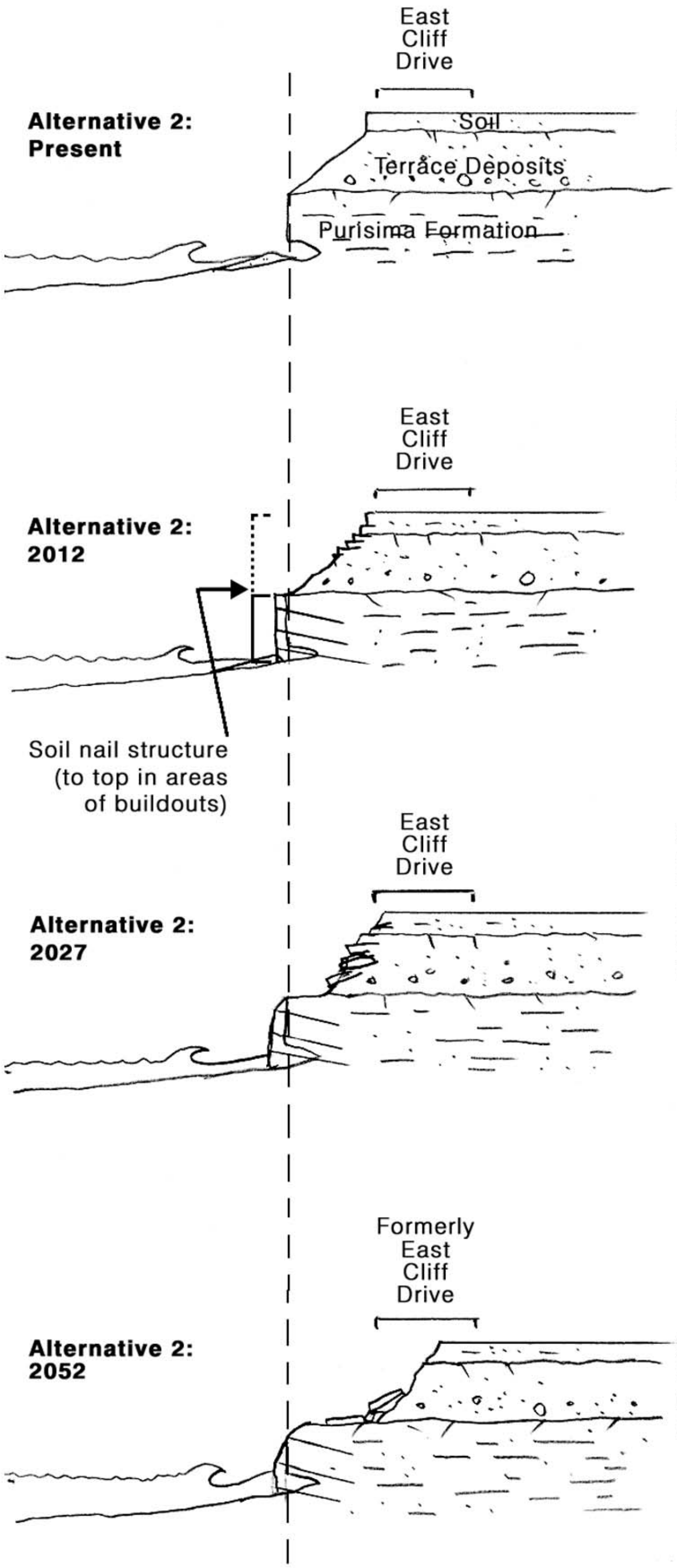
6.2.2 Partial Bluff Armoring with Full Improvements (Alternative 2)

Significant Impacts

Impact 6.2 Long-Term Slope Stability

Under Alternative 2, the Purisima bedrock underlying the terrace deposits would be protected to prevent undercutting and retreat. The terrace deposits would be subject to erosion processes, including wave action, weathering, and erosion by surface runoff and sliding and from people climbing on the slope, except in locations where full bluff armoring would extend to the top of the bluff and cover selected existing retaining walls. Other existing retaining walls would be left in place and repairs to these structures would be made. Additional soil nail walls would probably be constructed as needed to protect specific failure sites, as may also occur under the No Action Alternative. (Note: Work completed in 2004 under an emergency permit repaired the upper portions of three cribwalls between 35th and 36th avenues. One cribwall remains to be repaired, and the Purisima Formation at the base of the walls was not armored.)

Figure 6-2 illustrates the rates of bluff retreat expected under Alternative 2. The figure shows conditions 10 years, 25 years, and 50 years after completion of the partial bluff armoring. Because exposed terrace deposits would not be protected against large storm-generated waves, the terrace deposits in these areas would continue to retreat, ultimately encroaching upon East Cliff Drive. Retreat of the terrace deposits is likely to be accelerated during storms in El Niño years, but the timing and rates of retreat are unpredictable, and due to the episodic nature of wave erosion, impacts on East Cliff Drive could occur within the next few years. Failure of



Stage 1
Same as No Project.

Interlude A
Same as No Project until construction complete.

Stage 2
Purisima protected. No erosion of Purisima Formation.

