ABSTRACT
Over the years, various reaches of Ocean Beach, a 3.6 mile long beach located along the Pacific coast of San Francisco between the Cliff House and the Fort Funston cliffs, have suffered erosion at intermittent times and several seawalls have been installed in these locations. During the 1994/95 winter storm season, severe erosion occurred along an unprotected reach between Sloat Blvd. and the Fort Funston cliffs. A temporary revetment was designed to address the immediate threat that this erosion represents to the Great Highway and other City of San Francisco infrastructure. This revetment was designed to be temporary and to provide protection until a permanent seawall could be funded and built. Design of the revetment, a hybrid design that uses concrete-filled geotextile bags and a buried quarrystone scour apron, involved coordination with various agencies, in particular, the National Park Service, who owns the beach on which the erosion is occurring. The revetment was designed using relaxed designed criteria so that it could be constructed using the funds available, but still provide temporary protection to the most critical areas. Because relaxed criteria were used, there will be a higher risk of damage to the structure, and as such, a monitoring and emergency response plan is being developed to provide guidance for monitoring the protected and unprotected sections in this reach and to provide a framework for response to future erosion.

INTRODUCTION
Erosion along a 2,700 foot reach in the southern portion of Ocean Beach, San Francisco, is a threat to valuable City infrastructure including: the 4-lane Great Highway running alongside of Ocean Beach; the Lake Merced Tunnel, a 14-foot diameter conduit beneath the highway south of Sloat Boulevard that transports combined stormwater and wastewater to the Oceanside Water Pollution Control Plant; and, if left unchecked, the recently constructed Oceanside Plant itself.

With an eye toward managing the risk of future erosion, the City and County of San Francisco (the City), in a joint project with the U.S. Army Corps of Engineers (USACE), had a comprehensive investigation made into the beach processes along Ocean Beach, with special emphasis on the reach south of Sloat Boulevard. The final report was issued in September 1996, and discusses the entire range of concerns with a major shore protection project including: biological and environmental effects, physical and engineering aspects, sociological impacts, and economic considerations. The report concludes with the recommendation for a permanent seawall to be constructed along the reach of Ocean Beach south of Sloat Boulevard. The City is presently pursuing funding for the design and construction of a permanent seawall along this reach of Ocean Beach.
Recent storm events that have led to accelerated local erosion of the bluffs in this reach and loss of portions of a parking lot and walking path above the bluffs, prompted the City to design and install shoreline protection measures that could be constructed to protect the shoreline until a permanent seawall can be constructed.

The design of these measures was atypical in that they were purposefully designed with limited design-lives in order to be built within the City's imposed budgetary constraints, to be easily dismantled or incorporated into the permanent seawall at the time it is constructed, and to meet other agency-specified requirements. There is a higher potential for damage to these shoreline protection measures and, therefore, a monitoring and maintenance/emergency response plan was an important part of this project.

This paper describes the design of these temporary measures and includes:
- A description of historic and continuing shoreline changes at Ocean Beach
- A discussion of the need for a temporary structure
- The project guidelines and regulatory agency approvals needed to implement the project
- A description of the shoreline protection measures designed for short-term protection of the bluffs and City infrastructure behind the bluffs
- A description of key components of a monitoring and emergency plan developed to monitor the performance of the structure and respond to future erosion in the area.
Shoreline Change at Ocean Beach

Shore erosion is a recurring problem along Ocean Beach — a 3.6 mile long coastline of continuous beach with intermittent dunes and low bluffs, forming the westernmost limit of the City of San Francisco (Figure 1). The entire beach is open to direct wave attack from the Pacific Ocean.

Changes in the shoreline and beach profiles at Ocean Beach are complex in that they are influenced by both natural events and human activities. As such, conclusions about future changes in the shoreline based on historical, averaged data are difficult and can be
misleading. In addition to direct impacts on the shoreline due to activities such as road and seawall construction, indirect activities that affect the erosion and accretion patterns of the shoreline along Ocean Beach include beach nourishment, sand mining (stopped in 1967), and changes in the offshore San Francisco Bar from dumping of dredge sands (Moffat and Nichol 1995). All of these have influenced the patterns of erosion along Ocean Beach.

**Historic Response to Erosion**

Since the late 1800s, man has extended the natural shoreline along the west coast of San Francisco seaward 200-250 feet through the deposition of imported sand, soils, and construction debris largely during the construction of the Great Highway that runs the length of Ocean Beach. Additional material was deposited from local construction projects, such as the Oceanside Water Pollution Control Plant at the south end of Ocean Beach and the Westside Sewage Transport Box under the Great Highway north of Sloat Boulevard.

Episodic shoreline retreat and beach erosion has affected much of Ocean Beach ever since man began his modifications to the coastline and has threatened or damaged infrastructure constructed along the coastline since the 1890s.

*O'Shaughnessy Seawall* - In response to early erosion, the City constructed the 4,600 foot-long curved concrete O'Shaughnessy Seawall at the north end of Ocean Beach between 1915 and 1929. This seawall was originally planned to be constructed along the entire Ocean Beach shoreline to protect the highway and to make a boardwalk/ amusement tourist area. Economic conditions halted the project in 1929 (USACE 1996). This structure has prevented the loss of an extensive promenade and the adjacent Great Highway located next to the seawall.

