

IMPACT OF 1983 STORMS ON THE COASTLINE

Northern Monterey Bay

Santa Cruz County

By

GARY B. GRIGGS
Earth Sciences and Center
for Coastal Marine Studies
University of California
Santa Cruz, California

and

ROGERS E. JOHNSON
Johnson and Associates
Santa Cruz, California

INTRODUCTION

A dilemma of increasing magnitude that has developed in recent years is the conflict between ocean front construction and the inherent geological instability of the shoreline. In particular, the storms of 1978 and 1983 have inflicted major damage to many heavily developed portions of California's coastline. Public and private losses during 1978 reached over \$18,000,000. Damage to ocean front property from the 1983 storms has already exceeded \$100,000,000 (as of March 1983). Losses in 1983 were not restricted to broken windows and flooded floors; 27 ocean front homes and 12 businesses were totally destroyed. Three thousand other homes and 900 businesses were damaged (Swisher, 1983).

During both winters the simultaneous occurrence of a series of very high tides, storm surges, and very large storm waves set the stage for disaster. Although many of California's beach front areas appear quite stable during the calm summer months, the change to winter wave conditions can remove the protective buffer provided by the beach sand almost overnight. The difficulty arises where people have chosen to build permanent structures either on the beach itself, on a rapidly eroding sea cliff, or on sand dunes. The coastline of Monterey Bay provides a series of clear examples of the risk entailed in building in these locations. The storms of 1978 and 1983 have affected numerous structures on these sites. Storm damages in Santa Cruz County in January 1983 exceeded \$10 million, with eight houses destroyed, and 47 homes and businesses heavily damaged.

GEOLOGIC SETTING

Most of northern Monterey Bay (Figure 1) is flanked by an uplifted marine terrace which varies in height from about

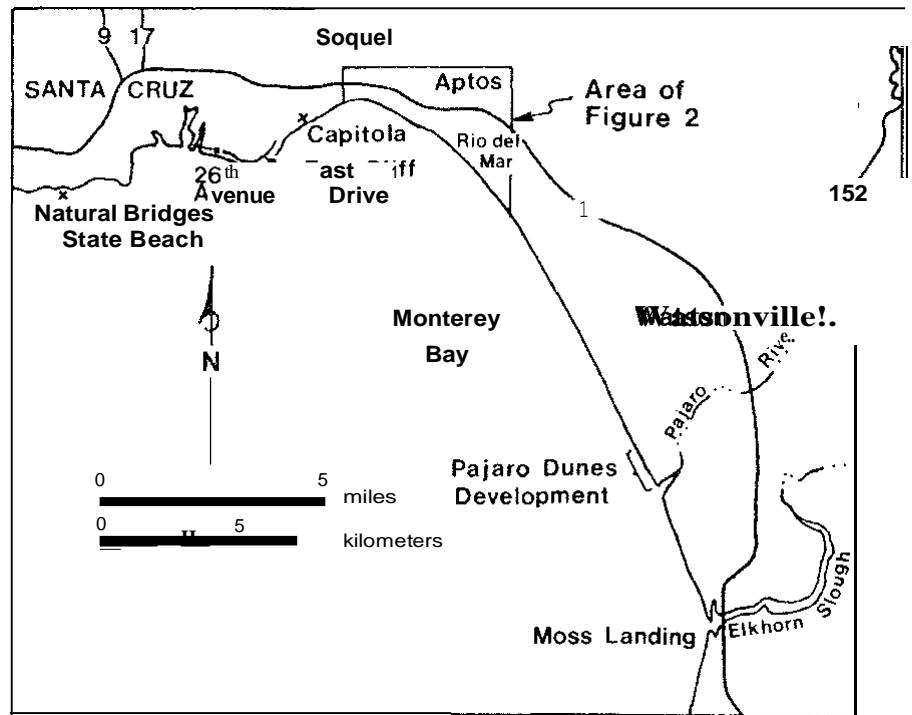


Figure 1. Index map of coastline points in central and southern Santa Cruz County. Numbers indicate major highways.

6 to 36 meters. The Pliocene Purisima Formation (siltstone and sandstone) forms the sea cliff from Santa Cruz to Rio Del Mar and is replaced to the south by Pleistocene Aromas Sand. This latter formation extends southeast to the recent dunes which began to appear several kilometers north of the Pajaro River mouth.

The Purisima Formation consists of thinly to thickly bedded, poorly to moderately indurated siltstones and sandstones with occasional interbeds or lenses composed almost entirely of mollusk shells. This formation is jointed, offset among numerous inactive faults, and in general, provides little resistance to wave erosion (Griggs and Johnson, 1979).

The Aromas Sand is predominantly massive semiconsolidated aeolian and fluvial deposits with occasional clay interbeds. Although the sand can stand in steep cliffs (100% grade) over 30 m high when protected by a beach, it erodes very quickly when exposed to wave action. During the severe rains of January 1982, slope failure in the Aromas Formation along the sea cliffs of inner Monterey Bay was widespread.

The Sunset Beach-Pajaro Dunes area forms the southern Santa Cruz County coastline. These dunes are active, which means they are still connected to their beach sand sources, and they periodically undergo erosion from wave action followed by subsequent buildup. Over at least the past 50 years the dunes appear to have been in dynamic equilibrium with the central Monterey Bay coastline.

The recent geomorphic history of the Pajaro Dunes area was analyzed using aerial photographs, combined with mapping of the internal dune structure and historical accounts. The aerial photographic record indicates that the seaward edge of the dunes has advanced and retreated in response to wind and wave action. For example, between 1939 and 1953, a maximum of 3-5 meters of recession took place at the front edge of the dunes. From 1953 to 1975, overall accretion of about 9 meters was evident. The storms of 1978 cut back the front face of the dunes as much as 7-9 meters in places. Following such an erosional episode, sand is gradually (over a number of years) accumulated against the scarp to recreate the windward face.

OCEANOGRAPHIC CONDITIONS AND STORM HISTORY

The recent historical record of coastal storm damage is the most useful data base for estimating the frequency and magnitude of major storms. The number of storms effecting Monterey Bay is large and waves which damage one section of coastline may cause little or no damage elsewhere. The orientation of the coastline relative to the direction of wave approach, the wave height and length, offshore topography, persistence of wave attack (such as the number of storms per season), tidal stage, presence or absence of a protective beach or an engineering structure are all important in determining the impact of any particular storm on any stretch of coastline. Three separate compilations of storm dates (U.S. Army Corps of Engineers, 1958; Bixby, 1962; California Coastal Commission, 1978) provided a basis for an investigation of newspaper accounts of past storms. In addition, wave hindcasting studies were used to quantify the wave data for the Monterey Bay area (National Marine Consultants, 1960).

