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Permalink

Journal
Coastal Engineering, 52(2005)

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Publication Date
2004

Data Availability
The data associated with this publication are available upon request.

Rapid Erosion of a Southern California Beach Fill

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ABSTRACT

A single severe winter storm in November, 2001 completely eroded a beach fill at Torrey Pines State Beach in Southern California. The fill was small compared to many projects – only 250,000 cubic meters. Rather than being constructed as a slope, the upper face of the fill remained level and terminated in a near-vertical scarp almost 2m high at approximately mean sea level. The incident wave climate was extremely well defined by the Southern California CDIP wave model and two CDIP directional Waverider buoys installed offshore of the fill at depths of 550m and 20m. This system provided continuous observations of the incident waves throughout the project. This fill was one of twelve roughly similar fills undertaken by San Diego Association of Governments (SANDAG) along the San Diego County coast during 2001. It was chosen for detailed monitoring by Scripps Institution of Oceanography (SIO) under a contract from the California Resources Agency and the Department of Boating and Waterways. Very detailed profiles were made biweekly. The dry beach was measured with a GPS-equipped all-terrain vehicle. The subaqueous profiles were obtained with a JetSki fitted with a similar GPS navigation system and a depth-finding sonar. The profiles extended to a depth of 8m and were spaced only 20m apart for the 500m length of the fill and 100m apart for approximately 1200m on either side of the fill. The temporal and spatial resolution provided by this surveying program, in combination with the wave measurements, provides an exceptional data set. The fill was completed near the end of April, 2001. During the summer and fall, the wave climate was typical, with H_s less than 1 m except for a few times when it ranged as high as 1.5 m. The scarp face remained intact and there was only a modest diffusion at the ends of the fill. At noon on Thanksgiving Day, 22 November, 2001, the H_s reached 3 m and remained in the range from 2.75 to 3.25 m until 7 PM. The fill was severely eroded. However, the pattern of material loss was unusual in that the scarp face was cut in a series of embayments. These cuts maintained sharp vertical faces as they eroded The fill was resurveyed on 23 November, one day after the storm. The role of sediment size in the stability of the fill, the characteristics of the Thanksgiving Storm, and the erosion patterns observed and measured are discussed.

Keywords: Beach fill, beach nourishment, erosion, waves, surveying techniques, Torrey Pines

Introduction

The San Diego Association of Governments (SANDAG) coordinated a series of twelve small beach nourishment projects in the southern half of San Diego County, California, during the spring and summer of 2001. The sand was obtained by dredging from several offshore locations at depths of 20 to 25 m. A small hopper dredge was employed and the slurry was discharged through a submerged pipeline that was installed offshore of each beach fill site. One of the sites was at the northern end of Torrey Pines State Park at the border between San Diego and Del Mar, as shown in Figure 1a and 1b. The coast is typically backed by high cliffs in this region, but the fill site was just south of a lagoon mouth in an area of low relief (see Figure 2.) The California Resources Agency and the Department of Boating and Waterways selected Scripps Institution of Oceanography (SIO) to undertake a detailed monitoring investigation of the Torrey Pines site. Surveys, as described in the following sections, were begun just prior to the fill construction and were continued biweekly for approximately one year and then monthly for an additional year. Sediment analyses of the native beach material and periodic sampling of the nourishment material were accomplished by others.

Beach Fill Project

The Torrey Pines nourishment contained approximately 140,000 m^3 of sediment with a median diameter (D_{50}) for the various samples that ranged from 0.15 to 0.25 mm. The native beach D_{50} was xx mm, such that [comments on suitability]. The alongshore extent was approximately 750m and the width about 70m. This volume is relatively small compared to many East Coast beach fills. For example, in 1992 Florida constructed almost 200 km of nourishment in a total of 33 projects or an average of about 6 km per project (Clarke, 1992.) Because of its short length this project could be expected to suffer large end losses (Dean and Yoo, 1992.) Beach nourishment initial or as-built geometries typically result in slopes much steeper than the native beach slope so that construction operations can be accomplished in the dry, for the most part. At Torrey Pines, the native beach was very narrow – less than 80 m from a riprap seawall protecting the adjoining highway to the mean sealevel line. Rather than burying the riprap wall and sloping the fill to the shoreline, the contractor elected to level the fill material such that a steep, almost vertical scarp almost 2m high was formed near the shoreline (see Figure 3.) The construction required about 2 weeks and was completed in the last week of April, 2001. The scarp was maintained with very little modification by waves and tides for a period of about 7 months.

