Chapter 1

THORNTON BEACH LANDSLIDE:
A CASE STUDY IN COASTAL DEVELOPMENT

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Throughout history, the impact of landslides along the California coastline has been tremendous. In 1983, California suffered over $100 million of coastal damage, including damage to approximately 3,000 homes and 900 businesses (Pepper, 1985). Landslide susceptibility is particularly high in unconsolidated sedimentary rocks along the coast. For instance, in the coastal hills of Palos Verdes, about one half of a square mile of unconsolidated shale began to slide in 1956 (Griggs and Savoy, 1985). The movement continued for several years, resulting in the damage or destruction of over 200 houses. The total property damage from the landslide exceeded $10 million in 1956 dollars.

Landslides and severe erosion typically occur during the winter, when storms saturate the ground and huge waves undercut the cliffs. The amount of erosion which can occur during a storm is often surprising. In the storms of January 1983, for instance, waves removed 46 feet of a Santa Cruz bluff (Griggs and Savoy, 1985). Frequently erosion of this magnitude threatens houses, roads and other man-made structures. Such is the case at Thornton Beach, Daly City (Figure 1), where a huge landslide threatens to damage many houses and roads.

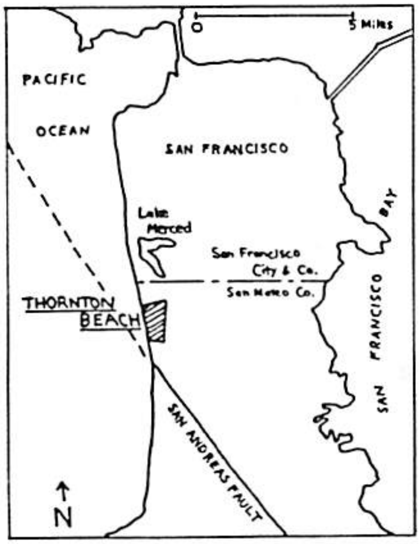


Figure 1. Location of Thornton Beach.
Source: After Sullivan (1975).

In this report I use the Thornton Beach landslide to illustrate the geologic hazards of coastal development in unconsolidated sedimentary rock. I will do this in two ways. First, I will describe the past impact of the landslide upon development; and second, I will map the erosion of the past 15 years in order to illustrate recent damage and to predict future damage.

Past Studies

Very little past research has been done concerning the Thornton Beach area specifically; however, several studies contain information about the geology of the region, including the geologic hazards along the south San Francisco coast (Schlocker, 1974; Sullivan, 1975). Sullivan (1975) analyzes the geologic and human factors which contribute to high rates of erosion in the area. Schlocker (1974) describes the engineering principles of landslides in the rock formations of the region.

Two studies document the progress of the Thornton Beach landslide; one by Lajoie and Mathieson (1985) covers the coast from San Francisco to Año Nuevo, focusing on the annual rate of erosion at Thornton Beach, as well as the damage caused by this erosion. The second is an unpublished report by Liston (1976) which illustrates the progress of the landslide with sequential photographs of the area.

Coastal Landslides

From a geologic standpoint the coastal hills of California are extremely young and steep, making erosion rapid (Sanders *et al*., 1974). In the unconsolidated sedimentary rocks of the coastal hills, landslides and slumping play a major role in erosion. Landslides are defined as the downward and outward movement of a mass of rock (Sanders *et al*., 1974). Slumping includes the sagging and sloughing of surface material.

In the Thornton Beach region, and elsewhere along the coast, the typical kind of landslide is known as a rotational slump. This type of landslide involves the rotating and falling of a whole section of earth (Figure 2). As the landslide moves downward and outward, potential energy is converted to kinetic energy and friction (Schlocker, 1974). Consequently, the resulting slope has less potential energy, and is therefore more stable. Along the coast the stability of a slope changes rapidly. As soon as a landslide stabilizes a slope, wave erosion begins to remove the lateral support, creating yet another unstable condition. In the Thornton Beach area, wave erosion is particularly important in the winter, when the narrow width of the beach offers little protection from the powerful winter waves.