Interlude B
Terrace deposits continue to erode by weathering, rainfall/runoff, and other slow processes until stable angle of repose is reached. Periodic high waves remove sediment from base of terrace deposits. Begins to threaten East Cliff Drive.

Stage 3
Purisima remains in place. Terrace deposits have retreated, leaving a ledge of exposed Purisima. Crib walls built to protect East Cliff Drive.

Interlude C
Terrace deposits continue to retreat due to slow weathering and periodic wave overtopping. Rate of retreat decreases over time. Debris from terrace deposits forms at foot of terrace deposit slope. Maximum retreat less than 50 feet. Portions of East Cliff Drive fail.

Stage 4
Retreat of Terrace deposits has removed portion of East Cliff Drive.

Source: Griggs 2001

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Alternative 2
Partial Bluff Armoring
Santa Cruz, California
Figure 6-2

Tetra Tech, Inc.

slopes in the terrace deposits that result in damage to East Cliff Drive and associated structures or underground utilities would be a significant impact. Because they would not fully protect the bluff slope, partial soil nail walls over the Purisima would not reduce these impacts to less than significant levels; therefore, this would be a significant and unmitigable impact.

Mitigation 6.2

No mitigation is identified that would reduce this impact to less than significant levels. This would be an unavoidable adverse impact.

Impact 6.3 Outflanking Effects for Fully Armored Segments over Existing Retaining Walls

As discussed for Alternative 1, the ends of the full-bluff protection structures are sites where continued erosion of the adjacent exposed bluffs could expose the ends of the bluff protection structure to wave attack from the back or sides, eventually resulting in failure of the structure. Short structures are more vulnerable to these effects than a single continuous structure. Although the ends of the short full bluff armoring segments that cover existing retaining walls would be designed to deflect waves away from the adjacent bluff to the extent possible, the results are not likely to be as protective as would be the ends of the long structures in Alternative 1. Short structures may fail more quickly than long structures, since there would be fewer soil nails holding the structures in place. An eroded or failed adjacent bluff, or a failed segment of full bluff armoring would be difficult to repair. Therefore, this impact would be considered significant and unmitigable.

Mitigation 6.3

No mitigation is identified that would reduce this impact to less than significant levels. This would be an unavoidable adverse impact.

Nonsignificant Impacts

Wave Overtopping

As discussed under Alternative 1, the elevation of wave run-up is not easily quantified. Under Alternative 2, the slope of the bluff would be less than under Alternative 1, because the terrace deposits would continue to retreat and the profile of the terrace deposits would not be as steep as it is when failure of the underlying Purisima Formation controls bluff retreat rates. Additionally, as described in Chapter 2.4, this alternative also would incorporate new MSE walls with shotcrete. These retaining walls would be constructed as needed to retain terrace deposits and support build-out areas for Parkway development. As a result of these build-out areas, the bluff armoring may extend to the top of the bluffs in the existing washout areas. With the slope of terrace deposits, wave run-up would likely be greater under Alternative 2 than under Alternative 1 (which effectively preserves the existing bluff profile), and would probably also be greater than under the No Action Alternative. However, since overtopping is considered to have a low probability under the No Action Alternative, and because the profile of the terrace deposits would be maintained to some extent with retaining walls and partial armoring of the bluffs, the impact of overtopping is expected to remain less than significant under Alternative 2.

Slope Stability Prior to and During Construction of the Bluff Protection Structure and Parkway

The impacts on slope stability before and during construction would be similar to those described for Alternative 1. Because the upper bluff would require less modification than under Alternative 1, the potential for adverse impacts on the upper bluff during construction would be less than that under the Alternative 1. The impact would be less than significant.

Effects of Construction Activity and Use of Heavy Equipment on the Beaches Fronting the Project Area

The effects would be similar to those described for Alternative 1 because the activity is not expected to affect the stability of the beach.

Reduction in Sand Contribution to Downcoast Beaches

Partial armoring of the bluff face would slow bluff erosion but would not prevent it. Because the percentage reduction in the amount of sand transported past the project area would be less than estimated for Alternative 1, the impact of this alternative on downcoast beaches also would be negligible.

Reduction in Sand Contribution to Project Area Beaches

The impacts of partial armoring on the beaches fronting the project area would be approximately the same as those described for Alternative 1 because the amount of sand contributed to the beach fronting the project area is small.

Impacts on Recreational Wave Breaks

The impacts of the partial bluff armoring on wave breaks would be the same as those discussed for Alternative 1 because the existing irregular geometry of the bluff face would be maintained and patterns of reflected wave energy would be generally the same as under existing conditions.

Enhanced Bluff or Beach Erosion Adjacent to the Project Area and Other End Effects of the Bluff Protection Structures

The end effects of a partial bluff armoring structure would be similar to those described for Alternative 1 for the portion of the structure covering the Purisima Formation. (End effects for structures extending to the top of the bluff would be significant, as discussed above.

Seismic Effects

The bluff protection structure of Alternative 2 would be designed to resist forces of ground shaking expected in a 7.9-magnitude earthquake on the San Andreas Fault. This may provide some additional support of the bluff relative to the No Action Alternative, although the terrace deposits may fail independently of the Purisima. The risk of injury from failure of the bluff protection structure would be comparable to that under the No Action Alternative (described below) and would be less than significant.