For the period of most detailed record (1910 to present) there have been at least 20 storms of some significance (such as either high seas and/or damage to some portion of the Monterey Bay region. For this 73 year period this amounts to a large storm every 3.6 years on the average. Although no major storms were recorded for some intervals as long as 7 years (1916-1923), in another case, five significant storms hit the coast in a single year (1931).

The historical record and the damage during the winters of 1978 and 1983 indicate that the northern half of Monterey Bay (Moss Landing to Santa Cruz) is most susceptible to damage when storm waves approach from the west or southwest. Waves from the northwest, which predominate along the central California coast, undergo major refraction, which results in a significant energy reduction, as they bend around point Santa Cruz to strike the beaches of the inner bay. Thus, although waves from the northwest and north-northwest dominate along this coastline, and do impact heavily along the open coast northwest of Point Santa Cruz, their effect on the interior of Monterey Bay is considerably reduced.

In contrast, storm waves approaching from the west, west-southwest, and southwest pass primarily over deep water on

their way to the shoreline within the bay and, therefore, lose little energy. These waves undergo little refraction before striking the coastline directly and have produced the most consistent damage at Capitola, Seacliff, Rio Del Mar, and adjacent areas. Of the 20 large storms which have produced the greatest damage to the coastline of northern Monterey Bay, only one is described as coming from the northwest, 13 arrived from the southwest, and no direction was listed for the remaining six. For the 73 years of good historical record, damaging storm waves from the southwest have struck the beaches of inner Monterey Bay every 3.6 years on the average. The past storm damage to this area was often caused by the simultaneous occurrence of high tide and large waves. This was a critical factor during both the winters of 1978 and 1983.

Using wave hindcasting data for offshore stations (National Marine Consultants, 1960) it is reasonable to expect waves with heights in excess of three meters to occur on the average for 23 days each year; waves in excess of 4.5 meters in height can be expected to occur three days each year on the average. During the storms of January and February 1978, waves with significant heights of 4.3 to 6.4 m were recorded along the central coast (Domurat, 1978). Tidal heights can also be analyzed for their frequency of occurrence. For the Monterey Bay area tides in excess of 6.0 ft (1.8 m) can be expected 25-

35 days a year, and tides in excess of 5.5 ft (1.7 m) about 100 days a year. These figures indicate that the probability of large storm waves occurring at times of high tides is reasonably large, and therefore, should be given serious and careful consideration in planning for coastal land use and protection.

COASTAL DAMAGE-1983

The storm waves which struck northern Monterey Bay during late January 1983 reached heights of 4 to 6 m and, coincided with a storm surge and several days of 6.6 foot (2 m) tides. Some areas damaged during the winter of 1978 were damaged again; in addition, coastal construction which had previously been unaffected, was hit hard. Those structures, roadways, and utilities built either: (1) directly adjacent to the top of eroding sea cliffs; (2) on active sand dunes; or (3) on the beach received the greatest damage. In every case, a thorough geologic investigation, including an analysis of a time-sequential series of aerial photographs and a geomorphic evaluation, would have indicated the instability of these environments.

Beach Front Construction

The interior of northern Monterey Bay presents a clear example of the seasonal problems associated with constructing permanent structures on the beach. A

• Tide tables given in feet.

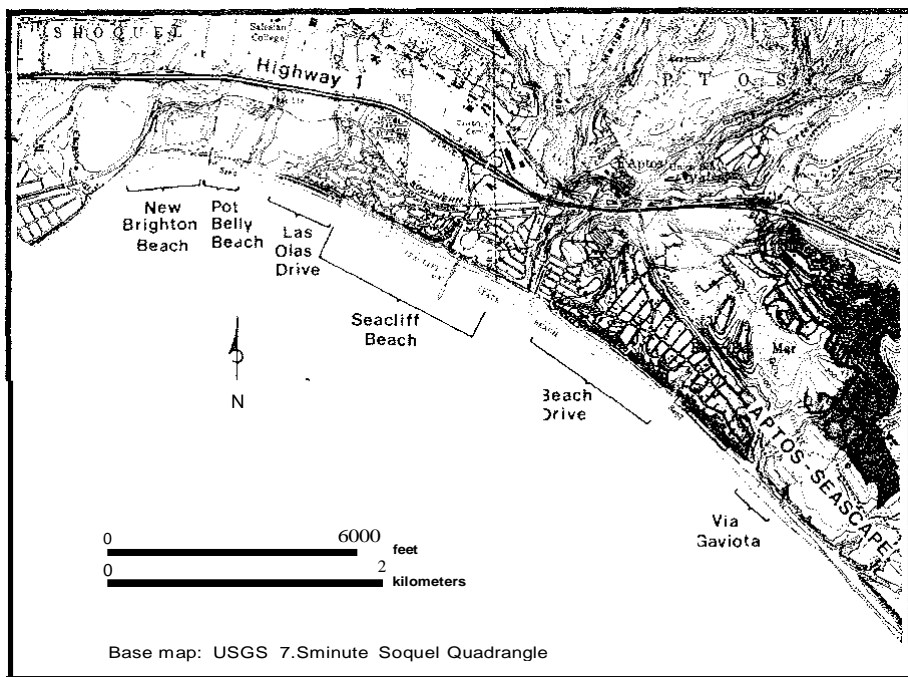


Figure 2. Location of shoreline developments from New Brighton Beach to Aptos Seascap, Santa Cruz County.

wide sandy beach which is in equilibrium with the predominant northwesterly waves, normally flanks this stretch of coast. The historical record, however, shows the repeated impact of storm waves from the southwest, which remove much of the sand, can carry large redwood logs across the beach, and often reach the base of the sea cliff. The presence of beach sand at the base of the cliff and the stranded driftwood logs are clear testimony to past storm activity. This back beach area is analogous to a rivers' flood plain. The question is not *if* it will be inundated, but when, how often, and how deep!

For a distance of 4.5 km from Pot Belly Beach to Aptos Seascape, public and private development has taken place on the back beach area (Figure 2). Dozens of private homes, in addition to a state beach recreational vehicle (R.V.) campground (Seacliff State Beach), a roadway, restrooms, and a major sewer line have been built on or buried beneath the beach. Damage during January 1983 in this area was extensive; a look at the historical record, however, shows that storms have repeatedly effected this area.