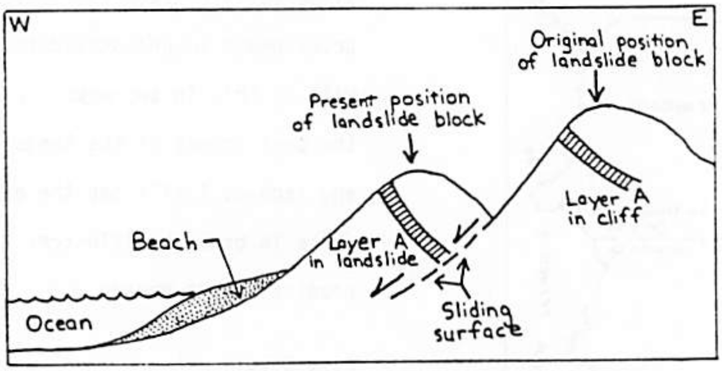


Figure 2. Schematic drawing of rotational slump.
Source: After Liston (1976).

From an engineering point of view, landslides are caused by two factors: high shear stress and low shear strength (Schlocker, 1974). High shear stress results from the removal of lateral support at the base of the slide, and from the addition of weight to the head of the slide. Low shear strength is a function of the type of rock which composes the slope. When the force of the shear stress exceeds the shear strength, a landslide occurs. At Thornton Beach, the low shear strength of the rock and the high shear stresses which result from wave erosion and ground saturation create ideal conditions for landslides.

Geology of Thornton Beach

The geology of the South San Francisco quadrangle, including Thornton Beach (Figure 3), was mapped by Bonilla (1959). Two different formations as well as artificial fill exist near Thornton Beach. The youngest formation is the Colma Formation, a "friable, well-sorted fine to medium sand containing a few beds of sandy silt, clay, and gravel" (Bonilla, 1971). The older Merced Formation has similar properties to the Colma Formation, except that it is a little firmer, and more resistant.