Offshore Scouring

The impacts of the partial bluff armoring on offshore scouring would be similar to but less than those discussed for Alternative 1.

6.2.3 Partial Bluff Armoring with Limited Improvements (Alternative 3)

Significant Impacts

Impact 6.4 Long-Term Slope Stability

Under Alternative 3, existing repaired walls would be left in place and only the Purisima Formation would be armored. No new repairs would be made to the existing walls and no new retaining walls would be constructed. As a result, the current unrepaired retaining walls would fail over time, due to exposure to wave run-up from large storms. The road and bluff top structures would eventually be threatened or lost completely. Figure 6-3 illustrates the way in which bluff retreat would proceed under this alternative and shows the general expected rate of retreat relative to other alternatives.

Because this alternative includes the armoring of the Purisima as in Alternative 2, the underlying Purisima bedrock platform is expected to be preserved, as it is under Alternative 2. However, the terrace deposits would continue to retreat, mainly due to direct wave attack in large storms. Because the terrace deposits would be allowed to fail, rather than being supported by new walls, Alternative 3 provides slightly less protection for East Cliff Drive than Alternative 2. However, as with Alternative 2, the primary mechanism for failure of the slope would be the removal of terrace deposit material from the toe of the slope, and the repaired walls provide little more slope protection from large waves than is afforded by the unprotected terrace deposits.

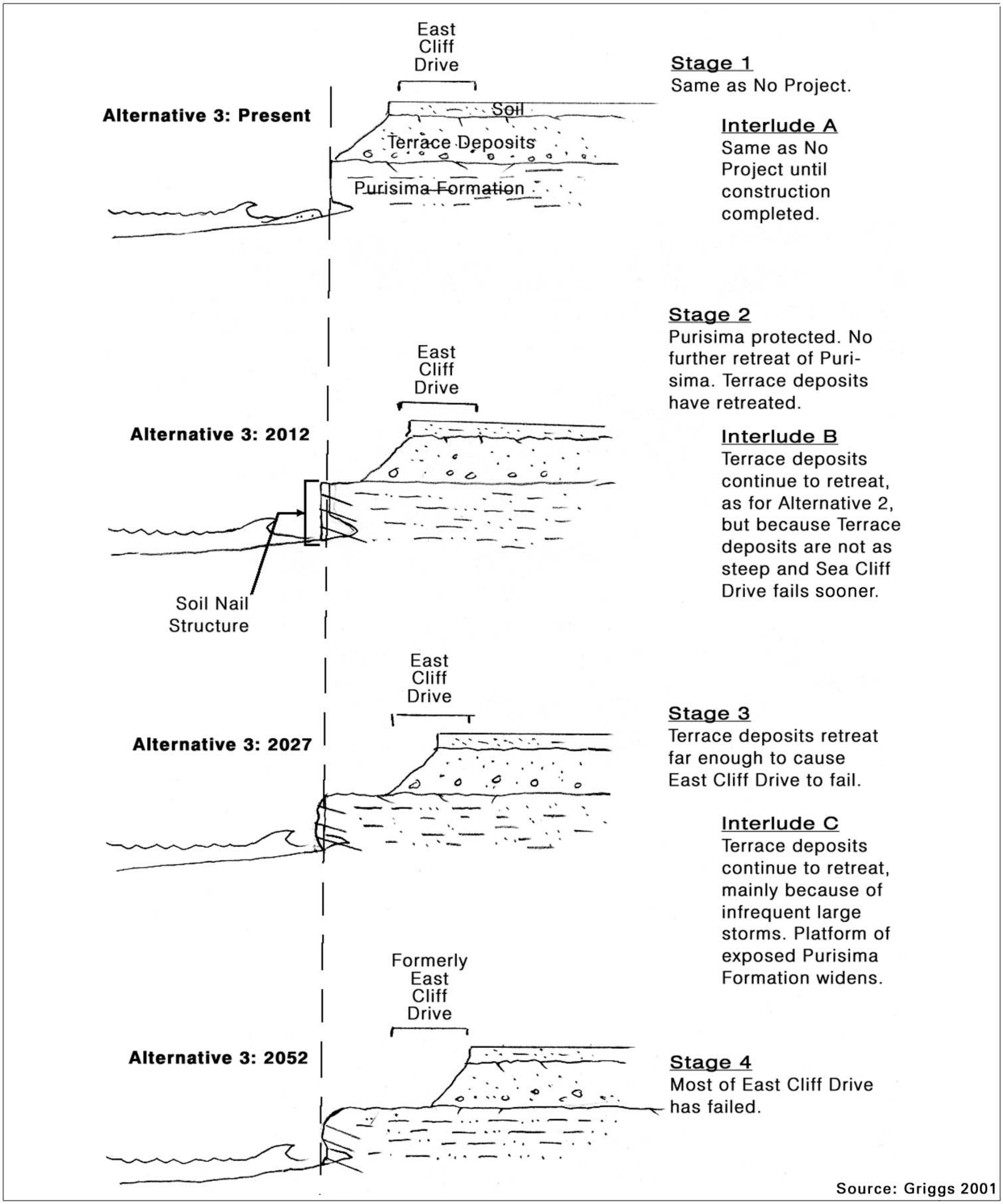
Eventually, a severe storm or seismic shaking would cause major damage to the existing retaining walls. A major seismic event capable of causing unrepaired retaining walls to collapse is likely to occur within the 100-year planning period. To the extent that the existing unrepaired retaining wall is relied upon to support new bluff top improvements, this would be considered a significant and unmitigable impact.