Seacliff State Beach

In the Seacliff Beach area, major storms from the west or southwest in 1926, 1927, and 1931 destroyed or partially destroyed a concrete seawall, a bathing pavilion and a concession building. In 1934 this beach front area was purchased by the state for camping and picnicking. The continued impact of storms on the protective structures built along this beach has been well documented (Table 1, Griggs, 1982). Eight times in 58 years, or about once every seven years, seawalls and bulkheads at Seacliff Beach have been damaged or destroyed. After extensive damage in 1939 and 1940, the bulkhead was rebuilt. Storms in the winter of 1941 destroyed it again (Photo 1). Following extensive damage to a piling and timber bulkhead and a recreational vehicle campground on the beach in 1978 and again in 1980, a new 817 m long piling and timber bulkhead was reconstructed along with the R.V. parking area at a cost of \$1,700,000.

Table 1 HISTORICAL DAMAGE TO THE SEACLIFF BEACH AREA
(From files of Santa Cruz Sentinel)

DATE OF STORM	DAMAGE DESCRIPTION	DIRECTION/TYPE OF STORM
Feb 14-16, 1927	Concrete seawall at Seacliff Beach destroyed.	"heavy southwester"
Dec 9-10, 1931	Timber bulkhead at Seacliff destroyed.	"southwest wind waves"
Dec 23-29, 1931	Concession building and bathing pavilion at Seacliff wrecked.	"winds first from southwest then northwest"
Dec 26-27, 1940	Crux of local weather problem at Seacliff. Logs up to 10 feet tossed onto road, houses damaged, 80 feet of state park lost, two sections of bulkhead ripped out.	
Jan 8-13, 1941	At Seacliff Beach, about one half of a timber bulkhead destroyed. Beach eroded to bedrock.	"waves and swell from southwest"
Feb 11-13, 1941	Residents in Seacliff cut off by slides.	
Feb 9-10, 1960	Camping sites destroyed, restroom nearly destroyed.	"southerly and westerly storms"
Feb 11-15, 1976	High waves washed completely over new seawall, carrying debris back to cliff. Portions of seawall undercut and caved in.	"southerly gale"
Jan 8-9, 1978	Seawall overtopped and logs and debris scattered across parking and camping areas. Extensive damage to seawall.	"storm from southwest"
Feb 1980	\$1.1 million in damage at Seacliff. Storm destroyed entire lower beach portion of park, taking roads, parking lots for 324 cars and a 2672 foot seawall.	"southwest"
Jan 28-30, 1983	\$740,000 in damage. 28(X) feet of new seawall damaged, 7(X) feet totally destroyed, eleven RV sites destroyed restroom heavily damaged, logs and debris washed back to cliff.	"waves from southwest"

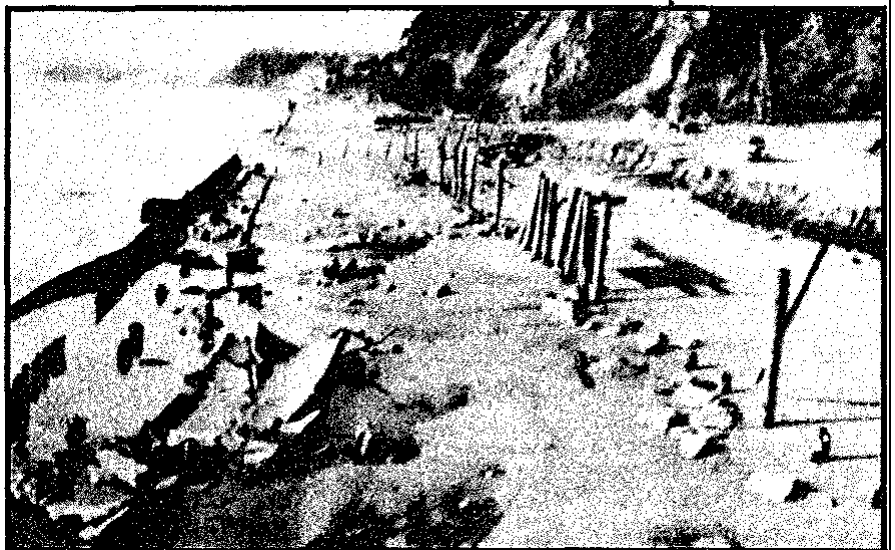


Photo 1. Seacliff State Beach in January 1941. The pilings to the right are the remains of a bulkhead built in 1940 and destroyed during the winter of 1940-41. Structure to the left is the remains of a seawall constructed in 1927 and destroyed the following winter.

This new structure was intended to last 20 years; in late January 1983, within two months of its completion and dedication, the waves and high tides overtopped the bulkhead (Photo 2). Large logs battered the timbers and pilings and over 214 m of the new structure were destroyed (Photo 3). The parking lot, utilities, and R.V. camping sites were damaged. Logs, sand, and debris were carried over and through the bulkhead to the base of the seacliff. Damage costs have been estimated at \$740,000.

Las Olas Drive

Immediately to the north, access to Las Olas Drive (Figure 2), a strip of oceanfront adjacent to Seacliff, was cut off for days because the access road through Seacliff State Beach was blocked by logs and debris. Homes on Las Olas Drive were seriously damaged during the 1978 storms because the 25 m wide beach was removed and waves undercut the foundations. One house partially collapsed whereas others lost glass windows, patios, decks, and stairways. Emergency rip-rap was brought in at a cost of about \$350,000 to protect 27 homes. In 1979 a request was made to the Coastal Commission to construct a permanent piling and timber bulkhead fronted with rip-rap. The engineer's report stated that the wall could withstand the most severe Monterey Bay storms, and that nothing should happen to it during the life of the homes.

After the 1980 storms, the Las Olas Drive homeowners again applied to the Coastal Commission to "repair, replace, and maintain" rip-rap over 566 m of beach frontage. An additional \$172,000 of rock was added to the structure.

During the January 1983 storm the bulkhead and rip-rap survived for the most part and did offer protection to most homes. The waves and high tides did overtop the structure, however, after scouring away the protective beach. A number of homes received minor damages (windows, decks, yards, broken or damaged); one home received major damage and a guest house was destroyed. Damage estimates total **\$400,000** (Swisher, 1983).