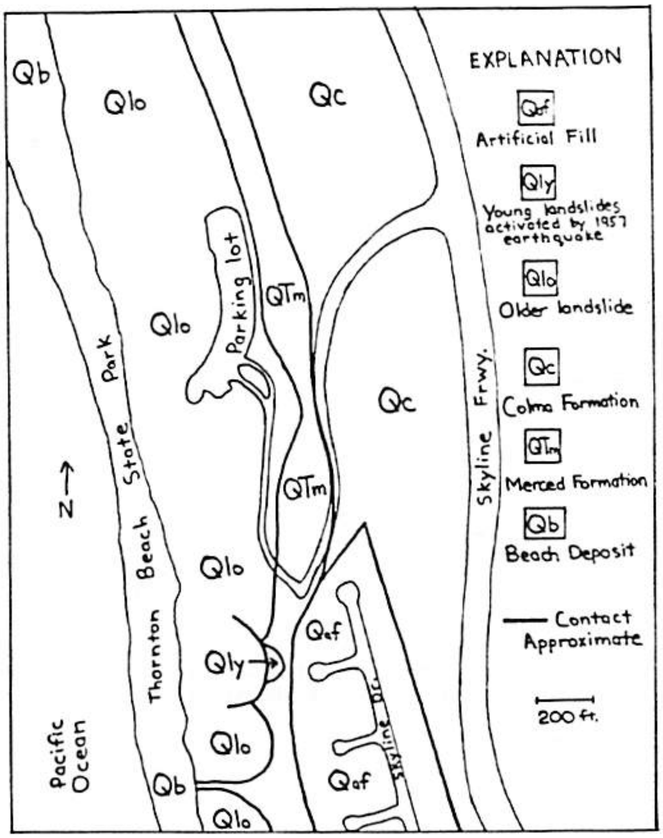
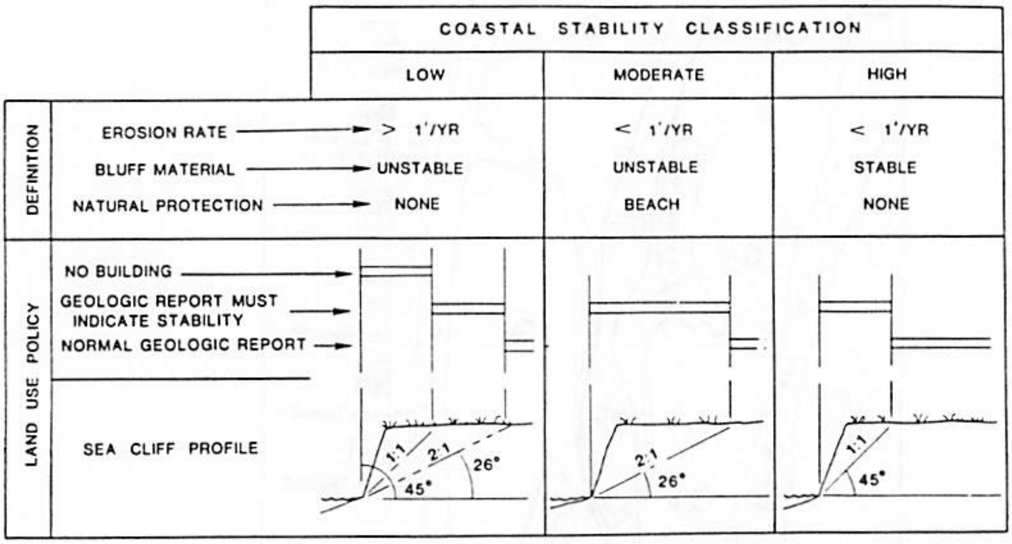


Figure 3. Generalized geology of Thornton Beach.
Source: After Bonilla (1959).

The artificial fill, as well as the silt and clay of the Colma Formation, create local variations in rock density and porosity. These variations often channel water flow, creating ideal surfaces for rotational slumps. In addition to the erodible properties of these formations, the Merced Formation tilts steeply below the horizontal Colma Formation. This factor adds more instability to the region.

From 1866 to 1956, the head of the cliffs at Thornton Beach has eroded at an average rate of 20 inches per year (Lajoie and Mathieson, 1985). The use of average rates requires some caution since erosion varies greatly from year to year. The variability of erosion usually results from the episodic and unpredictable nature of winter storms, during which most of the erosion takes place.

By any standards the Thornton Beach region has to be classified as highly unstable. In 1975, the California Coastal Zone Conservation Commission created a threefold stability classification (low, moderate, and high stability) based on historical erosion rates, bluff material, and natural protection. The classification system (Table 1) has been summarized by Lajoie and Mathieson (1985). If a region has an erosion rate greater than one foot per year, unstable bluff material, and little natural protection, then the area receives the lowest stability classification. On the basis of these factors, Thornton Beach is classified in this category.



		COASTAL STABILITY CLASSIFICATION		
		LOW	MODERATE	HIGH
DEFINITION	EROSION RATE	> 1'/YR	< 1'/YR	< 1'/YR
	BLUFF MATERIAL	UNSTABLE	UNSTABLE	STABLE
	NATURAL PROTECTION	NONE	BEACH	NONE

Table 1. Shoreline stability categories used by the California State Coastal Zone Conservation Commission and by the County of San Mateo to regulate land use along the San Mateo coastline.
Source: Lajoie and Mathieson (1985)

Development at Thornton Beach

In spite of the region's potential hazards, three major development projects have occurred this century. The first one was the Ocean Shore Railroad, constructed on a bench approximately 150 to 200 feet above the ocean. The railroad operated from 1907 to 1920, when it was abandoned due to financial problems (Sullivan, 1975). In 1933, the railroad bed was regraded and widened to accommodate Coast Highway 1. The highway required extensive maintenance, particularly between 1950 and 1957, when the road was closed 17 times for a total of 174 days (Sullivan, 1975). The road was finally abandoned in 1957 after an earthquake measuring 5.3 on the Richter scale triggered a series of landslides which blocked the road. Eventually the old highway was converted into the access road for Thornton Beach State Park.