*Taraval Seawall* - Erosion 8,000 feet south of the south end of the O'Shaughnessy Seawall in 1931 and 1939 caused damage to a pedestrian tunnel under the highway at Taraval Street. The City constructed the 662 foot-long Taraval Seawall in 1941 to protect this underpass (Berrigan 1985, Weggel 1988). This seawall is a 3-sided steel sheet pile structure with a concrete cap that remains buried except during periods of high waves and tides. In November 1983, the top 2 feet or so of the cap was uncovered during a major coastal erosion event. Aside from this event, the Taraval Seawall is normally covered in sand and has performed well in protecting the reach behind the structure.

*Great Highway Seawall* - The latest seawall was installed from 1987-1993 starting 4,400 feet south of the O'Shaughnessy Seawall for a 2,900 foot reach (Moffat and Nichol 1995). This seawall was needed to prevent damage to the highway and the Westside Transport Box then under construction. (The Westside Transport Box is a conduit beneath the Great Highway that delivers sewage and stormwater to the Westside Pump Station at Sloat Boulevard.)

*Beach Nourishment* - Beach nourishment using excavated sand from construction projects adjacent to Ocean Beach and from off-site locations in the early years of development have had various degrees of success, depending on localized beach erosion processes. Windblown sand has been a persistent problem along much of Ocean Beach north of Sloat Boulevard, particularly along the O'Shaughnessy Seawall and intermittent areas.
south of there. The City, under a special use permit with the National Park Service, has been removing excess sand from these areas since the early 1980s and nourishing the beach areas where erosion has been a problem. The latest beach nourishment in the area south of Sloat Boulevard was in 1994 and consisted of 25,000 cubic yards of sand being placed on a 1V:3H slope adjacent to the south parking lot located alongside the western lane of the highway. This sand has almost completely eroded away since then.

Erosion and Accretion Along Ocean Beach
As mentioned above, evaluation of long-term erosional and accretional trends along Ocean Beach is difficult due to limitations of the existing database, effects of construction along the coast and other human activities that can influence the sediment loads in the system. Short-term changes can be significantly influenced by episodic events such as storms during the 1994/1995 season that caused 30 to 40 feet of retreat in the bluffs in areas south of Sloat Boulevard over the course of a few days.

Both long- and near-term changes at Ocean Beach are discussed below. Although long-term changes are important for planning and design of shore protection projects, it is the potential of near-term changes such as those that occurred during 1994/1995 that needs to be considered in decisions to implement immediate shore protection in the study area.

Long-term Trends
Figure 2 reproduces sediment transport patterns postulated in Moffat & Nichol (1995) based on a synthesis of available data. Sources of sand that have been associated with
Ocean Beach include sediment that is transported shoreward from the San Francisco bar that lies offshore from Ocean Beach. In addition to sediment carried from the bay and deposited on the bar with ebb tides, additional sediments dredged from the bay and from the ship channel leading into the bay have historically been disposed of onto the bar just south of the ship channel. Erosion of the Fort Funston cliffs approximately 0.6 miles south of Sloat Boulevard also contribute to the sand supply.

Beach changes at Ocean Beach can be affected by a number of factors, including the offshore bar, sediment transport patterns, storm paths, sea level rise (both short term as with El Niño events and long term eustatic rises), and localized vertical movements of the coast. For the area south of Sloat Boulevard, the trend, as much as it can be ascertained, is for continued erosion of the beach.

Average long-term trends in the study area south of Sloat Boulevard, based on shoreline mapping and photogrammetry from 1929-1992, indicate an average bluff toe advance of 1-foot per year along a reach extending 2,500 feet south of Sloat Boulevard and the retreat of 1-foot per year in the reach just south of that. The long-term advance may have more to do with man-induced changes than natural processes. Even if this is a real advance, these potential long-term gains have been overshadowed by near-term losses due to recent storm events.

Near-Term Trends
Near-term shoreline changes were addressed by Moffatt and Nichol (1995) using beach width as a measure of the changes. It was concluded that there was a high probability that the beach width could decrease significantly from what it was in 1993, the last year of topographic data used in their study. The typical beach width then of 175 feet underwent seasonal decreases of 50 feet, and fluctuations of 150 feet had been observed. The study concluded that the beach in front of the area of concern could disappear completely during a future storm event. Waves running up the much diminished beach would then impact and erode the bluff slopes.

Indeed, the erosion of 1994/1995 has born out the concerns in earlier studies. A series of surveys by the City has documented the changes since April 1993. Unfortunately, none of the beach transects made by the Corps of Engineers in 1993 aligned with those
made by the City in 1995 and 1996. Figure 3 shows locations of survey transects made by the City within the study area superimposed on top of a topographic map generated based on the Corps 1993 survey. Changes in the shoreline topography for the reach between the two parking lots can be seen by comparing spot elevations near the bluffs from the City's survey with contours from the Corps survey. Figure 4 shows profiles of the beach transects surveyed by the City from August 1995, April 1996, and October 1996 compared with cross sections scaled from the USACE April 1993 mapping. It is readily apparent that dramatic erosion has taken place between 1993 and the present.