Mitigation 6.4

No mitigation is identified that would reduce this impact to less than significant levels. This would be an unavoidable adverse impact.

Impact 6.5 Wave Overtopping

As discussed under Alternative 2, the terrace deposits would retreat relative to the Purisima Formation under Alternative 3. However, unlike Alternative 2, there would be no reinforcement of the terrace deposits from new walls and partial armoring to the bluff tops. This lack of reinforcement combined with continuing erosion of the terrace deposits would likely make the slope less vertical over time compared to the existing slope. As a result, the lower angle of slope would present less obstruction to wave run-up, making it more likely for large waves to hit the slope and overtop the bluff. It is difficult to estimate the significance of this impact, because wave overtopping would continue to have a low probability, and the increased potential for overtopping would depend on the evolution of the bluff profile. However, because the impacts of wave overtopping could be severe if it occurs, and because wave run-up calculations for Alternative 1 suggest that wave run-up could occur to the top of the bluff under existing conditions, the increased potential for overtopping presented by Alternative 3 would be considered significant.



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Alternative 3 Erosion Estimate
Protection of Purisima Only
Santa Cruz, California

Tetra Tech, Inc.

Figure 6-3

Mitigation 6.5

Construction of a bluff protection structure or other barrier at the bluff top, and reinforcement of the bluff top to steepen the slope of the terrace deposits are not options under Alternative 3, which is intended to have minimal engineering intervention above the Purisima Formation. Therefore, mitigation is limited to implementation of precautionary public safety actions, such as warning residents, closing the road, and evacuation of the affected area if conditions warrant. These measures would also be available under the No Action Alternative or other alternatives if needed, but they would not reduce the impacts of wave overtopping to less than significant levels. Therefore, wave overtopping is considered an unavoidable adverse impact of Alternative 3.

Nonsignificant Impacts

Slope Stability Prior to and During Construction of the Bluff Protection Structure and Parkway

The short-term impacts on slope stability would be similar to those described for Alternative 2.

Effects of Construction Activity and Use of Heavy Equipment on the Beaches Fronting the Project Area

The impacts from construction activity under Alternative 3 would be similar to those described for alternatives 1 and 2. Sand would be removed from the Purisima bedrock at the toe of the bluff in order to construct the keyway for the bluff protection structure. The sand would not be permanently removed from the beach and would not have any effect on sand transport. Therefore, the effects would be temporary and less than significant.

Reduction in Sand Contribution to Downcoast Beaches

As discussed under alternatives 1 and 2, the bluffs contribute minimally to the sand that forms beaches, and therefore, a decrease in this contribution due to stabilization of the bluff under Alternative 3 would not significantly impact the sand available to downcoast beaches.

Reduction in Sand Contribution to Project Area Beaches

The impacts of partial armoring on the beaches fronting the project area would be approximately the same as those described for Alternative 2 because the amount of sand contributed to the beach fronting the project area is small. Most of the beach sand is supplied from the sand continually transported downcoast by longshore currents.

Impacts on Recreational Wave Breaks

The impacts of the partial bluff armoring under this alternative on wave breaks would be the same as those discussed for Alternatives 1 and 2 because the natural irregularity of the bluff face would be maintained.

Enhanced Bluff or Beach Erosion Adjacent to the Project Area and Other End Effects of the Bluff Protection Structures

The effects of a partial bluff armoring structure under this alternative on beach and bluff erosion would be similar to those described for Alternative 2.

Seismic Effects

The seismic impacts would be similar to those of Alternative 2, except that the terrace deposits would not be stabilized. The impacts on the terrace deposits would be the same as under the No Action Alternative.

Offshore Scouring

The impacts of the partial bluff armoring on offshore scouring would be similar to but less than those discussed for Alternative 1.