The final phase of development was the creation of residential subdivisions. Between 1956 and 1960 developers leveled off the hill tops, filled the canyons, and erected small housing tracts (Lajoie and Mathieson, 1985). These houses, which are primarily modest one-to-two bedroom homes, are located on top of the steep bluffs approximately 400 feet above the beach (Sullivan, 1975). Since development, the expanding landslide has forced six of these homes to be removed and one to be abandoned (Lajoie and Mathieson, 1985).

Methodology

My fieldwork was composed of two separate projects. The first was to map the present features and topography of the landslide on an aerial photograph of the region at a scale of 1" = 200'. I mapped the fractures, debris, and head of the landslide as they presently exist.

The second project was to map the changes in the landslide features and topography during the past 15 years. To show the changes, I picked three years, 1971, 1977, and 1983, which best illustrate the changing topography of the region. The period between 1971 and 1977 was extremely dry (Table 2), with six of the seven years having below average precipitation (U.S. Department of Commerce, 1971-1986). Between 1978 and 1983, the situation was reversed, with five of the six years showing above average precipitation and 1983 being one of the wettest years on record. To determine what the topography was like in a given year, I examined aerial photographs from the Cal Trans Geotechnical Division, which photographs the area two times per year (Appendix I).

The next step was to plot the landslide's progress over the years onto two maps to determine how the expanding landslide has affected the houses and roads of the region. I use these maps to predict how the landslide might affect development in the future if present coastal erosion patterns continue.

Data

The data are condensed into two maps: one map shows the topography of 1971 and 1977 (Figure 4), and the other map shows the topography of 1983 and 1986 (Figure 5). Between 1971 and 1977, the dry years, few changes occurred. In both of these years, the region south of the access road shows