Beach Drive. Rio Del Mar

The Beach Drive area is immediately down coast from Seacliff State Beach and Las Olas Drive (Figure 2). A large number of summer homes are situated along Beach Drive, both on the beach side of the roadway and also on the opposite side against a steep sea cliff incised into poorly

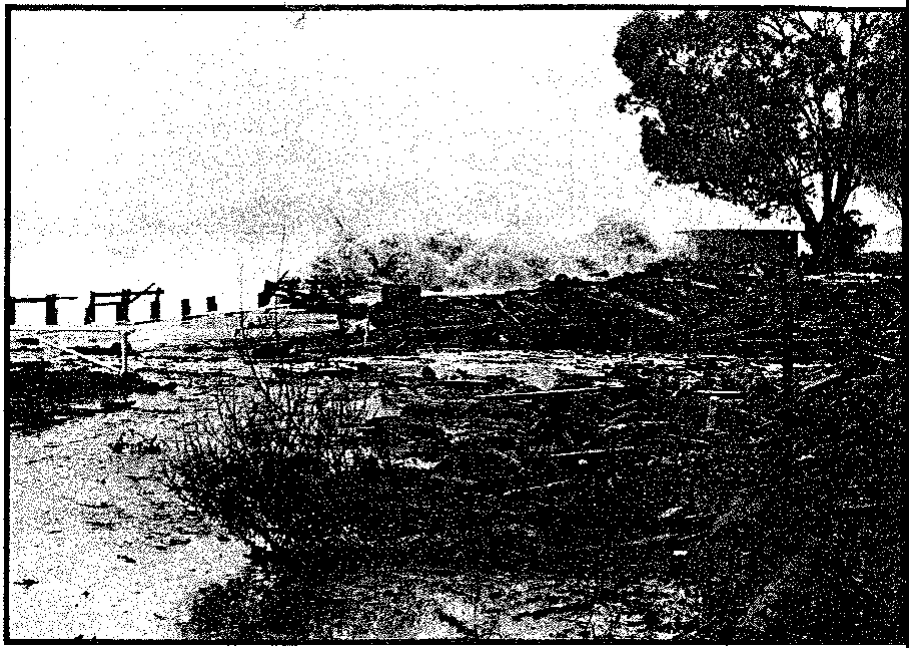


Photo 2. Waves overtopping the seawall at Seacliff State Beach on January 27, 1982, during a 6.6 foot (2 m) tide. The logs and debris on the right have been washed over the seawall and deposited in the camping area.



consolidated Aromas sand. Some of these homes have been there since about 1939. Slope failure in the weak cliffs due to high rainfall in January 1982 destroyed two Beach Drive homes and damaged a number of others situated at the base of the cliff.

Waves during 1981 storms destroyed a seawall protecting Beach Drive, the sidewalk, one lane of the road, and a portion of a sewer line placed beneath the roadway (Photo 4). During this storm some Beach Drive homes were subjected to broken windows and flooding. An unsuccessful



Photo 3. The remains of the Seacliff seawall in March 1983. Approximately 240 meters of a new 800 meter long piling and timber bulkhead were totally destroyed during January 1983 within 2 months of completion.



Photo 4. Storm damage during 1978 storms along Beach Drive in Rio Del Mar. Note remains of timber bulkhead and collapsed sidewalk. A temporary barrier of cabled oil drums failed almost immediately.

ful attempt to halt further erosion by utilizing 50 gallon steel drums was followed by the emplacement of temporary rip-rap. Following this effort, a joint private/state/federally funded \$1.5 million seawall was erected along the central portion of Beach Drive. This structure consists of steel I beams used as pilings, with

heavy timbers forming the wall, which is capped with concrete (Photo 5). Although the wall was overtopped during the January 1983 storms, and water and sand washed across Beach Drive and into some homes, overall damage to the structure and homes behind the structure was relatively minor.

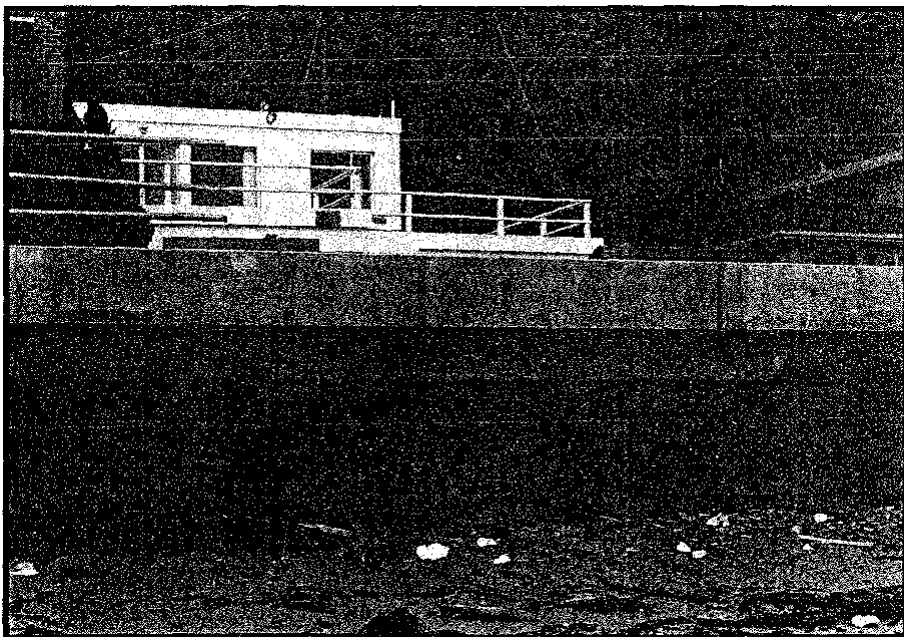


Photo 5. New seawall along Beach Drive (approximately same location as Photo 4). This \$1.5 million structure was completed in 1982 and consists of steel H beams with connecting timbers and a concrete cap. Although the wall was overtopped and railings were broken off in places, the structure survived the 1983 storms with no damage.

At the south end of Beach Drive, beyond the new seawall, damage was severe. A state beach parking lot was heavily damaged because a timber and piling bulkhead identical to that at Sealiff was destroyed. Waves and logs overtopped the structure, battered the timbers loose, and undermined the asphalt which subsequently collapsed (Photo 6).

South of the parking lot twenty-six homes, which were constructed on the seaward side of Beach Drive over the last 25 years, were protected by a variety of structures, such as large concrete blocks, timber bulkheads, and a concrete bulkhead which protected seven homes. The 3-4 days of 4 - 6 m waves and 6 ft+ (2 m+) tides destroyed or damaged virtually every protective structure. The concrete bulkhead which had remained intact for years was totally destroyed. The lack of a uniform protective structure took its toll; weaker structures were overtopped or battered down leaving the waves to wash the sand from behind the adjacent structures (Photo 7). By the end of January, with the protection gone, waves quickly undermined the houses exposing piers and pilings (Photo 8). Two houses with shallow piers collapsed and were total losses (Photo 9); others had some pilings undermined or lost windows, decks, and stairways. Estimated damage is at least \$2,000,000. Emergency rip-rap was brought in to provide temporary protection to the remaining homes.