The present bluff and beach profile at survey transect RI (based on the 1996 survey) represents a typical cross section for the heavily eroded area between the two parking lots and is shown in Figure 5 in relation to the Great Highway, Lake Merced Tunnel, and the storm drain for the Great Highway. The scaled profile from the Army Corps of Engineers April 1993 mapping is superimposed for comparison. All elevations are in feet MLLW datum.

The National Park Service in August 1996 smoothed the bluff slope from approximately 200 feet north of the entrance to South Lot to the south end of South Lot to rid the area of unsightly remains of the destroyed steps and pathway including the
slope at transect R1. These changes in the bluff slope at R1 were small and are not shown in Figure 4.

Potential Future Changes

For an eroding beach under the action of storms and complex breaking wave patterns, year to year changes in beach topography cannot be predicted with any certainty. The amount of erosion in a given year depends on a large part on the severity of the winter storms in the North Pacific Ocean. It is appropriate to address potential future beach profiles based on probabilities.

The estimated return-period dune or bluff toe retreat for any given point on Ocean Beach in a single storm season based on projections in USACE (1992) is shown as the lowest curve in Figure 6. Based on this curve, there is about a 5% chance that 25 feet or more of toe retreat will be experienced in any one year. The other curves were developed from the 1-year curve and are for cumulative retreats over 2-, 3-, 5-, and 10-year periods. For example, the curve labeled “2 years” presents the probability that the retreat over the
first year plus retreat over the second year will exceed a certain value. The dashed horizontal line represents a cumulative toe retreat of 25 feet, which approximated the remaining minimum distance between the bluff edge and the west edge of the highway in the area between the two parking lots at the start of the project. For a given time period, the probability of a 25 foot or greater toe retreat is:

1 year = 5%
2 years = 11%
3 years = 18%
5 years = 31%
10 years = 60%
and 50% based on an 11.8 feet MLLW toe elevation for a typical wintertime beach. A worst-case scenario for bluff recession was judged to be where the beach profile just touches the crown of the Lake Merced Transport box at its closest approach to the west edge of the highway. There is a 16% probability that this could happen by the year 2003.

The Need for Temporary Protection Measures

The study area, shown in Figures 1 and 3, was the reach from the north end of the North (Sloat) Parking Lot to the terminus of the sand access ramp with the beach at the south end of South Parking Lot. The bluffs in this area consist of a natural formation -- the Colma Formation -- consisting mostly of friable sand that is easily crumbled by hand. This foundation layer is covered with sand from both natural deposition and man's intermittent efforts at beach nourishment.

Like the rest of Ocean Beach, this area is tremendously popular to all types of beachgoers -- surfers, surf fishermen, sunbathers, joggers, and tourists. The two parking lots south of Sloat Boulevard had been constructed alongside the west lane of the Great Highway to provide parking and access to the beach below.

Recent shoreline retreats in the 2,700 foot reach from Sloat Boulevard south to the Fort Funston cliffs pose an imminent threat to this infrastructure. Waves and high tides in the winter of 1994-1995 eroded the shoreline, causing a 30-40 foot retreat and oversteepened much of the bluff slope over approximately a 2,200-foot reach. These events prompted the City to mitigate the erosion in the short term and to plan for a more permanent long-term solution to shore erosion.

The most pronounced shoreline retreat was found to be the 1,920-foot reach from approximately 550 feet south of Sloat Boulevard to 200 feet south of the south edge of the South Lot, and it was in this reach that the study concentrated.

In the erosional events of 1994-1995, the North Lot lost all 4 of its access stairways to the beach, and the bluff edge retreated into 8 feet of the west edge of the parking area. At the South Lot, erosion destroyed 5 beach access stairways from the top of the bluff to the beach, but left intact riprap mounds of 700 pound median weight stones at each of the sites protruding 10-20 feet onto the beach. An asphalt pathway along the bluff fell onto the beach along with a storm drain conduit. Concrete debris has been exposed for several hundred feet in this area. Figures 7, 8, and 9 show the appearance of the project area in July 1996.
Figure 7

(Top) South limit of temporary shore protection is the riprap mound (right edge). Survey Transect 5C is at left edge of the photograph. (August 1996)

(Bottom) Bluff face about halfway between the two parking lots. Painted quarystone near center of picture measures 4x4x6 feet. (August 1996)
(Top) Eroded bluff with surfers about to descend the bluff slope to the beach. Stakes in the beach (right edge of photo) are at Survey Transect R1. (August 1996)

(Bottom) North limit of temporary shore protection at South (Siota) Lot is at bluff toe at the far right fence post on the bluff’s edge. Survey Transect R2 is 20 feet left of the beach stake. (August 1996)
Figure 9
(Top) Looking South from South end of South Lot. The Great Highway is at the upper left, and the south limit of the temporary shore protection is the riprap mound at the bluff toe (top center). (August 1996)