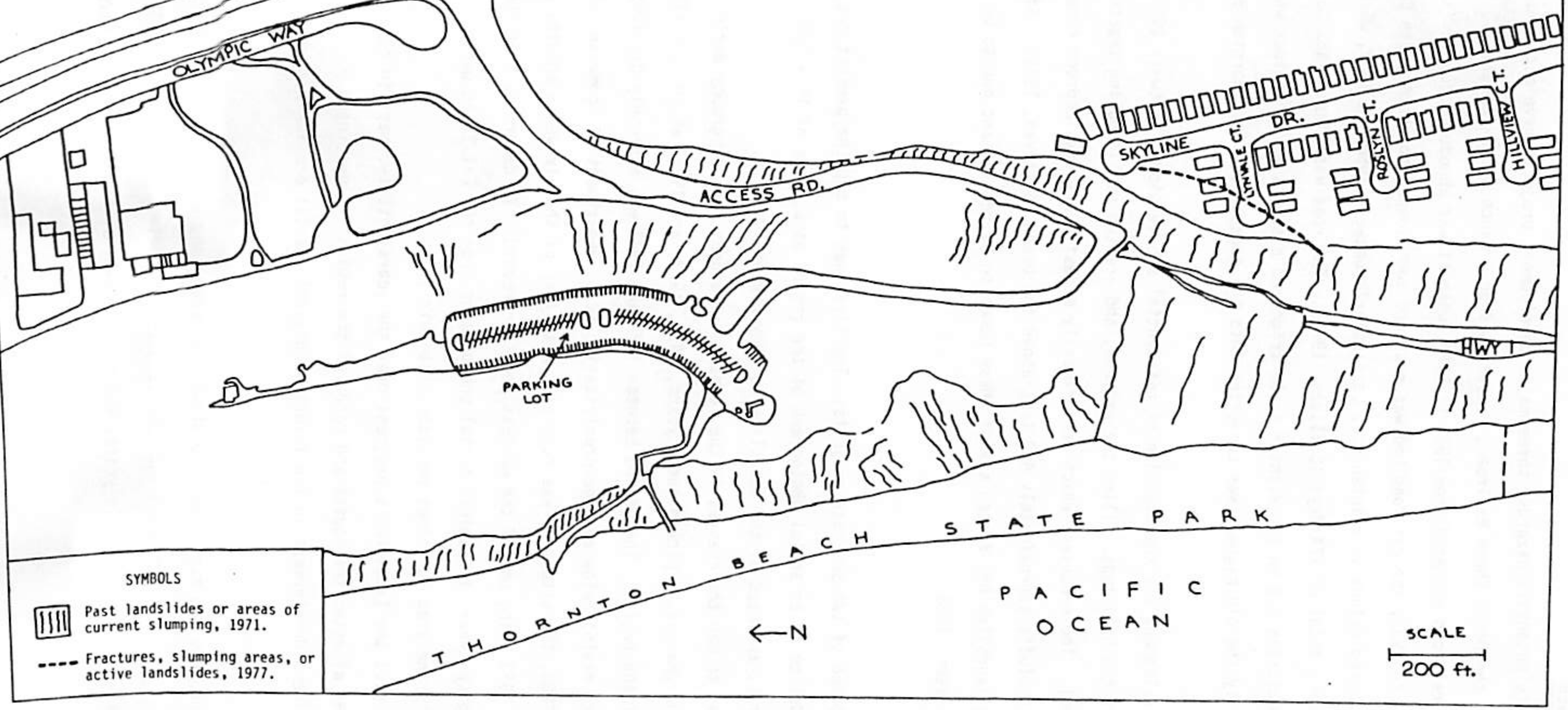


Figure 4. Map of landslides, 1971 and 1977. Note that the only difference between 1971 and 1977 is a fracture across Lynvale Court (upper right).