Directly downcoast from Beach Drive in Rio Del Mar a sewer main runs beneath the back beach. Manholes were exposed by wave scour during the late January 1983 storm, and one section of pipe was severed so that a half million gallons of raw sewage poured into Monterey Bay daily for two weeks.

Aptos Seascape

Aptos Seascape is another beach front development south of Rio Del Mar's Beach Drive (Figures 1 and 2). The first of these homes was built in 1969 despite disapproval and warnings by the County Planning Department. Twenty-one homes were eventually built on fill added to raise the elevation of the back beach. The project initially approved called for a protective steel sheet pile seawall with homes set back at least 20 feet from the seawall. Instead a rubble mound of rip-rap was used and a ten-foot setback was utilized; later even this ten foot requirement was removed. During the first heavy

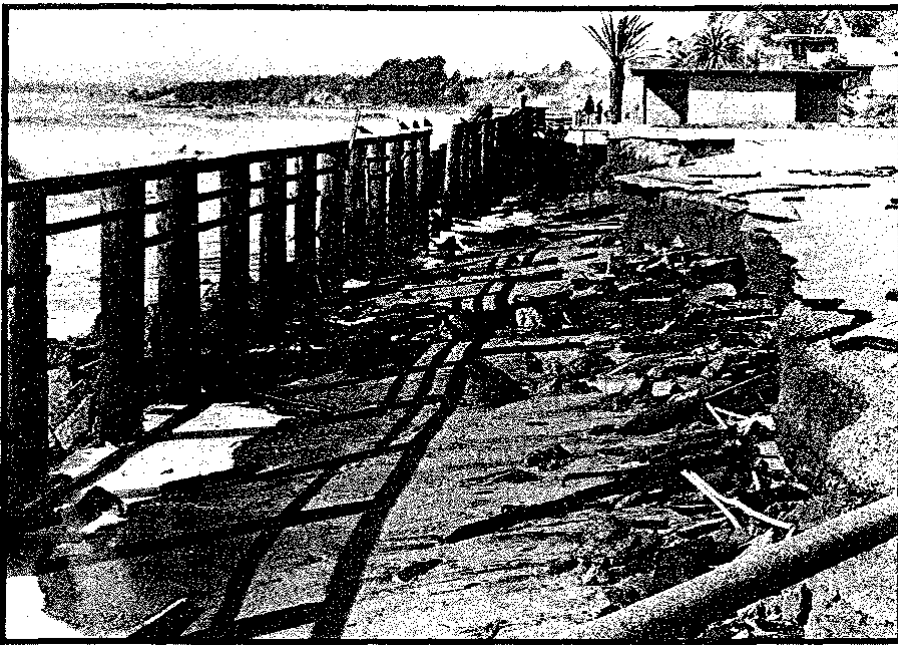


Photo 6. Timber bulkhead along Beach Drive parking lot destroyed during January 1983 storms.

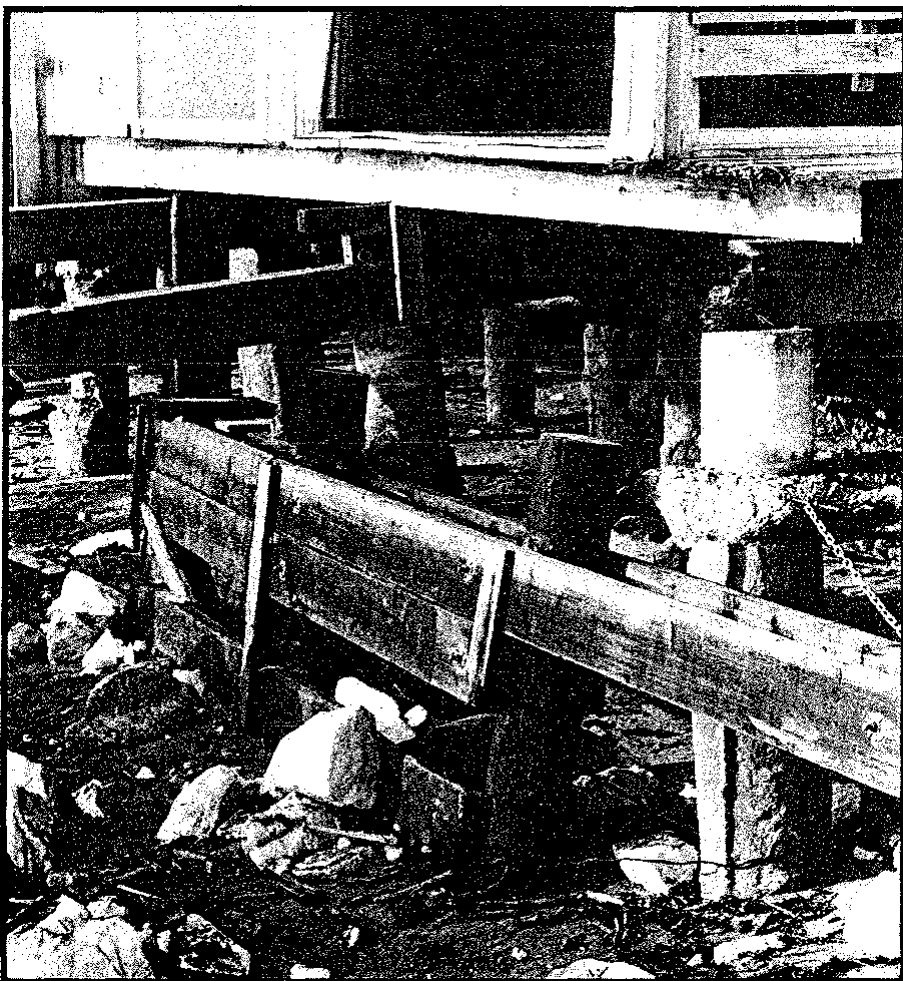


Photo 7. Foundation undermining and seawall collapse at the south end of Beach Drive in Rio Del Mar.

southwest storms in late January 1983, 4-6m waves riding atop tides of 6.6 ft (2m) overtopped the protective rip-rap. Nineteen of 21 homes received major damage (Photo 10). In most cases the waves broke through the windows, doors, and house fronts facing the ocean and washed all the way through the homes (Photo 11). Decks, stairs, and landscaping were also destroyed. One house partially collapsed as the wall facing the sea was demolished (Photo 12). Damage estimates at Seascape range from \$2 to \$2.5 million.