(Bottom) Approximately 180 feet north of South Lot looking South. South limit of temporary shore protection is the riprap mound at the damaged pathway to the beach. Concrete pipe (center) angled into the beach is an abandoned wastewater pipe.
In most areas, the bluff slope has been oversteepened to an angle of 40-70 degrees from the toe to a 12-15 foot distance above the toe where a vertical escarpment extends another 3-5 feet to the bluff edge. Precipitation runoff and foot traffic has caused further erosion, with gullies extending landward of the typical bluff edge in the area between the two parking lots. In March 1997, one storm formed a gully that eroded up to approximately 15 feet further into the bluff. This erosional feature is shown in Figure 10. Due to these more recent events, the bluff edge is now less than 15 feet from the west edge of the Great Highway in one place between the two parking lots.

The immediate area of concern requiring shore protection is the 600-foot reach between the two parking lots, shown in Figure 3, where another event like those in 1994/1995 could damage the highway and the stormwater drainage line that parallels the western edge of the pavement.

The Lake Merced Tunnel, shown below the highway in Figure 5, is located below the groundwater table. With loss of the overbearing material, buoyancy forces could lift and damage the concrete pipe unless it was ballasted with water inside the pipe. Provided that the pipe remained intact, further retreat of the bluff would be slowed or even halted once the beach level eroded below the crown, as the pipe would act as a “shore protection structure.” It would be a catastrophic event for the beach to lower far enough that the pipe would be undercut, however it is not an event one would expect based on what is known about the area.

In the near-term, there is a one in two chance that the bluff will retreat inland far enough by the year 2003, that the storm drain and part of the Great Highway will be damaged without shore protection in the area between the two parking lots. The parking lots themselves also would be damaged or destroyed, but the highway and storm drain would be spared in these areas because they are further inland.
Project Guidelines/Agency Requirements

The need for immediate shore protection in the area between the two parking lots was of concern to the City, the National Park Service (NPS), the California Coastal Commission (CCC), and the U.S. Army Corps of Engineers (USACE). All of these agencies were consulted during initial portions of the study in order to develop appropriate project guidelines for the design and other agency requirements for implementation of the final solution.

Primary concerns and roles of each agency were:

The City - As lead agency for planning and funding the shore protection structure, the City was very concerned about damage to its infrastructure near the bluff and the adverse impacts loss of the highway or damage to the Lake Merced Transport box would have on the residents served by these public structures.

National Park Service (NPS) - In 1972, the City deeded the beach from the west edge of the right-of-way of the Great Highway to the NPS for incorporation into the Golden Gate National Recreation Area. Because of this, no action could be taken by the City beyond the western curb of the highway without full consent of the NPS. As such, the NPS was consulted throughout the design study with regards to their concerns on various design elements of the measures. As owner of the property on which the structure would be placed, NPS was interested in minimizing the impact that the structure would have on the natural appearance and behavior of the seashore. NPS also coordinated with the U.S. Fish and Wildlife Service regarding biological impacts including issues related to Snowy Plover nesting habitat north of the site and impacts to swallows that live in the Fort Funston cliffs.

California Coastal Commission (CCC) - The CCC participated in the planning process to help ensure that the project would not affect public access to the beach and that the least intrusive means were used for erosion control.

Corps of Engineers (USACE) - USACE representatives were present at early coordination meetings, largely to ensure that the City understood their permitting requirements and timeframes so that the permit process would not become an obstacle to timely construction of the revetment. However, because the design of the revetment allowed all of the construction on the surface of the beach to be above Mean High Water, no USACE permit was required.

There were ample prior studies and recent large shoreline erosion to justify taking action for slowing or halting the retreat of the shoreline in the interest of preserving costly infrastructure. Further studies, although adding to the knowledge base, would only lengthen the time before action could be taken. Thus, the City made the decision to proceed as quickly as possible with the design of a temporary shore protection structure to be installed in the summer of 1997 until a permanent solution to the erosion could be put in place, which would involve a much longer process.

Throughout the design process, the City provided the NPS, CCC, and USACE information and drawings for their review and comments. Additionally, the California Department of Boating and Waterways provided review and comments on the proposed shore protection structure.
The following guidelines were developed for the design of the shoreline protection measures based on the concerns of the above agencies.

- Emphasis on Alternatives to Quarrystone - Determine if there are alternatives to quarrystone or riprap revetment structures that would be suitable for the site. An exposed quarrystone revetment should not be used unless it is the only feasible method. NPS considers that quarrystone revetments would pose a safety hazard to people walking on the stones and provide habitat for rats that could disturb the swallows inhabiting Fort Funston cliffs south of the South Lot.

- Temporary Structure - Structure should be temporary and designed with a 5-10 year life, and will be removed or incorporated into the permanent solution yet to be adopted for the site.

- Proven Methods - Selected alternative(s) should be proven methods used in similar high wave energy wave environments on open coasts.