Monitoring Program

The field measurement program involved surveying the fill and adjoining beach segments with unusually high resolution in space and time, and recording the local directional wave climate continuously during the two year span of the project. Two Datawell directional wave measurement buoys were installed directly offshore of the fill – one at a depth of 20m and the second at a depth of 550m, as shown in Figure 1b. These buoys were components of the Coastal Data Information Program (CDIP), a wave measurement network operated by SIO since 1976 (Flick et al, 1993; http://cdip.ucsd.edu.) In addition to providing a continuous record of the waves incident on the coast at the fill site, these nearshore buoys provided a means of validating the CDIP Southern California swell prediction model (O'Reilly XXXX), a refraction-diffraction model initiated with deep water observations outside the offshore islands. Figure 4 shows typical spectral plots from the inner buoy at this site.

Bathymetric and beach elevation observations were made using advanced Global Positioning System (GPS) surveying techniques. Profile lines, approximately normal to the local shoreline, were established at xx m alongshore intervals within the original fill envelope and at xx m alongshore intervals for xx m upcoast and downcoast from the fill. Figure 5 shows the profile line locations. The subaerial portion of each profile line was typically obtained with an all-terrain vehicle outfitted with a GPS navigation system. The 3-dimensional position of the vehicle was recorded with an on-board computer which also provided the driver a screen display of position relative to the profile line (see Figure 6.) For detailed or difficult terrain locations, such as the steep scarp face, the survey system could be transferred to a hand-pushed dolly or carried as a backpack. The subaqueous surveys were conducted using a similar system mounted on a JetSki craft and the profiles were extended to the 8 m depth contour (see Figure 7.) The JetSki was equipped with a dual-frequency acoustic depth sounder. The lower frequency sonar was used outside the surfzone to insure adequate penetration at depth. The higher frequency sonar has a much improved ability to penetrate bubbles in the water column so that it was effective in breaking waves and bores within the surfzone. As discussed in the introduction, the initial surveys were roughly biweekly, with actual survey dates adjusted to avoid large wave events and to favor higher tide ranges. Figure 8 shows a contour plot of the elevations and depths on 27 April, 2001, immediately following the construction of the fill.

Wave and Tide Climate

In the approximately seven month interval between the completion of the construction of the fill in April, 2001 and a moderately severe storm in November of that same year, the significant wave height (H_s) seaward of the surf zone varied between about 0.4 and 1.5 m. During this time there were 15 episodes where H_s exceeded 1m, as shown in Figure 9. This wave climate is typical for the summer season in this location. During the same period in 2002 the wave record was essentially identical and in 2003 the H_s range was slightly higher -- 0.4 to 2.1m -- with three episodes over 1.5m. The annual tide range at this location is about 1.6m.

About midnight on November 20, 2001, the H_s exceeded 1.5m and continued to increase, reaching a peak of 3.5m on the afternoon of Thanksgiving Day, November 22. It remained above 1.5m until the morning of November 24, as shown in Figure 10. The period of peak energy at the height of the storm was 16 seconds. The storm peaked at about 9AM on the 22nd. Figure 11 shows the predicted tide elevations for the last half of the month. The high tides (1.2m) bracketed the storm peak, remaining at a level of 1m or above. However, Figure 11 shows clearly that the storm coincided with the neap tides for that period.

Pre-storm Performance of Fill

During the post-construction period and prior to the peak of the Thanksgiving Day storm, there were a variety of changes to the region of the fill. Figure 12 shows a sequence of elevation changes, each relative to the post-construction survey. All of the neighboring beaches within the survey area showed the typical migration of the winter bar onto the beach, with the exception of the fill region, where it appears to have stalled offshore. One possible explanation for this anomaly is that the steep berm face had a very high reflection coefficient compared to the adjacent natural beaches and that the reflected energy inhibited the onshore sediment transport in front of the fill.

Figure 13 shows a difference plot between post-construction and mid-October, 2001, shortly before the November storm. Accretions of as much a one meter were observed. The landward portion of the fill was unchanged. The seaward edge was largely unchanged in the northern half of the fill but eroded from 0.5 to more than 1.2m in the southern half. Southward longshore transport appears to have deposited some of the sand from the upcoast beach in front of the northern end of the fill site. Similarly, material appears to have been displaced southward from the downcoast beach adjacent to the southern end of the fill. The steep berm face was maintained during this entire period, even in the southern part of the fill where the elevation was decreased.