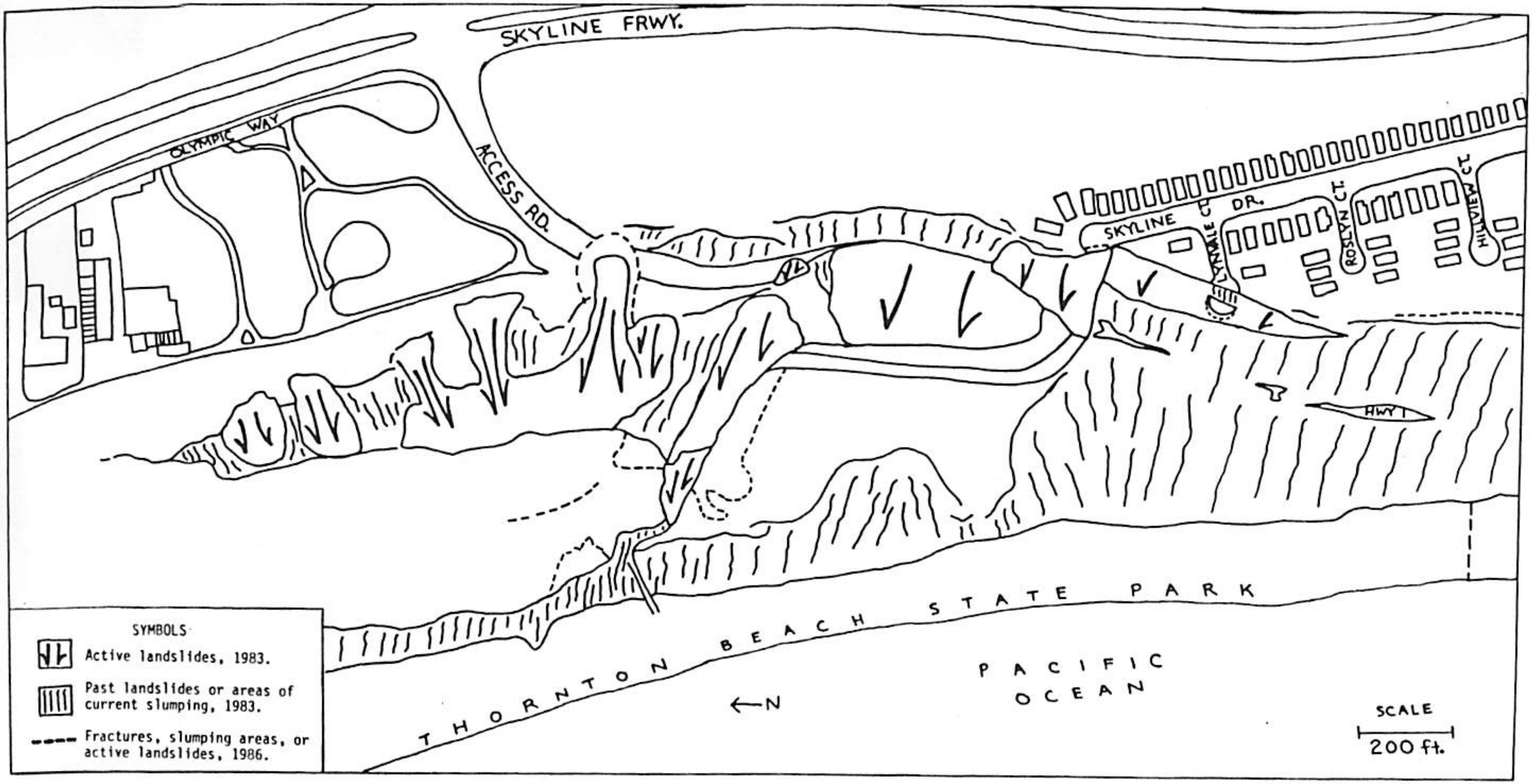


Figure 5. Map of landslides, 1983 and 1986.

Year	Precipitation (inches)	Departure From Normal (inches)
1971	9.80	-8.89
1972	16.97	-1.72
1973	31.38	+12.69
1974	15.60	-3.93
1975	17.25	-2.28
1976	10.02	-9.51
1977	12.54	-6.99
1978	25.81	+6.28
1979	24.57	+5.04
1980	18.34	-1.19
1981	23.47	+3.94
1982	34.81	+15.28
1983	38.34	+18.63
1984	14.13	-5.58
1985	12.57	-7.14
1986	19.01*	——
Jan. 1983	6.83	+2.18
Feb. 1986	8.09	+4.86**

* Precipitation through October 31, 1986.

** Calculated using the normal value for all recorded years before 1983.

Table 2. Annual Precipitation (Jan.1 - Dec.31) in San Mateo County (San Francisco Weather Service Office at the San Francisco Airport.

Source: U.S. Department of Commerce(1971-1986).

ndslides and slumping above and below old Highway 1, which is about half-covered with debris. Minor iding then continues along the State Park access road, with a major slide existing above the parking t. In both 1971 and 1977 landslides and slumping occur along the length of the beach in the lower rt of the bluffs. The one difference between 1971 and 1977 is a major fracture which developed ross Lynvale Court. By 1975 the fracture was great enough to force the removal of three houses on nvale Court (cf. Figures 4 and 5).

Unlike the relatively stable period between 1971 and 1977, the winter of 1983 produced dramatic anges in the topography of the region (Figure 5). In January of 1983, everything to the west of the acture across Lynvale Court slid down the hill, leaving a vertical scarp along the former fracture ne and dropping the cul-de-sac of Lynvale Court about 20 feet straight down. The fresh scarp face ntinues north of Lynvale Court and comes right to the edge of the Skyline Drive cul-de-sac. The position of landslide debris in this region is clearly observable by examining Highway 1, which is, mpared to 1977, almost completely buried with earth.