- No Beach Nourishment - Beach nourishment should not be considered as an alternative. Since the site is an eroding beach, beach nourishment would be a recurring operation and would require costly maintenance and disruption of the ecology and public use of the area.

- Preserve Access - Access to and use of the recreational beach in front of the bluffs should be preserved to the fullest extent possible.

- Limited Protection - Near-term erosion protection shall be placed only as necessary to protect the Great Highway and buried infrastructure rather than along the entire 1920-foot reach. NPS considered that some damage to the parking lots would be acceptable.

- Construction Before Winter 1996/1997 - The design was to be constructable prior to the 1996/1997 winter storm season. (This was the original goal, but subsequent delays made it necessary to delay the planned installation until the summer or early fall of 1998.)

- Streamline Permits - A structure that can be constructed above MHW (5.3 feet MLLW) was preferred in order to reduce permitting requirements.

**Shoreline Protection Design**

The design of the shoreline protection was done in two parts:

An initial assessment was made of areas immediately in need of shoreline protection based on current (1996) site conditions. Identification and screening of alternatives was done to identify measures that would satisfy the project guidelines, and recommended alternatives were presented for protection of the areas of concern in the near-term.

Immediate shoreline protection design in which a short-term structure for arresting erosion in the most critical areas was designed.

The following presents the results of the alternative analysis from the initial assessment, the design of the temporary toe protection revetment (TTPR) designed for protection of the shoreline until a permanent seawall could be constructed, and the design of an interim measure to protect the bluffs from further erosion over the 1997/1998 winter storm season.

**Alternatives Analysis**

Extensive research into the suitability of alternative methods meeting the guidelines
presented above showed that there were few alternatives that one would have confidence in at the site based on papers in the professional literature and USACE (1981, 1984, 1985). Each potential alternative was evaluated using the guidelines above as well as the following criteria:

- Availability of design criteria and practices.
- Survivability of the structure on an eroding beach in which the structure would be exposed to higher wave energy as the beach erodes.
- Performance of structures at other locations.
- Availability of materials to meet the construction schedule.
- Ease of construction.
- Construction cost.
- Maintenance.
- Beach "footprint". The smaller, the better.
- Aesthetics and beach access.

Table 1 shows the alternatives rejected during the initial screening and the reasons they were rejected. Six types of structures were considered for further review. These alternatives were deemed to meet all or most of the design criteria. These were: (1) Longard Tubes, (2) Patented Sand Container Systems, (3) Sandbags, (4) Quarrystone Revetment, (5) Geotextile Bag Revetment, and (6) Perched Beach.

**TABLE 1. APPROACHES REJECTED DURING INITIAL EVALUATION**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Rejected Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Sands</td>
<td>Low wave-crested design, does not withstand well, not acceptable in available materials.</td>
</tr>
<tr>
<td>Concrete Beams</td>
<td>Corrosion-prone structural element, for long-term solutions.</td>
</tr>
<tr>
<td>Boulders</td>
<td>Moderate to high costs, not acceptable, used by some proponents were more.</td>
</tr>
<tr>
<td>Rocks</td>
<td>Observed overhang which is unacceptable, fixing of galleons is a major problem, would require significant means of staging, too bulky, or limited scope. Most had proper shape and were not generally acceptable.</td>
</tr>
<tr>
<td>Fingers</td>
<td>Corroded and other failures present that a single and recognizable are very important obstacles to most projects. This method has no proven record for shore protection.</td>
</tr>
<tr>
<td>Bagged Material</td>
<td>A number of materials, some small but in mass and conventionally expensive, especially in remote locations. Not method to prevent erosion in a major consideration and for economy. When landform, a rigid structure is fitted in general is found. Concrete-based containers must be forged yet may not be used as a container, often in ocean water and have been proposed.</td>
</tr>
<tr>
<td>Finning Mats</td>
<td>Require too many ships to achieve shaped movement. Various sizes are commonly used and have been shown to be very effective for open ocean applications.</td>
</tr>
<tr>
<td>Stylized</td>
<td>Stylized units</td>
</tr>
<tr>
<td>Large Coastal Overhang</td>
<td>A layer of large overhangs placed over an area damaged under what is acceptable in existing ocean waves or storms. Large waves are rigid for the horizontal environment.</td>
</tr>
<tr>
<td>Concrete Reinforced Rocks</td>
<td>Not acceptable for hurricane or wave environment. Bonded strength with rock, but future of the material can lead to a more cost-effective use of the structure that prevents rainwater runoff.</td>
</tr>
<tr>
<td>Coastal Model</td>
<td>Special concrete rings molded to place with concrete and cast against the bottom of the concrete or similar in appearance.</td>
</tr>
<tr>
<td>Sand Revetment</td>
<td>Not acceptable for hurricane or wave environment. Bonded strength with rock, but future of the material can lead to a more cost-effective use of the structure that prevents rainwater runoff.</td>
</tr>
<tr>
<td>Composite Model</td>
<td>Special concrete rings molded to place with concrete and cast against the bottom of the concrete or similar in appearance.</td>
</tr>
<tr>
<td>Rock Material</td>
<td>Not acceptable for hurricane or wave environment. Bonded strength with rock, but future of the material can lead to a more cost-effective use of the structure that prevents rainwater runoff.</td>
</tr>
<tr>
<td>Wood</td>
<td>Some product is used to produce composite and has been used for the structure on the beach. The material for concrete forms.</td>
</tr>
</tbody>
</table>
These are presented and reviewed briefly below. The first three involve the use of soft or semi-rigid containers made of geotextile or nylon-type fabrics that are filled with wet sand. Based on the review the last three methods were considered the most viable means of shore protection at Ocean Beach.