In 1966, the County Planning Director had written that "the lot design is not in the interest of public safety where subject to inundation. It is not shown to what extent that lots and the street on the beach will be protected from ocean wave action." Nonetheless, the project was approved. The original plan proposed was to continue this development a mile down the beach. Before this was carried out, however, the expansion was denied by county supervisors. The denial led to a lawsuit which has now been appealed to the State Supreme Court.

Sand Dune Development

Much of inner Monterey Bay from several miles north of the Pajaro River to Monterey is backed by coastal dunes. Cooper (1967) and Dupre (1975) discuss the history and morphology of dunes in the Monterey Bay area and recognized both older stabilized dunes and younger active dunes. The Pajaro Dunes area is a very young dune field which extends for several miles north of the mouth of the Pajaro River (Figure 1). These modern dunes consist of a series of closely spaced, commonly overlapping parabolic dunes generally less than 6 m high.

The recent historical record of the Pajaro Dunes area indicates periodic erosion and inundation of the dunes followed by subsequent progradation or outbuilding. Historical accounts of the area are somewhat sketchy. A former resort, Camp Goodall, was built on the back dune area just south of Beach Road about 1882; a pier in the vicinity had been constructed about 14 years earlier, but was destroyed by a storm in 1904. In 1911 a new 1700 foot long wharf was constructed just north of the present Pajaro Dunes condominium development. The following year the new wharf was damaged by a large storm. "On the beach, the waves dashed up to the Casino Building (part of Camp Goodall?) on top of the sand dunes." This

storm was described at the time (Watsonville Pajaronian, October 1912) as "the heaviest sea in the history of Monterey Bay" and waves "threatened to overflow the sand dunes on the Beach." Two months later in December 1912 another large storm hit Monterey Bay and "huge breakers rolled over port Watsonville flooding Capalco" (a planned subdivision located somewhere in the dune field.)

Numerous other storms have effected the Pajaro Dunes area but apparently little redevelopment occurred until 1968 when the present project was initiated. The existing development consists of 309 condominiums at the north, twenty-four townhouses and 145 single family dwellings in the middle, and 87 additional condominiums at the south end adjacent to the mouth of the Pajaro River. All units are built on the active dunes with 66 houses and a number of the townhouses and condominiums built directly on the foredunes above the beach. Most of the structures are built on conventional concrete foundations rather than on elevated pilings.

The 1931 aerial photographs shows that the dune area just north of the mouth of the Pajaro River was completely destroyed by either lateral scour of the river during high flow, or overwash by surf, or perhaps a combination of both. Subsequent airphotos show the dune field gradually reforming. The zone which was totally inundated is now occupied by 87 condominiums and 7 individual houses.

In 1969 as the Pajaro Dunes development was in the initial stages of construction, storm waves attacked the dunes. Twelve of the ocean front lots were severely eroded; automobile bodies were brought in and placed at the toe of the wave eroded scarp for protection.

Nine years later in 1978, storm waves, from the southwest combined with high tides again cut into the dunes. The beach was cut back to the dunes along a frontage of about 3.2 km, and severe erosion threatened three particular locations. Empty steel drums, large concrete blocks, and sandbags were emplaced by residents in order to halt erosion.

The dunes had not fully recovered due to the severe storms in subsequent years when the January 1983 waves and high tides ensued. Dune retreat took place quickly so that continued wave action threatened at least 17 houses and 25 condominium units (Photos 13 and 14). Rip-



Photo 8. Bulkhead failure and house collapse from undermining of shallow piers along Beach Drive. Rock was brought in after January 1983 storm damage.

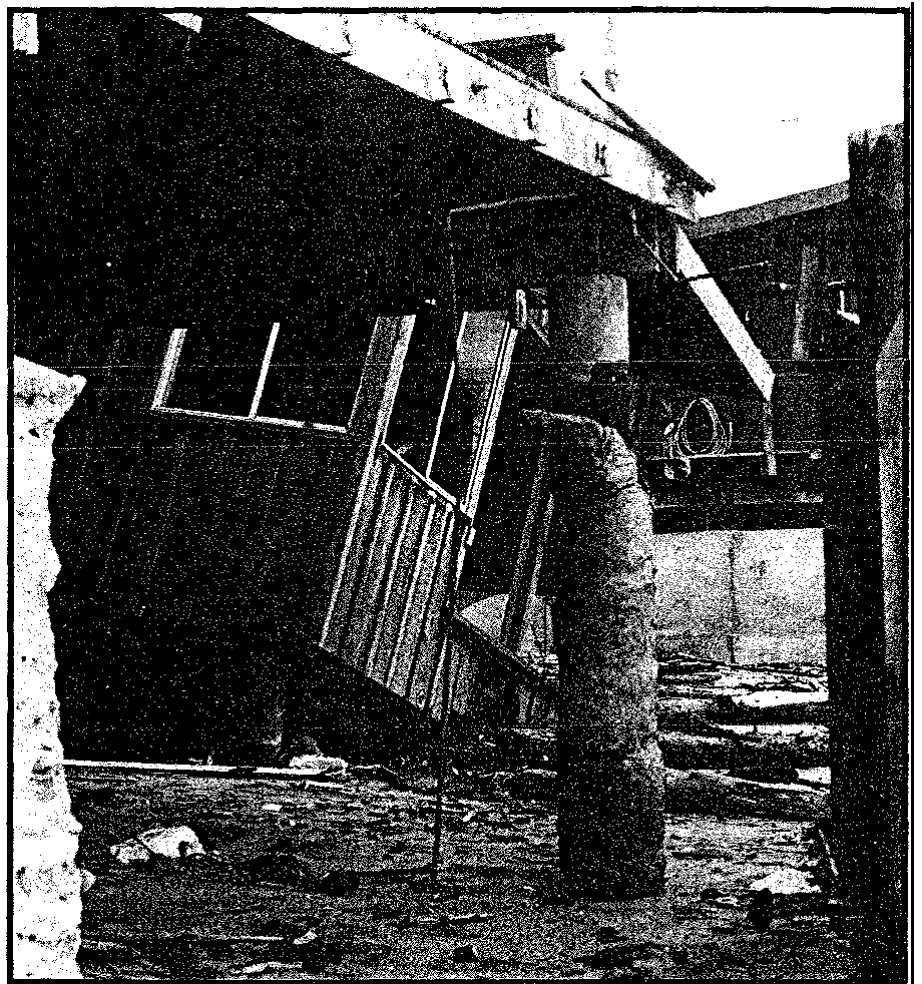


Photo 9. Wave scour during January 1983 storms removed up to 2 meters of sand, leading to failure of shallow piers beneath two houses along Beach Drive followed by collapse.