Also in 1983, a large slump block just north of Skyline Drive destroyed the access road and posited debris on top of the parking lot. In one section of the access road, the slump block dropped as much as 21 feet (Lajoie and Mathieson, 1985). A series of connected landslides to the north of the access road also helped to bury the parking lot.

By 1986, after an extremely wet February (Table 1), the boundaries of the landslide had expanded along the south end of the parking lot and along part of the access road. The cul-de-sac of Lynvale Court also slid several more feet down the bluff. In addition to the expanding boundaries of the slide, fractures developed west of Roslyn and Hillview Courts, across the west edge of the Skyline Drive cul-de-sac, and west of the Thornton Beach parking lot.

Discussion

One of the most noticeable aspects of the maps is the variability in the frequency of landslides. In some years, such as the dry period between 1971 and 1977, no landslides occurred, whereas in other years, such as 1983, which had nearly two times the average rainfall, landslides occurred throughout the region. Although it is extremely difficult to predict when storms and landslides will occur, it is not too difficult to foresee where a landslide will occur. For instance, in 1977, when a fracture developed across Lynvale Court, it was only a matter of time before the area west of the fracture slid down the hill. Therefore, by examining the fractures, one can predict the future locations of some landslides. It is impossible to predict all of the locations since many landslides do not exhibit warning signs.

The most obvious site for a future slide is at the cul-de-sac of Skyline Drive. On the west side of the cul-de-sac, a sharply undercut and extremely unstable scarp marks the head of the landslide. Just to the east of this scarp face, the pavement of the cul-de-sac has several fractures in it. These fractures are likely to become the future boundary of the landslide. As this occurs, part of the cul-de-sac as well as one house are likely to be damaged. The boundary of the landslide is also likely to move headward to the fractures west of Roslyn and Hillview Courts. The houses on these streets do not appear to be in imminent danger, but ultimately may be endangered. The other fracture which lies west of the parking lot does not appear to threaten any man-made structures. Another potentially dangerous region is the area west of Olympic Way. Although no fractures have developed, the area is capable of eroding rapidly without any warning signs as it did in 1983.

All of the endangered buildings and roads in this region were constructed before the California Coastal Act of 1976. The Coastal Act, which evolved from a study done by the California Coastal Zone Conservation Commission, created regulations for general land-use within the coastal zone (Pepper, 1985). Under this act new development cannot extend farther seaward than a certain point as determined by the geologic conditions of the region (Table 1). One of the primary goals of the Coastal Act is to prevent the construction of houses, roads, and other structures which are likely to be damaged by future erosion. In other words, the Coastal Act attempts to prevent situations such as the one at Thornton Beach, where development took place with little regard for the potential hazards.

Once development occurred, could anything have been done to slow erosion or to minimize the hazards of landslides? A few options existed, but from an economic standpoint, none of them seemed practical. One option would have been to build a riprap barrier or a seawall to protect the bluffs from marine erosion. The cost would have been on the order of one million dollars, and would not have guaranteed adequate protection (Griggs and Savoy, 1985). Since most of the houses and roads lie well above the beach, terrestrial processes as well as marine erosion contribute to the landslide hazard.

Another option would have been to construct concrete terraces or crib walls along the bluffs to stabilize the soil. These concrete structures cost even more than seawalls or riprap and are of questionable stability (Kuhn and Shepard, 1984). All things considered, the most practical solution was probably to do nothing. This policy is especially attractive in light of the relatively cheap cost of relocating houses. The expense of relocating a typical moderate-sized structure is in the range of $10,000-$20,000 (Griggs and Savoy, 1985).