**Longard Tubes.** Longard tubes may be 6 feet in diameter and 100 feet long. They are subject to damage from vandalism and debris impacts and are prone to shifting. Their use on an open coast was deemed to be impractical.

**Patented Sand Container Systems.** These are relatively recent inventions and have been used from Florida to New York and have provided protection during hurricane storm surge events (Harris 1988, 1989). These systems have compartmentalized chambers in the fabric tubes so that loss of sand from a damaged chamber does not lead to progressive failure of the whole structure. The tubes are affixed to a geotextile fabric mat that forms the scour apron. The entire structure is then covered with sand. At the present time, design criteria are based on experience of the designer and not established practices, but the science is evolving. Units also require special manufacture and strict monitoring to ensure they are correctly installed. Because of cost, timely availability, and the fact they would be placed on an eroding beach and become exposed to damage or vandalism, they were not considered a viable solution. Additionally, their performance under frequent wave attack on an open coastline was a concern.

**Sandbags.** Sandbags containing up to 4 cubic yards of sand have been used for slope protection on Arctic oil-rig artificial islands (Gadd, circa 1989) and in Southern California at Zuma Beach approximately 18 miles west of Santa Monica. Performance has been good, but Zuma Beach lies in a partially sheltered area east of the Channel Islands and in a region subject to much less frequent wave action. Cover sand must be kept over the bags to prevent vandalism or other damage. Sandbags were not considered to be a reliable means of shore protection at Ocean Beach.

**Quarrystone Revetment.** This is the best understood structure, as this method has been around for centuries, and extensive design practices exist. A preliminary analysis showed that a median armor stone weight of 4,600 pounds would be needed. As discussed above, quarrystone revetment designs were discouraged by NPS because they are felt to present safety hazards and provide habitat for rodents.

**Geotextile Bags.** These are similar to sandbags except they are constructed of geotextile material and are filled with concrete. Because they are concrete filled, they do not have the same potential for damage as the sand-filled concepts presented above. Geotextile bags are filled in-place, and when stacked, are relatively solid. Therefore, they do not present the safety hazards or potential rodent habitats that were associated with quarrystone. On the other hand, because they create a more solid surface, they do not have the same energy absorption characteristics of quarrystone.

**Perched Beach.** This design used a buried scour structure of armor stones approximately 25 feet seaward of the existing bluff toe, with median stone weights of 3,200 pounds. A toe revetment of concrete-filled, 2.2 cubic yard capacity geotextile bags would line the toe of the bluff to an elevation approximately 6 feet above the winter beach toe elevation.
A wave runup apron of Armoflex concrete mats on a 1V:2.5H prepared slope would extend from the top of the bags to 3-5 feet below the edge of the bluff. The scour apron and area between it and the bags would be covered in smooth pebbles and cobbles. The entire structure would then be covered with a layer of sand that would be eroded away in one or 2 winter seasons. Wave action on the pebbles and cobbles would provide wave energy absorption, yet still provide a walkable surface. A narrow strip of usable beach would still remain when the beach eroded lower in front of the scour apron.

The alternative selected for development was a hybrid revetment that incorporated geotextile bags along with limited amounts of quarrystone. The design, called the Temporary Toe Protection Revetment (TTPR), is described below.

**Temporary Toe Protection Revetment Design**

The structure that best met the design criteria above was a geotextile bag revetment that incorporated limited amounts of quarrystone. This design is referred to below as the Temporary Toe Protection Revetment or TTPR. This was the structure that all the organizations adopted as the approach to use. The preliminary versions in CH2M HILL (1996) were modified in response to cost considerations and more refined analyses during the design process. Table 2 lists the design basis for this temporary structure with the understanding that more stringent criteria would have been used for a permanent structure.