6.2.4 Groins and Notch Infilling (Alternative 4)

Significant Impacts

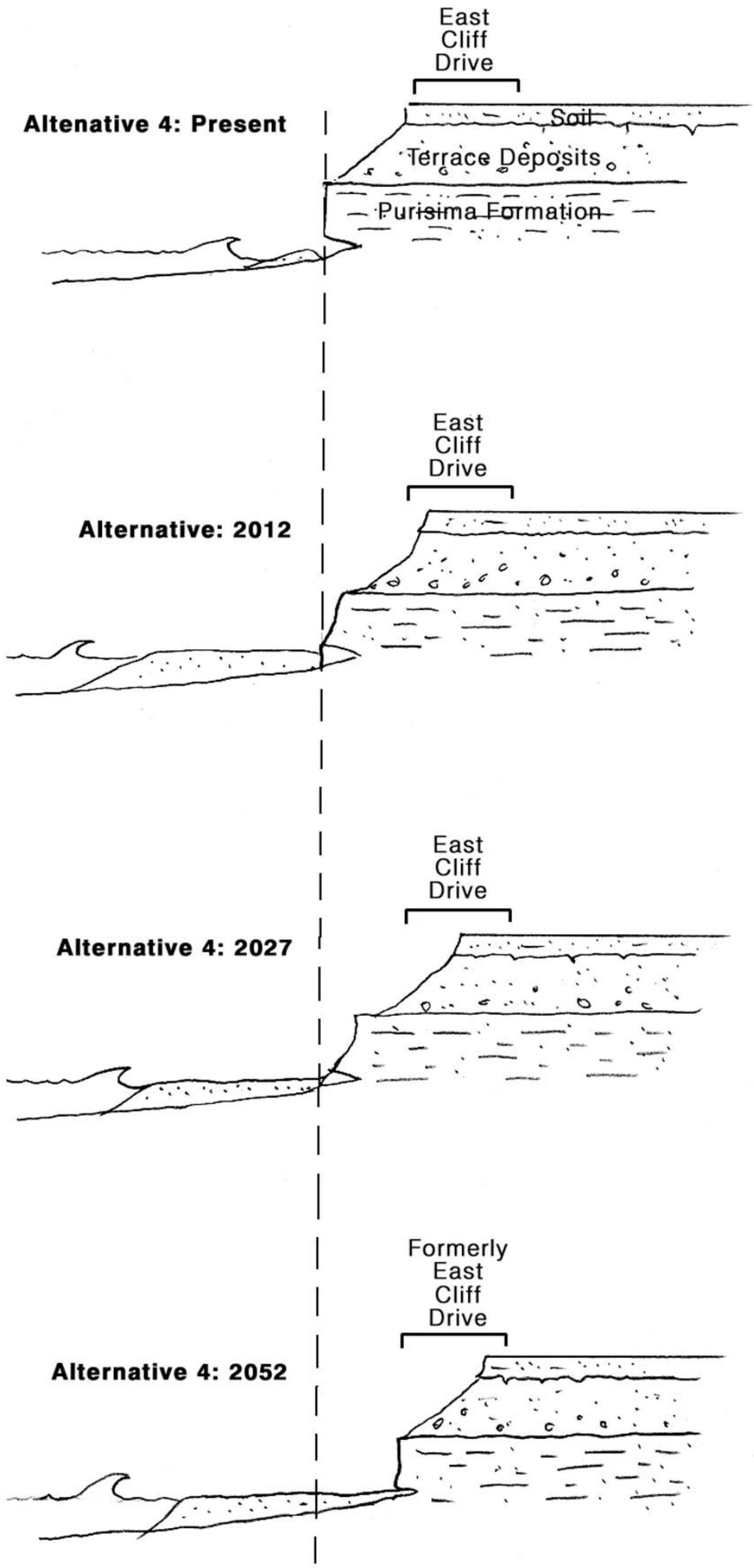
Impact 6.6 Long-Term Slope Stability

Under Alternative 4, bluff protection would come directly from filling the existing undercut notches in the Purisima Formation at beach level and indirectly from the formation of pocket beaches as a result of construction of three low profile sand-trapping groins that would extend seaward approximately 100 feet from shore. The pocket beaches would form during the summer, under predominantly calm sea conditions, and would be eroded during the winter by higher energy waves. Therefore, the groins would offer little or no bluff protection during the times when wave attack is typically greatest. The beaches would reduce, somewhat, the rate of Purisima undercutting during high tides in summer by dissipating some of incident wave energy. Filling the existing undercut notches in the Purisima would greatly reduce the rate of retreat of the Purisima but would not prevent it because the exposed portion of the formation would continue to be attacked by wave action. Eventually, new notches would be cut, and if not filled, would result in collapse of the Purisima, as under the No Action Alternative. Under Alternative 4, the bluff would continue to retreat, but probably at an average annual rate less than under the No Action Alternative. This would result in a significant impact, similar to that described for the No Action Alternative. East Cliff Drive may be affected within a few years of construction of the alternative, and most of the road would probably be lost within about 50 years. The general process of cliff retreat under Alternative 4 is illustrated in Figure 6-4.

Under this alternative, no groins would be constructed at The Hook, although any notches in the Purisima would be filled. As discussed in Section 2.6, The Hook area lacks sandy beaches and any natural finger formations. This combined with the existing geological characteristics of the area, would cause increased erosion and scour immediately downcoast from a constructed groin. Currently, however, there are no undercut notches in the Purisima Formation in this area. Under this alternative the bluff would continue to retreat at average annual rates of about six inches to one foot per year, resulting in a significant impact because it would present a hazard to existing structures and infrastructure and to people living in or using the project area. As a result, the impacts at The Hook under Alternative 4 would be significant and unmitigable, as described under the No Action Alternative.

Mitigation 6.6

No mitigation is identified that would reduce this impact to a less than significant level. This would be an unavoidable adverse impact.



Stage 1
Same as No Project.

Interlude A
Same as No Project until construction is completed, then Purisima and Terrace deposits continue to retreat, but at a slower rate than for No Project.