Photo 10. Wave damage to ocean front homes at Aptos Seascape during January 1983. Although these homes were elevated 3-4 meters above the beach and partially protected by a rip-rap seawall, wave overtopping led to damage to 19 of the 21 homes.

rap was brought in and placed in front of at least 60 houses following the first storm (Photo 15). The initial erosion occurred in late January 1983 when up to 12 m of dune sand was removed leaving a near vertical scarp 4.5 to 5.5 m high adjacent to the foundations of some of the homes. An estimated 200,000 cubic meters of dune sand fronting the Pajaro Dunes de-

velopment was removed by surf erosion during the first two days of the storm that began on January 26, 1983.

Subsequent storms and high tides through February and early March eroded the segments of dunes that were unprotected by the emergency rip-rap to the extent that virtually every structure on



Photo 11. Wave damage to house fronts at Aptos Seascape. Waves created major structural damage by removing supporting posts and walls.

the seaward side of the development was threatened.

In at least two areas the initial rip-rap settled into the sand as much as 3 to 4.5 meters vertically and also moved seaward about a meter. Additional rock and other emergency protection had to be quickly emplaced to prevent destruction of the homes lying behind the rip-rap which had settled. At the end of the storm season a massive rip-rap seawall was emplaced along the entire seaward frontage of this development, at a cost of several million dollars.

CONSTRUCTION ATOP ERODING SEA CLIFFS

Far more homes and structures in the Santa Cruz-northern Monterey Bay area have been constructed on top of eroding sea cliffs than in back beach or dune areas. For 11.2 km of the 15.2 km of coastline from Natural Bridges State Beach to Aptos Seascape (Figure 1), single family dwellings, apartments, motels, roads, bike trails, and parking areas have been constructed along the edge of the sea cliffs.

Marine and terrestrial processes are constantly shaping an active sea cliff. Surface and subsurface runoff progressively erode and weaken the cliff from above; large scale failure occurs through rock falls and slumping. Surf action, combined with constant wetting and drying, weakens and erodes the cliff from below.

Lithologic and stratigraphic differences in the Purisima Formation, which forms the sea cliff in most of this area, combined with the presence or absence of a protective beach, have produced average annual erosion rates varying from less than ten to over 100 cm per year (Griggs and Johnson, 1979).

Of the 15.2 km of northern Monterey Bay coastline, about 53 per cent or 8 km is now protected by rip-rap or seawalls. As a result the erosion rates have been considerably reduced at most locations. On the other hand, where the cliff face is inaccessible, or in some cases, where public rather than private property is at stake, little if any protective structures have been emplaced. These unprotected areas have continued to erode. One striking example is at the end of 26th Avenue along East Cliff Drive. Adjacent property owners have protected their cliffs with rip-rap but the cliff face at the end of this county road has remained unprotected. Storm drain runoff has also been discharged



Photo 12. The roof of this ocean front house at Aptos Seascapes collapsed when waves destroyed the front wall in January 1983.

here. Not only is the sea cliff at the foot of the road being cut back at 135 cm/year, but the cliffs on either side are now being eroded laterally, leading to serious private property losses (Photo 16).

Erosion that occurred during the storms of early 1983 significantly altered the "long term" coastal erosion rates.

This reaffirms the earlier conclusion (Griggs and Johnson, 1979) that sea cliff retreat usually occurs episodically or in pulses during major storms, rather than through gradual attrition. Large blocks commonly fail or collapse due to undercutting or weakening when wave action is intense and the cliffs are weakened through saturation from rainfall and runoff.



Photo 13. Erosion of dunes at Pajaro Dunes development in January 1983 exposed the foundations and threatened a number of homes. Rip-rap was brought in for emergency repair.

The 25 m-high steep cliffs which stretch from Capitola to New Brighton State Beach were severely eroded. The jointing and faulting in the flat lying Purisima Formation, the lack of a protective beach, and the effect of both surface and subsurface runoff on the terrace deposits and sedimentary bedrock have led to "average" annual erosion rates of 45 to 90 cm during the past 5 or 10 years. The failure of large slabs of the cliff are a regular occurrence. In March 1983 a slab 30 meters long and 2-4 meters wide collapsed and fell to the beach below. A portion of the cliff top road was removed adjacent to an area where a large apartment complex has been seriously undermined and a duplex was totally removed (Photo 17) about 7 years ago. The road has been closed and a concern now exists for additional failure. In 1980 an adjacent area gave way, taking with it sewer and water lines. A thousand feet of rip-rap with an estimated cost of about \$850,000 is now being proposed for federal disaster assistance.

Several kilometers upcoast from Capitola, storm waves on January 29, 1983, completely undercut a beach front house constructed on a concrete slab. The "sea cliff" here is only several feet above sea level. The owners had just moved into the \$350,000 nearly new home 10 days earlier. Within a few minutes on the morning of January 28, the entire slab and two story home tilted towards Monterey Bay as it was undermined. Early the next morning the house slid the rest of the way into the ocean leaving nothing behind but a small pile of wreckage (Photo 18).

Along West Cliff Drive between Natural Bridges State Beach and Lighthouse Point in the City of Santa Cruz, waves damaged a bicycle path, the roadway, and property of Lighthouse Field State Beach (Photo 19). Again high tides and storm waves simply overtopped the lowest marine terrace and cut back the unconsolidated terrace deposits. Along one particular stretch of West Cliff, 14.1 m of cliff retreat occurred in the first two months of 1983. From 1931 to 1983 a total of 7.7 m of retreat had taken place. "Average" annual cliff erosion for this 51 year period jumped from 15.1 cm to 42 cm when the 1983 cliff failure occurred. The events were similar along much of West Cliff and East Cliff Drive (Photos 20 and 21).

CONCLUSIONS

The storms of the last five years have had a significant impact on the coastline

of Santa Cruz and northern Monterey Bay. Public and private construction on the back beach, on sand dunes, and atop eroding sea cliffs has repeatedly been damaged or destroyed, with damages in January 1983 alone amounting to over \$10 million.