Erosion During the November Storm

The beach fill began significant erosion early on Thanksgiving Day, November 22, 2003 – although the first visual observation by project personnel was not until the afternoon. The combined tide and runup overtopped the fill berm. Profile lines were run during daylight hours that day using GPS survey equipment contained in a backpack or mounted on a hand-propelled dolly (see Figure 14.) A full post-storm survey was completed a week later using the conventional equipment described above. As shown in Figure 15, the erosion was marked by a series of embayments which were spaced roughly 50m apart. Erosion of the intervening cusp-like material occurred at a slower rate than observed in the embayments. Figure 16 shows a sequence of pictures illustrating the erosion of one of the projecting features during a single wave uprush event. Although similar patterns of berm erosion have been observed elsewhere (Inman, 2002), there is no available theory to explain the quasi-periodic character of the embayment

formation. By daylight on November 23, the fill had been almost completely eroded to the riprap revetment at the back of the beach. Figure 17 shows the changes in the beach elevation that occurred between the surveys of 17 November, 2001 (pre-storm) and 30 November, 2001. Beach erosion exceeded 3m and the offshore accretion exceeded 1m. The location of the center of mass of the bar southward of the center of the fill is consistent with wave direction during the storm. The second offshore bar to the north of the fill is probably from the lagoon delta erosion.
Figure 18 shows a view of the fill site during the following summer of 2002. Although the beach recovered to a near-normal configuration, there was essentially no visual evidence of the fill location.

Modeling the Erosion
As an element of the research project, the U.S. Army Corps of Engineers computer program SBEACH (refXXX) was evaluated to determine its usefulness in West Coast beach modeling. Although all of the adjustable parameters were tuned to force maximum erosion, SBEACH was unable to predict erosion of the fill by the November storm. Similar results on West Coast beaches have been reported XXXXXXXXXXXX. The model was developed and validated on data from laboratory experiments and East Coast beaches, where much reduced infragravity wave activity would be expected compared to West Coast beaches. The absence in SBEACH of the enhanced runup and overtopping associated with the local infragravity energy may have been responsible in part for its failure to model the observed results.

Discussion
The temporal and spatial density of sand elevation measurements and the continuous wave records at the site provide an unusually rich data set. In addition to the capture of the details of a major erosional event, unique evidence of the translation of the winter bar to the beach during the summer season is provided. The data suggest that this experiment may yield a valuable resource for sediment transport model development and validation.

The astronomical tide appeared to have only a small influence on the erosion of the fill as its elevation during the event was only slightly greater than one half of the annual maximum.

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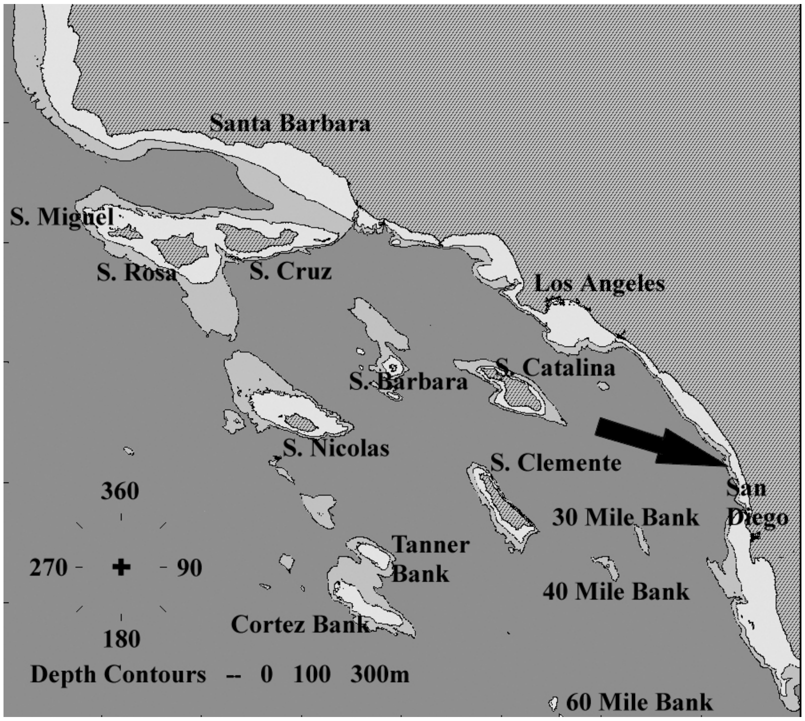
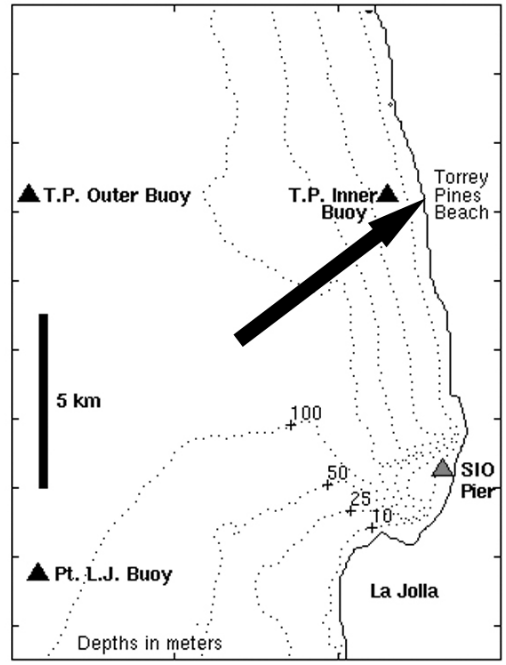
O'Reilly