Stage 2
Pocket beaches form, reducing wave erosion at base of Purisima. Terrace deposits have retreated to East Cliff Drive.

Interlude B
Terrace deposits continue to retreat but at a slower rate than Alternative 3. Purisima retreats slowly, but filling notches slow the rate of retreat.

Stage 3
Portions of East Cliff Drive have failed.

Interlude C
Purisima continues to fail and retreat, as do terrace deposits. New notches form in Purisima and, unless filled, eventually cause Purisima to fail.

Stage 4
Most of East Cliff Drive removed. Purisima unprotected and retreats, as for No Project.

Source: Griggs 2001

Alternative 4
Groins and Notch Filling

Santa Cruz, California

Figure 6-4

Tetra Tech, Inc.

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Impact 6.7 Wave Overtopping

As discussed under Alternative 3, protection of the Purisima bedrock (in this case by filling the notches at beach level) without protecting the terrace deposits would result in a less vertical slope in the terrace deposits and potentially greater wave run-up elevations than under the No Action Alternative, where the entire bluff face remains relatively vertical. As with Alternative 3, this would result in a significant impact.

Mitigation 6.7

As under Alternative 3, this alternative precludes construction of engineering controls to protect the terrace deposits from wave erosion. As under Alternative 3, mitigation would be limited to implementing precautionary safety measures, such as warning residents, prohibiting public access to the bluffs, and evacuation of the affected area. Since these measures would not reduce the impacts to less than significant levels, wave overtopping is considered an unavoidable adverse impact of Alternative 4.

Nonsignificant Impacts

Reduction in Sand Contribution to Downcoast Beaches

Under Alternative 4, the annual contribution of sand from bluff erosion would be reduced but would not be halted. The groins would be designed to trap some of the sand carried past the area by littoral drift and would cause it to be deposited on the beaches in the project area. Initially, the groins would be filled with imported sand, resulting in no net reduction in the amount of sand transported past the area by littoral drift. Each winter, depending on wave activity, it is expected that the beach would be eroded or reduced in width, and each summer the beach would be rebuilt by natural wave action and littoral drift. The beaches in front of the project area are expected to contain a total of about 15,000 cubic yards of sand. This is approximately 25 times the volume of sand currently produced by average annual bluff erosion in the project area and represents approximately three to six percent of the total annual volume of sand that migrates past the project area. The volume of sand moving along the shore is large, relative to the volume of sand needed to fully charge the beaches. The annual natural process of rebuilding beaches in the project area could slow beach development immediately downcoast of the project area because some of that sand would be deposited on the project area beaches. The effects are not expected to be significant when compared to annual variations in beach-forming conditions.

Reduction in Sand Contribution to Project Area Beaches

The groins in Alternative 4 would extend approximately perpendicular to the shore. During the summer, moderate sized waves push sand from the offshore "river of sand" toward the shore. As discussed in the Affected Environment section, these waves approach at a slightly oblique angle to the shore, so that as sand is pushed shoreward to form beaches, the beach sand also migrates slowly down the shore. This slow downshore movement limits how far the beaches extend seaward. The groins would slow this downshore movement, causing sand to accumulate on the upshore sides of the groins. The groins would not alter the movement of sand toward the shore from the offshore region, but would slow the migration of sand in the direction parallel to the shore. As a result, the thickness and breadth of beaches immediately upshore of the groins would increase, but the groins would have no affect on the shoreward movement of sand.

Groins have the potential to "starve" immediately downshore beaches of sand; but because the groins in Alternative 4 would be low and would not extend far out from the shore, this "shadow" effect on beaches immediately downshore of the groins would be minimal. The groins would result in a net increase in the size of summer beaches in the project area, and would cause less than significant depletion effects on adjacent downshore beaches.

Impacts on Recreational Wave Breaks

Since there would be no groins at The Hook, Alternative 4 would not impact wave breaks offshore of The Hook. Impacts on breaking waves from Pleasure Point Park to 38th Avenue would derive from the protrusion of the groins offshore. During summer, the groins would trap sand and cause the beach to extend farther seaward than it does currently. The beach would absorb much of the incident wave energy, except in extremely high tides, and would not affect the location of the wave break offshore. The groins would extend only 100 feet offshore and would have low relief. Waves usually break at 300 to 600 feet offshore and, depending on tidal levels, break on the exposed offshore Purisima wave-cut platform. Almost all surfing occurs more than 100 feet offshore, therefore the groins are not likely to directly interfere with surfing in shallow water. The groins could reflect or refract some of the incident wave energy, depending on the angle at which waves approach the shore. When filled with sand, the additional relief of the groins would be negligible, compared to natural variations in relief on the Purisima bedrock. During winter and at high tides, the groins and the beach would be overrun by waves, and the effect of the groins would be larger, but still less than significant.

Enhanced Bluff or Beach Erosion Adjacent to the Project Area and Other End Effects of the Bluff Protection Structures

Implementing Alternative 4 could reduce deposition of sand on the downcurrent side of the groins, with the potential for making these areas slightly more vulnerable to wave run-up and scouring. However, the groins would be positioned to enhance existing finger outcrops on the Purisima, in areas where existing downcurrent deposition is already minimal. Therefore, Alternative 4 would not significantly increase the potential for erosion of the bluffs adjacent to the project area.