Oceanographers at Scripps Institution of Oceanography are predicting that the southern California climate is changing and that in the future a more variable climate can be expected, in contrast to the "mild" conditions which prevailed from 1946 to 1976. This was also the period of rapid development and construction along the coastline. With the change to a more severe climate will come more frequent and intense storms with their impact on beaches and sea cliff erosion and any construction in these areas. The impacts on the coastline of a continuation of the winter storms of the past 5 years would be devastating. Although various engineering works have been used for years in an attempt to protect coastal property, these are expensive and are temporary solutions at best. The history of seawall and bulkhead destruction at Sea-cliff State Beach is a case in point. Although disaster relief money is being requested, reconstruction is underway, and new coastal protection projects are on the drawing boards, now is the time to give serious thought to the lessons of the past.

For effective long-term protection of public and private interests, there is a need to recognize that large-scale earth processes can not be subdued at any cost, and that attempts to do so will ultimately end in failure. Coastal land use controls and a realistic view of coastal protection structures must be based on an accurate assessment of coastal processes and economic factors rather than simply a continuation of past practices and sympathetic and emergency disaster relief. This control will only occur when the public and decision makers or legislators at all government levels accept the concept that severe storms and coastal erosion, floods, landslides, and earthquakes are not "acts-of-God." Once a city, county, or the state government institutes policies that control new development, reconstruction, or re-protection in hazardous coastal areas (as the Alquist-Priolo Special Studies Zones Act does in fault zones, for example), then it will be possible to develop performance standards that allow a community to eventually retrofit to geologic conditions. In the long term,

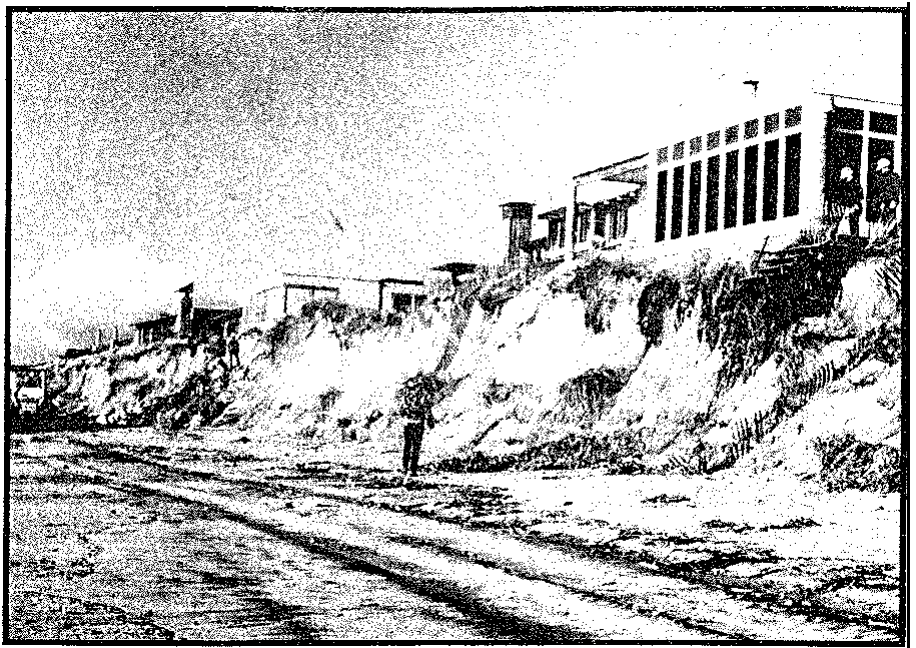


Photo 14. These homes at Pajaro Dunes were constructed atop the first or primary dune. Forty feet of dune retreat occurred almost overnight and waves began to threaten the homes.

this approach will greatly reduce public expenditures and subsidy by reducing existing programs of disaster relief, low interest loans, and re-protection of poorly placed public and private facilities and structures.

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Photo 15. Emergency rip-rap was emplaced along almost a mile of ocean front at Pajaro Dunes during January 1983 storms.

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Photo 16. Rapid sea cliff retreat at the end of 26th Avenue in the East Cliff area of Santa Cruz. The lack of cliff protection at the end of a public road has led to lateral erosion of private property.



Photo 17. Large rock fall in the Capitola area during March 1983. This particular failure was about 30 meters long and 2-4 meters wide.



Photo 18. The remains of a house along East Cliff Drive (arrow) which was destroyed in January 1983 when its foundation was undermined and it slid into Monterey Bay.



Photo 19. Rapid erosion of unconsolidated terrace deposits took place in January, February, and March 1983 along Wt,st Cliff Drive in Santa Cruz.

Photos by G.B. Griggs.

Photo 20. Undercutting of East Cliff Drive just east of the small craft harbor in late January 1983.

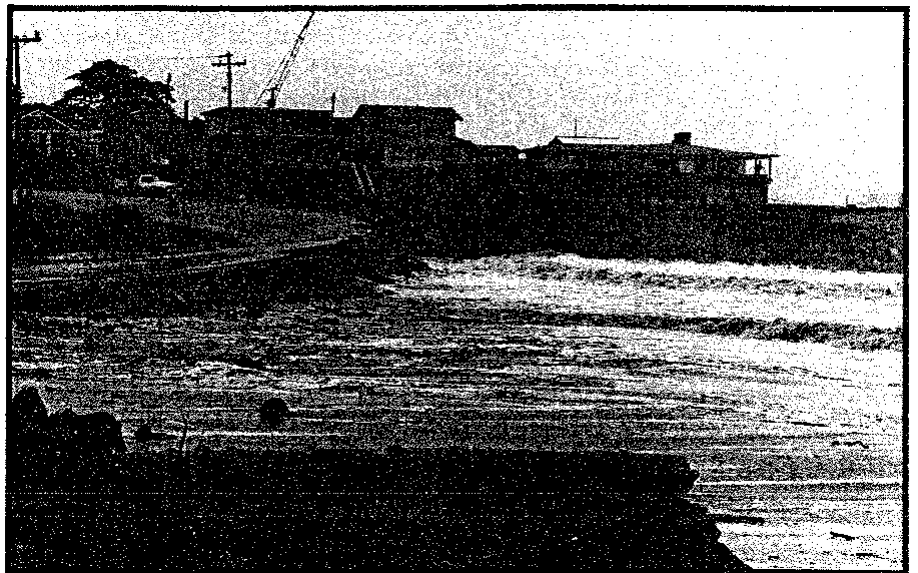


Photo 21. Surf washing over East Cliff Drive between Santa Cruz and Capitola during a 6.6 foot high tide in January 1983. "



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