### TABLE 2. DESIGN PARAMETERS FOR THE OCEAN BEACH TEMPORARY TOE PROTECTION REVETMENT.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Required for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Surface Elevations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Still Water Elevation (continental tide + storm surge)</td>
<td>8.8 ft MLLW</td>
<td>Wave Runup Calculations</td>
</tr>
<tr>
<td>Water Elevation (SWL + 1.5 ft wave surp)</td>
<td>10.3 ft MLLW</td>
<td>Calculating Maximum Breaking Wave Height</td>
</tr>
<tr>
<td>Max. Design Water Depth at the Seaward Face of Scour Apron</td>
<td>5.3 ft</td>
<td>Calculating Maximum Breaking Wave Height</td>
</tr>
<tr>
<td>Wave Design</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significant Wave Height, Hs and Period</td>
<td>19.0 ft (0.6 sec)</td>
<td>Staging Structural Elements and Wave Runup Calculations</td>
</tr>
<tr>
<td>Hs and Period (Average of highest 3% waves)</td>
<td>29.5 ft (0.6 sec)</td>
<td>Staging Structural Elements and Wave Runup Calculations</td>
</tr>
<tr>
<td>Max. Design Breaking Wave Height</td>
<td>8.8 ft</td>
<td>Staging Structural Elements</td>
</tr>
<tr>
<td>Structural Characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-Stone Size</td>
<td>50% of stones ≥ 2700 lbs</td>
<td>Structure Stability under design conditions</td>
</tr>
<tr>
<td>Geotextile Bag Size (filled with concrete)</td>
<td>2 ft H x 6 ft W x 10 ft L</td>
<td>Structure Stability under design conditions</td>
</tr>
<tr>
<td>B-Stone Size</td>
<td>50% of stones ≥ 2700 lbs</td>
<td>Structure Stability under design conditions</td>
</tr>
<tr>
<td>Maximum Runup Elevation</td>
<td>20.0 ft MLLW</td>
<td>Elevations of top of runup apron to prevent backshore erosion from wave</td>
</tr>
</tbody>
</table>

(1) The maximum design breaking wave height is calculated based on a 1% annual exceedance return period wave at an approach wave from an angle such that the height of wave is equal to 10% of foreshore water depth.
A plan view of the TTSP is shown in Figure 11. The main body of the revetment would be 570 feet long with an additional 20-foot length of structure at both ends for transition.
to the natural surroundings. A cross section at beach transect R1 is shown in Figure 12 and is typical of the main body of the TTSPR. The structure would require approximately
the following material quantities:

<table>
<thead>
<tr>
<th>Material</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A-Stones (median wt. 2,700 lb)</td>
<td>1,070</td>
</tr>
<tr>
<td>Class B-Stones (median wt. 270 lb)</td>
<td>1,840</td>
</tr>
<tr>
<td>Pebbles and Cobbles</td>
<td>1,190</td>
</tr>
<tr>
<td>Geotextile Bags (4.1 CY capacity)</td>
<td>236</td>
</tr>
<tr>
<td>Concrete for Bags</td>
<td>930</td>
</tr>
<tr>
<td>Geotextile Filter Fabric</td>
<td>31,950</td>
</tr>
<tr>
<td>Sand Excavation and Backfill</td>
<td>4,600 CY</td>
</tr>
</tbody>
</table>

It was anticipated that the beach could erode below the crest of the A-stones in the scour apron fronting the geotextile bags, with the eroded beach toe lying along the face of the bottom row of A-stones. At this point, wave action would greatly increase at the structure as the higher high tides would reach the bottom row of A-stones if the beach erodes far enough. The TTPR was designed with the assumption that the permanent seawall would be installed before the beach erodes below the bottom row of A-stones in the scour apron. Static stability analyses showed that the geotextile bags will remain in place without any A-stones in the scour apron. However, the dynamic response of the structure would cause downward shifting of the bags when the B-stones began to displace under wave action. The structure, however, can be reinforced in response to an eroding beach if the permanent structure is not built in time.

As designed, the estimated construction cost of the TTPR in 1996 dollars was $680 per linear foot of beach width, using a 10% adjustment for general conditions and 20% for contingency.

Only minimal dewatering effort using pumps to remove excess water from the excavation was assumed, with no cofferdams or sheet piles being placed. If more extensive dewatering is required, the cost estimate would be considerably more. It was anticipated that construction would be “in the wet” to the top layer of B-stone or even the top of the pebbles and cobbles under the bottom row of geotextile bags, especially at tide elevations higher than 4.1 feet MLLW. The exact location of the groundwater table and its response to tidal action is not known for the site.

**STORM SEASON 1997 TEMPORARY REVETMENT DESIGN**

Delays made it apparent that the TTPR could not be constructed until 1998. CH2M HILL advised the City in July 1997 of the increased risk of erosion in the 1997/1998 winter because of the El Niño event developing along the eastern Pacific, as well as the increase in the number of higher high tides starting in 1998 through 2013 compared to a nadir in 1997.

In 1983, another major El Niño event comparable to the ongoing one was associated with the highest water levels ever measured in the San Francisco region (8.7 feet MLLW at the Presidio on January 27, 1983), which was 2 feet above the predicted high tide elevation. Major shore erosion occurred along certain reaches of Ocean Beach, particularly off Taraval Street (the extent of erosion south of Sloat Boulevard was not documented). If this storm surge had coincided with a predicted tide of 7 feet or more, the resulting erosion at Ocean Beach would likely have been much worse.