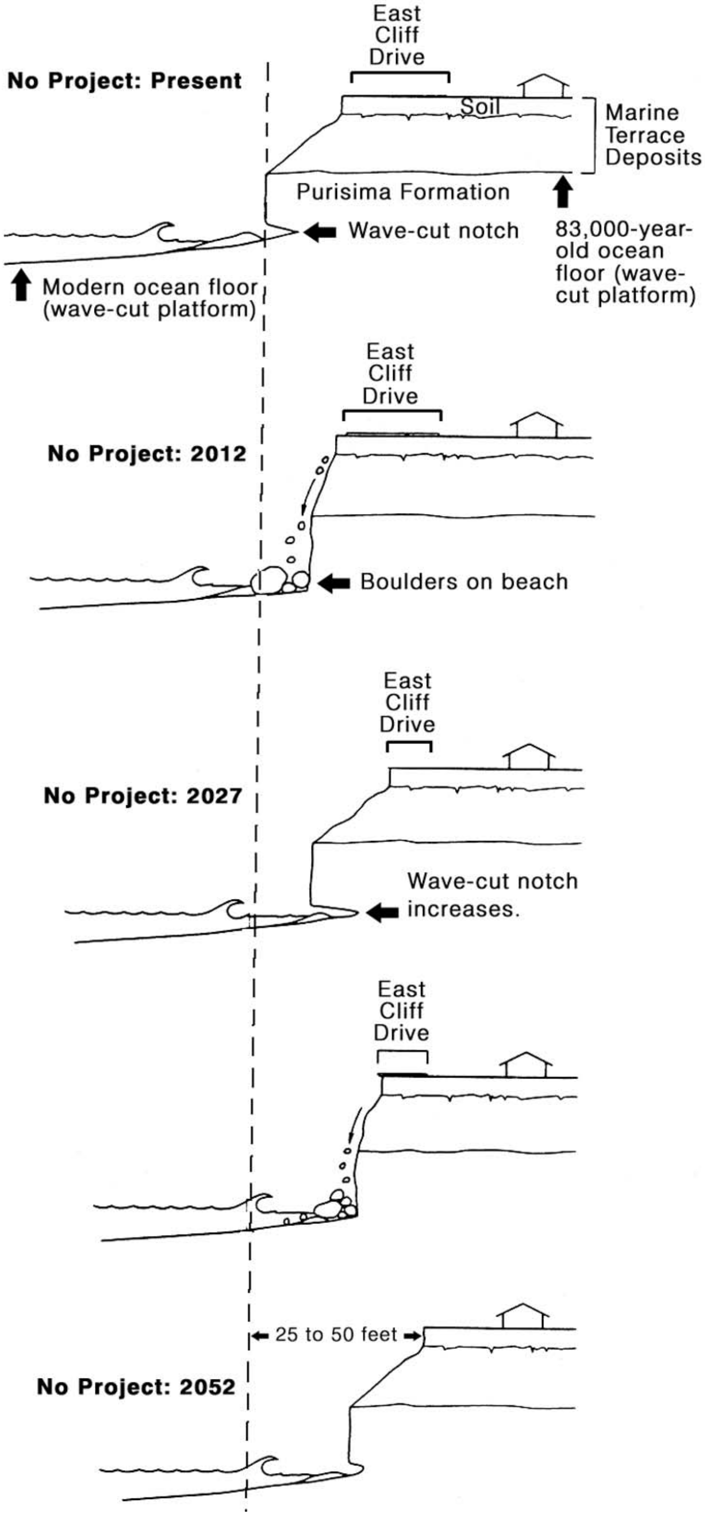
Seismic Effects

The seismic effects of Alternative 4 would be identical to the No Action Alternative.

6.2.5 No Action Alternative

Slope Stability

Under the No Action Alternative, the bluff would continue to retreat at average annual rates of about six inches to one foot per year. These existing conditions would not present an immediate hazard to existing structures and infrastructure and to people living in or using the project area. In some areas, bluff top retreat has already caused segments of the road to fail, requiring road or lane closures and emergency repairs. Portions of the bluff are supported by retaining walls that are in poor condition and beginning to fail. Over time, the Purisima Formation would continue to be undercut by wave action, resulting in incremental collapse and failure of the overlying terrace deposits (Figure 6-5). Figure 6-5 can be used to compare the relative rates of bluff retreat



Stage 1
Cliff formed in the terrace deposits is nearing equilibrium, as indicated by the low slope angle. Lower half of cliff formed in the Purisima Formation is being undercut by wave erosion. Portions of East Cliff Drive are now in this condition.

Interlude A
Wave erosion continues to undercut cliff to the point where it will collapse. Top of the cliff is experiencing little, if any, erosion.

Stage 2
Undercut cliff collapses. A large mass of debris is deposited in the surf zone and must be removed by wave action. Cliff is now vertical. While wave erosion removes debris from surf zone, the upper half of the cliff now begins to weather and fail as a series of small landslides. East Cliff threatened.