(a)



(b)

Figure 1 Location of the Torrey Pines Beach Fill. a) shows the complexity of the offshore bathymetry in the Southern California Bight. b) shows local bathymetry and the location of directional wave buoys.

Figure 2. View of the beach fill site showing the Torrey Pines cliffs to the south and the lagoon mouth to the north.


Figure 3. Post-construction scarp at Torrey Pines beach fill.

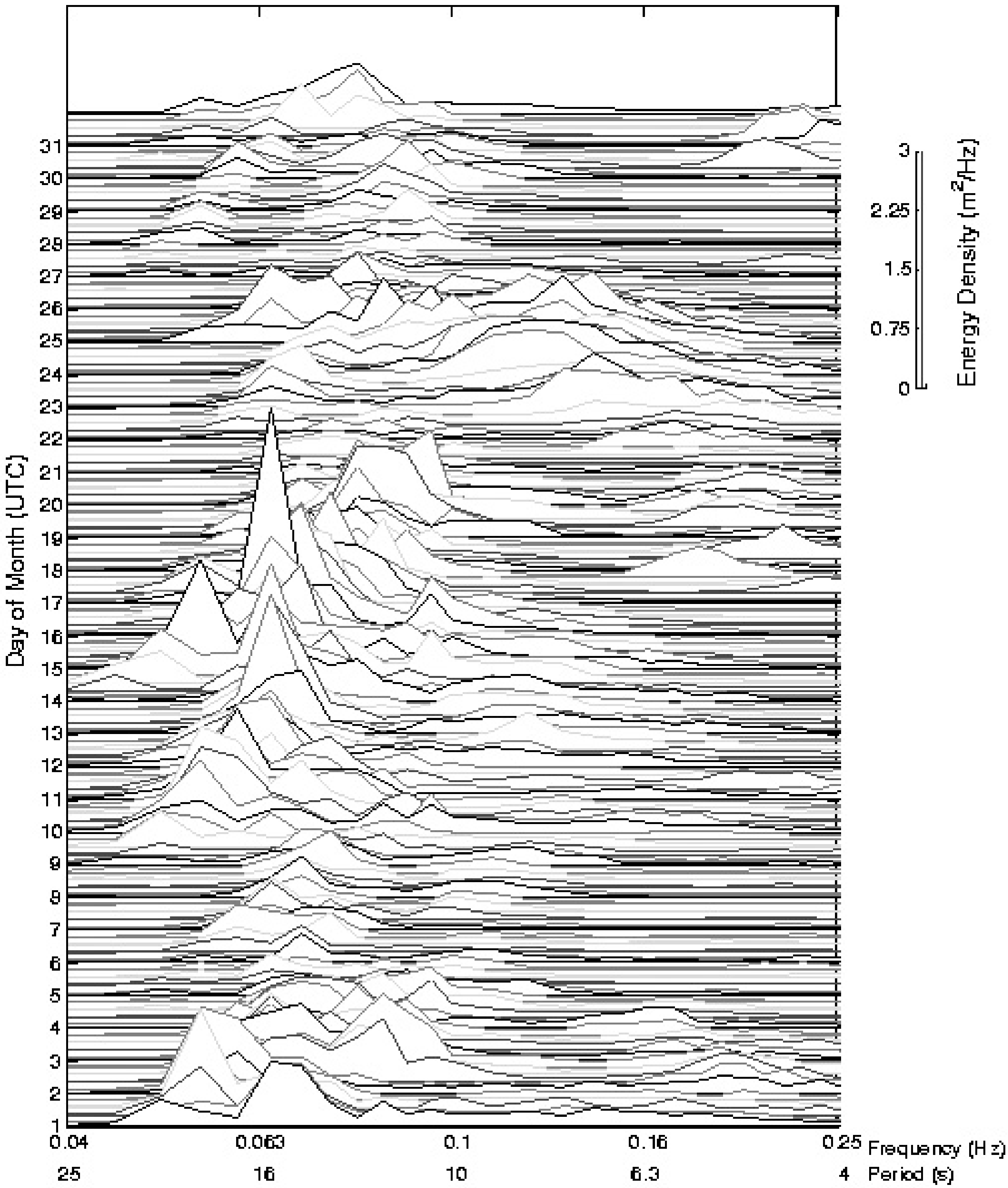
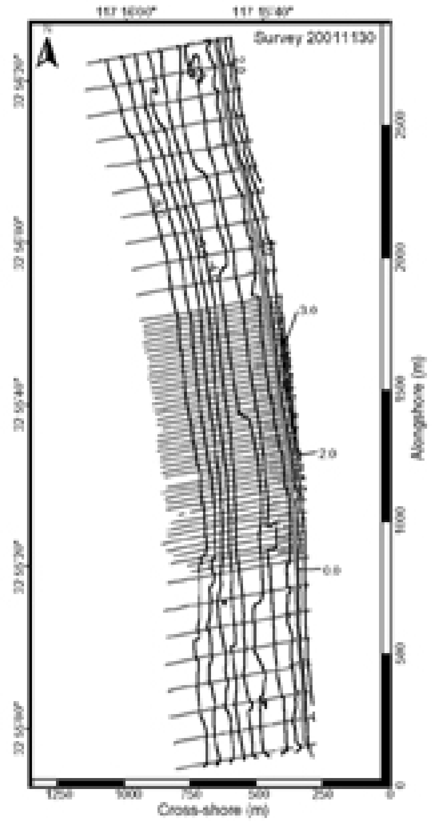