The City and the NPS recognized that a higher than normal risk of substantial erosion was possible in the 1997/1998 storm season. A low cost, easy-to-install design was prepared for a one-year shore protection structure that would be removed in the
summer of 1998 when the TTTPR would be constructed. The only viable, low cost structure that could be installed before the onset of the winter storms was a quarrystone revetment placed along the toe of the bluff. This was called the “Storm Season 1997 Temporary Revetment” and consisted of a 4-5 stone cross section of armor stone (median weight 2,700 pounds) placed directly on Mirafi 1120N non-woven geotextile cloth. A one-foot deep trench was dug along the toe, and the filter cloth was placed from an elevation of approximately 4 feet above the toe to along the bottom of the trench, with the armor stones placed directly on the fabric. The stones will be reused in the TTTPR when it is constructed in 1998.

Construction of the revetment was completed in October 1997. The structure was designed using relaxed design standards as the structure is only intended to prevent catastrophic bluff slope erosion from wave undercutting for the 1997/1998 storm season. It is anticipated that some of the stones could shift in response to the general lowering of the beach profile during the winter. Without this minimal structure, the survivability of the remaining bluff between the Great Highway and the beach was doubtful.

Monitoring and Emergency Response
Once the TTTPR is in place and until the permanent shore protection solution is installed, cooperative management of the beach will be required between the City, NPS, and the CCC. The City is the principle organization responsible for taking action, and it is responsible for all costs incurred. Continued beach erosion in the unprotected areas north and south of the TTTPR and maintenance in response to changes in the beach and TTTPR itself, will require action by the City to maintain an effective erosion protection structure for the area between the two parking lots. Erosion will eventually damage or destroy the parking lots, but as mentioned earlier, would have to be catastrophic to extend to the Great Highway. The management of the beach south of Sloat Boulevard, therefore, has two primary objectives: (1) to monitor the 1920-foot reach and designate criteria for taking action to prevent undue damage to the parking lots or make the decision to let the parking lots go, and (2) monitor the TTTPR and immediate areas for changes and take action based on those changes to preserve the shore protection’s integrity.

At the time of this paper, a draft of Emergency Plan for Ocean Beach South of Sloat Boulevard has been under review by the City and eventually by the other concerned organizations. Implementation of the plan likely will not take place until after the TTTPR is constructed.

This plan addresses responses by the City in coordination with other agencies for:

1. Preventing catastrophic erosion in the critical area between the two parking lots and for making repairs to the TTTPR, including the installation of additional shore protection abutting the north and south ends of the TTTPR.
2. Monitoring erosion in the reach south of Sloat Boulevard.
3. Installing temporary shore protection in areas outside the immediate area of concern for the TTTPR until a permanent shoreline maintenance solution is implemented.

The emergency plan consists of the following sections:
Section 1.0 Introduction discusses the need for the plan and its objectives.
Section 2.0 Organizations and Responsibilities lists the organizations that will be
responsible for monitoring and maintaining the temporary revetment and for participating in decisions on responses to further changes to the shoreline in the area of the revetment.

Section 3.0 Existing Beach Processes and Design Limitations summarizes the present conditions of the beach and the limitations of the temporary revetment design.

Section 4.0 Monitoring Inspections and Surveys describes the monitoring requirements including types of inspections and surveys, schedule and frequency of monitoring, and documentation requirements.

Section 5.0 Evaluating and Responding to Changed Conditions describes procedures for evaluating damage, presents potential damage scenarios that require action by the City, and defines procedures for responding to additional erosion of the bluffs.

Section 6.0 Recommendations for Sources of Material and Stockpiling presents potential sources for obtaining materials needed to repair or maintain the revetment and makes recommendations for stockpiling materials required for emergency repairs.

When the plan is finalized, probably in late 1998, it will form a basis for responding to changes along the beach and should expedite the decision making process when action must be taken. The plan will help ensure that CCSF can maintain the integrity of the TTPR in a timely manner, which will reduce greatly the cost of maintenance.

SUMMARY AND CONCLUSIONS

A temporary revetment was designed that would provide protection for City infrastructure that is threatened by localized erosion. Because of the potential impacts of further erosion, it was important for the City to get a revetment designed and constructed without undue delays.

All interested agencies were invited to participate from the start of the project to make sure that they understood the issues (including the risks of not building a revetment), to receive their comments and concerns early in the process, and to ensure the City would meet all agency requirements.

A permit was received from NPS for construction of the revetment. Permits from USACE and CCC were not required because the revetment is to be constructed outside of their jurisdictions.

The revetment is an interim measure that is intended to provide protection to limited areas of the shoreline that were considered to be at greatest risk until a more permanent solution can be implemented. Relaxed design criteria were used to allow the revetment to be constructed with the funds that the City had available.

Continued erosion is expected in the areas adjacent to the revetment that were not protected. Also, because of the relaxed design criteria, there is a higher risk of damage to the structure, especially if the beach in front of the revetment recedes at a greater rate than projected.

Because of the risks of continued erosion in the area, an important part of the project was the development of a monitoring and emergency response plan that will provide guidelines to the City for identifying and responding to further erosion in the area. The
plan, which is currently being completed, will establish monitoring procedures, define damage or erosion levels that will warrant response by the City, and define procedures for response that have been agreed to by the City and NPS.

REFERENCES