Interlude B
Continued failure of the top of the cliff undermines portions of East Cliff Drive. Portions of the road must be closed. The debris from the rock fall of Stage 2 is now completely removed by erosion.

Stage 3
Erosion continues to cut back top of slope. Almost half of East Cliff Drive eroded away. Undercut notch deeper. Cliff ready to collapse. Note similarity of the cliff profile to Stage 1.

Interlude C
Erosion continues at both the top and the base of the cliff, but undercutting by wave erosion causes cliff to collapse.

Stage 4
Cliff has collapsed. Once again a large mass of debris has been deposited in the surf zone. Cliff is once again nearly vertical. Note similarity to Stage 2. East Cliff Drive is at the top of a steep cliff.

Interlude D
Wave erosion removes rock debris from the surf zone, while the terrace deposits experience a phase of accelerated erosion. Upper portion of cliff face experiences rapid retreat.

Stage 5
Cliff top erosion destroys East Cliff Drive. Wave erosion begins to cut a new notch at the base of the cliff.

Source: Weber 2000

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No Project Time Sequence of Erosion

Santa Cruz, California

Figure 6-5

Tetra Tech, Inc.

from each of the alternatives to conditions under the No Action Alternative. Based on the SAGE report, the bluff is marginally stable under static conditions and the wedge-type failure is the most likely mode of failure at the site. Even if a circular failure occurred, according to SAGE analysis, it would most likely be truncated to a similar shape as the wedge failures (SAGE 2005b).

Based on average historical rates of retreat and the recent SAGE threat analysis, failures along parts of East Cliff Drive could occur within the next few years, and most of East Cliff Drive would be lost in the next 50 years. Bluff failure from undercutting of the Purisima can result in sudden collapse of blocks as much as five to 10 feet wide. Utilities, such as water mains, storm and sanitary sewer lines, and aboveground electrical lines, would eventually be undermined and would need to be relocated. Public access to and use of this portion of the coast would be reduced. Existing protected portions of the bluff would protrude farther from the shore and might gradually become cut off from the shore.

End Effects of Existing Bluff Protection Structures

Under the No Action Alternative, end effects could continue to occur as a result of existing bluff protection structures. Among these effects is passive erosion, by which the protected portion of the shoreline remains resistant to erosion, while the unprotected portion continues to recede. One of the impacts is the potential loss of beach in the "shadow" of the projecting protection structure, and growth of beach upcoast of the protection structure where it acts as a groin to trap sand.

Additionally, the existing shotcrete structures may focus wave run-up onto an adjacent bluff face, eroding the adjacent areas. This effect can also occur without a structure, due to the natural shape of the shoreline, such is the case at the small indent in the shoreline below the park at 41st Avenue. The adjacent structure, as well as the shape of the shoreline, have likely focused wave energy toward the interior of the indent, causing rapid retreat at the point of focus. Similarly, the shotcrete structure west of Pleasure Point Park may be enhancing the retreat of the adjacent bluff to the east.

This focusing effect results in uneven rates of bluff retreat. The armoring of small portions of the bluff, instead of addressing the entire bluff as an integral unit, has the potential to reduce the useful life of the bluff overall. This is because some of the uses of the bluff (for example, as a vehicle thoroughfare, for public access, or as a utility corridor) depend on maintaining a minimum bluff top width throughout its entire length. The closure of one lane of traffic along the entire bluff due to past bluff retreat is an example of this type of impact. Similarly, the failure of a portion of a utility line could impact the entire utility network.

Wave Overtopping

Under the No Action Alternative, the profile of the bluff face would remain very similar to its current profile as the Purisima bedrock continues to fail and the bluff recedes. While wave overtopping has been observed in other areas, overtopping has not been reported in the project area. Therefore, although wave overtopping is considered to be possible, it is expected to occur very infrequently.

Reduction in Sand Contribution to Downcoast Beaches

The bluffs tend to retreat non-uniformly, resulting in an indented shoreline. This non-uniformity may be enhanced by local protection structures, such as riprap or shotcrete walls that protect specific properties. Because of these local protection structures, beaches may widen in areas where the retreat is faster. However, overall, under the No Action Alternative bluffs would continue to retreat at approximately the current rate, producing about 308 cubic yards of beach sand per year. No additional downcoast effects on beach development are expected.

Impacts on Recreational Wave Breaks

Under the No Action Alternative the recreational wave breaks would be unchanged from current conditions. However, if the current rate of bluff retreat were to continue, it would slowly change the way waves break over the next 30 to 50 years.

Seismic Effects

Minor bluff failure did occur at Peeper's Beach during the Loma Prieta Earthquake. The relatively dry conditions that preceded the earthquake may have reduced the amount of failure however as happened elsewhere in the area. Rock slides were observed in many locations along the coast, and the Purisima is subject to failure along joints and fractures, especially where it has been undercut by wave action. The sudden collapse of the bluff face during an earthquake, either because of collapse of the Purisima or liquefaction of the terrace deposits, represents a potential safety hazard and could result in economic loss if it damaged bluff top structures. However, the magnitude of the hazard is low, relative to other seismic risks.