Figure 4. Energy spectra from Torrey Pines Inner Buoy for October, 2001



1. Figure 5. Typical survey profile lines. These are the actual lines run in the post-storm survey.

Figure 6. GPS-navigated all-terrain vehicle for dry beach surveys.

Figure 7. GPS-navigated JetSki for underwater surveys

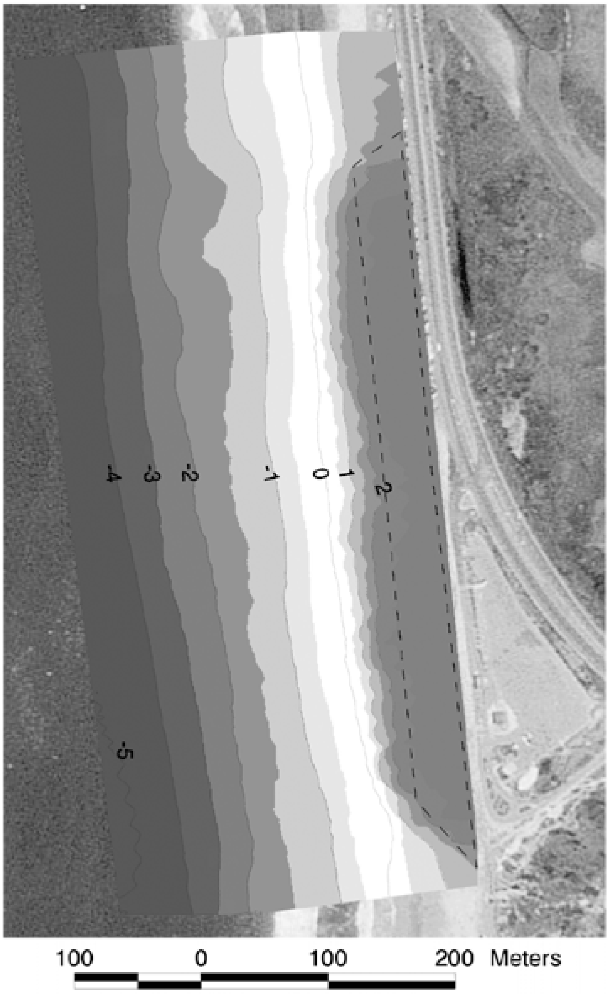


Figure 8. Configuration of the beach fill in April, 2001 at the completion of construction. Contours in meters.