Conclusion

For the future, the policy of doing nothing where housing exists along the bluffs still seems most desirable. Although it is inevitable that homes will be lost, it seems more sensible to relocate these homes than to spend large sums of money on protective structures which do not guarantee safety. For Thornton Beach State Park, the state is considering a proposal to turn the land over to the National Park Service. This proposal seems like a good idea since park use appears to be more appropriate for the region than development.

In conclusion, I would like to emphasize the importance of strong coastal zone regulation. Due to the difficulties involved with protecting structures from landslides, the only logical solution seems to be to prohibit development in hazardous regions. This can be done only through strict regulation.

Appendix I. List of aerial photographs used in mapping.

Date	Scale	District, County, and Route	Code
1-24-71	1" = 500'	04-SM 1-4	ASC 7107-4
1-24-71	1" = 500'	04-SM 1-6	ASC 7104-4
1-24-71	1" = 500'	04-SM 2-4	ASC 7104-4
1-24-71	1" = 500'	04-SM 2-5	ASC 7104-4
1-24-71	1" = 500'	04-SM 2-6	ASC 7104-4
5-13-74*	1" = 500'	04-SM 1-10	ASC 7407-17(1)
10-22-75*	1" = 500'	04-SM 1-20	ASC 7507-14(2)
5-17-77	1" = 500'	04-SM 4-9	ASC 7707-13
5-17-77	1" = 500'	04-SM 4-10	ASC 7707-13
5-17-77	1" = 500'	04-SM 4-11	ASC 7707-13
3-19-83	1" = 500'	04-SM-35 16-10	ASC 8307-17
3-19-83	1" = 500'	04-SM-35 16-11	ASC 8307-17
3-19-83	1" = 500'	04-SM-35 16-12	ASC 8307-17
4-19-86	1" = 500'	04-SM-35 9-8	ASC 57-8606-48
4-19-86	1" = 500'	04-SM-35 9-9	ASC 57-8606-48
4-19-86	1" = 500'	04-SM-35 9-10	ASC 57-8606-48

* Photos used to determine the date of removal for the three homes on Lynvale Court.

REFERENCES CITED

Bonilla, M.G., 1959. Geologic observations in the epicentral area of the San Francisco earthquake of March 22, 1957; California Division of Mines and Geology, Special Report 57, pp. 25-37.

_____, 1971. Preliminary geologic map of the south San Francisco quadrangle and part of the Hunters Point quadrangle, California. U.S. Geological Survey, Miscellaneous Field Studies Map MF-311.

Griggs, G. and L. Savoy, 1985. Seacliff erosion. In Living with the California coast; G. Griggs and L. Savoy, eds.; Durham, North Carolina, Duke University Press, pp. 27-35.

Kuhn, G.G., and F.P. Shepard, 1984. Sea cliffs, beaches, and coastal valleys of San Diego County: some amazing histories and some horrifying implications; Berkeley, California, University of California Press, 195 pp.

Lajoie, K.R. and S.A. Mathieson, 1985. San Francisco to Año Nuevo. In Living with the California coast; G. Griggs and L. Savoy, eds.; Durham, North Carolina, Duke University Press, pp. 140-177.

Liston, J., 1976. Thornton Beach to Mussel Rock: A study in geological hazards. Unpublished report for Geology 110, University of California, Berkeley, 19 pp.

Pepper, J., 1985. Coastal land use planning and regulation: reducing the risks of environmental hazards. In Living with the California coast; G. Griggs and L. Savoy, eds.; Durham, North Carolina, Duke University Press, pp. 69-80.

Sanders, J.E., A.H. Anderson, and R. Carola, 1976. Physical Geology; New York, New York, Harper and Row Publishers, Inc., 584 pp.

Schlocker, J., 1974. Geology of the San Francisco north quadrangle; U.S. Geological Survey Professional Paper 782, 109 pp.

Sullivan, R., 1975. Geological hazards along the coast of San Francisco; California Geology, v. 28, no. 2, pp. 27-33.

U.S. Department of Commerce, 1971-1986. Climatological Data California; v. 75-90.