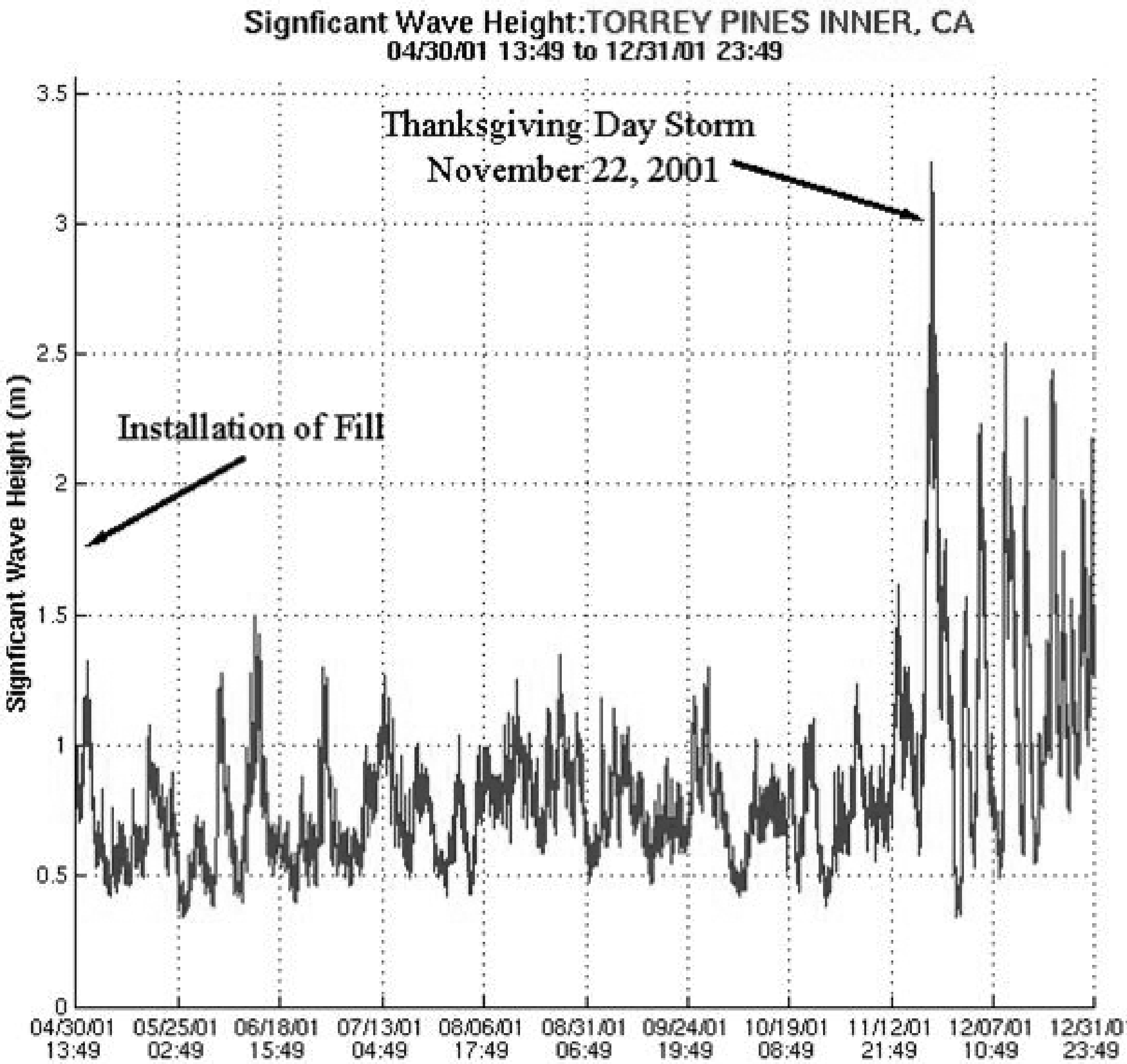


Figure 9. History of significant wave heights at Torrey Pines beach fill

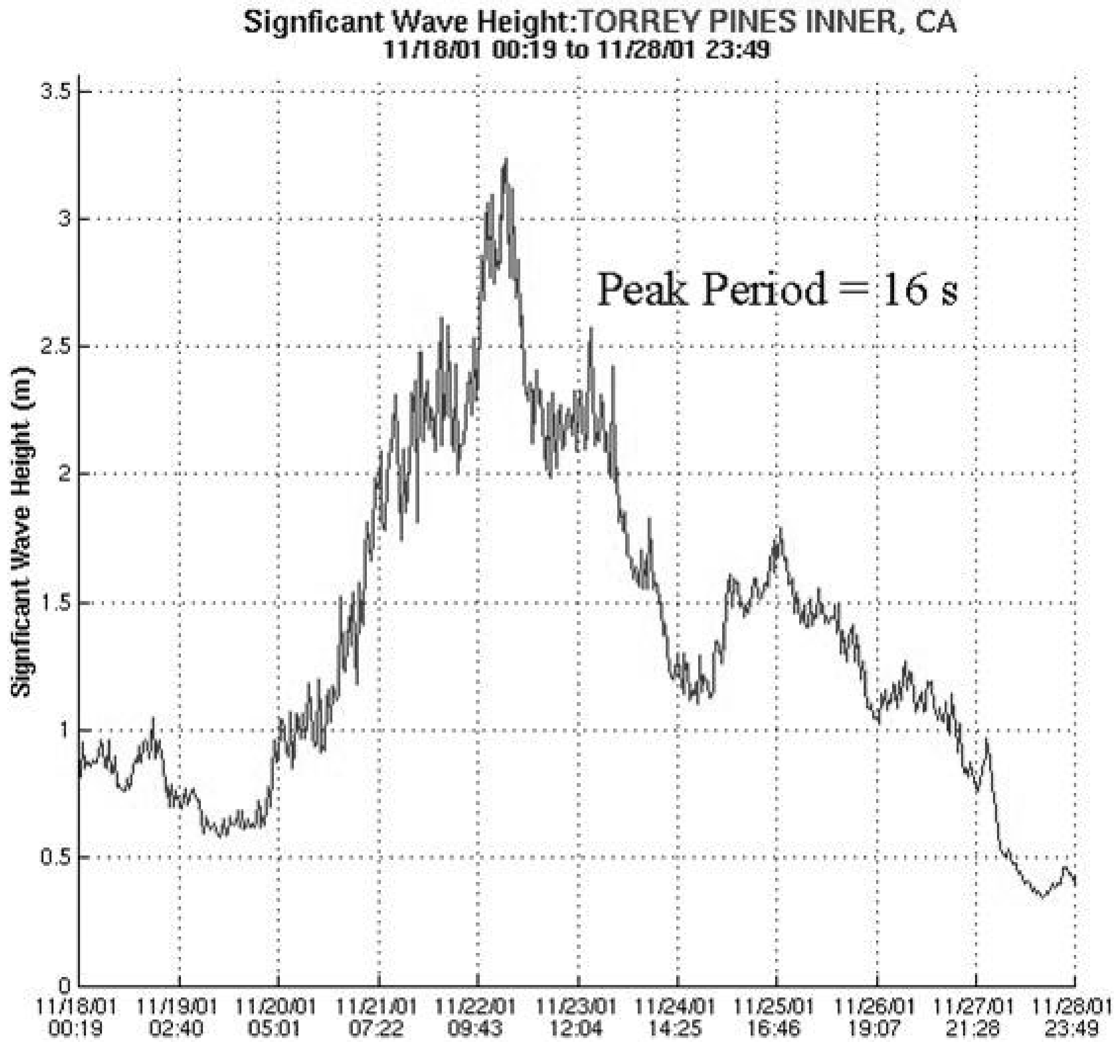


Figure 10. Significant wave heights at Torrey Pines during the Thanksgiving Day Storm

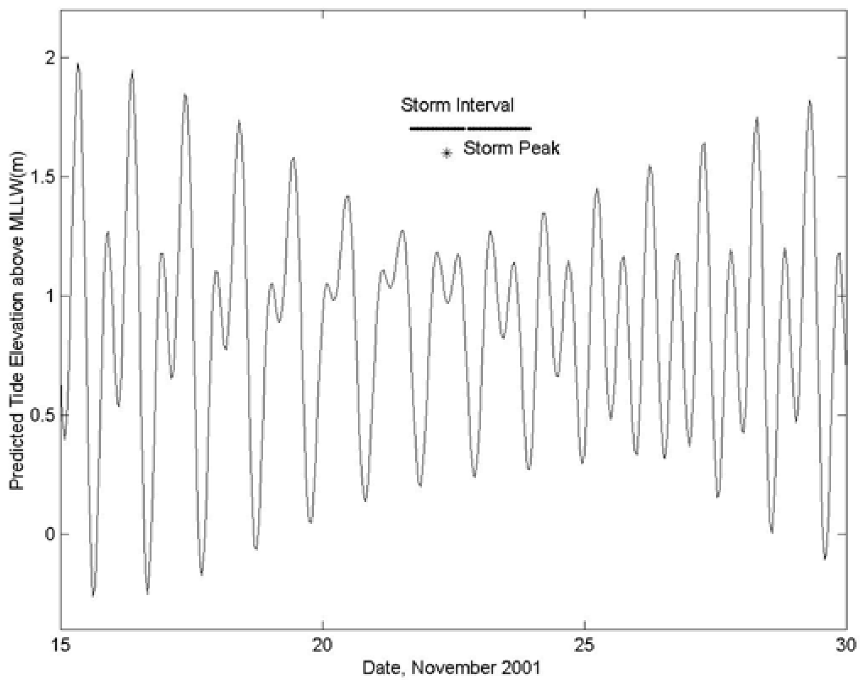


Figure 11. Tide elevations at Torrey Pines during the last two weeks in November, 2001

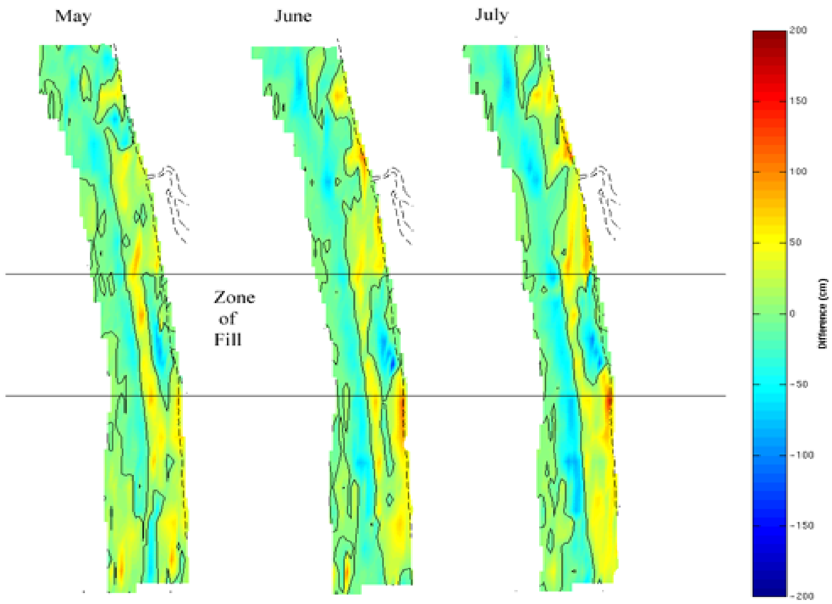


Figure 12. Sequence of differences between elevations following construction and mid-month surveys in May, June and July, 2001.

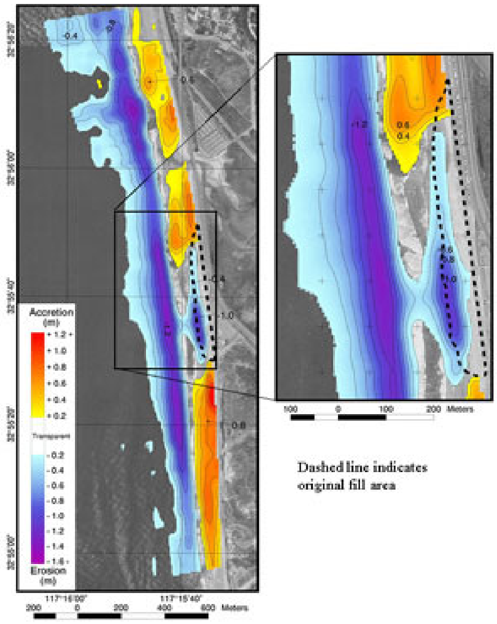


Figure 13. Changes in sand elevation between post-construction and 16 October, 2001 surveys

Figure 14. Survey activities during the storm using backpack (left) and dolly (right)

Figure 15. Beach fill erosion as a series of embayments

Figure 16. Sequence over one wave period showing erosion of the tip of a cusp

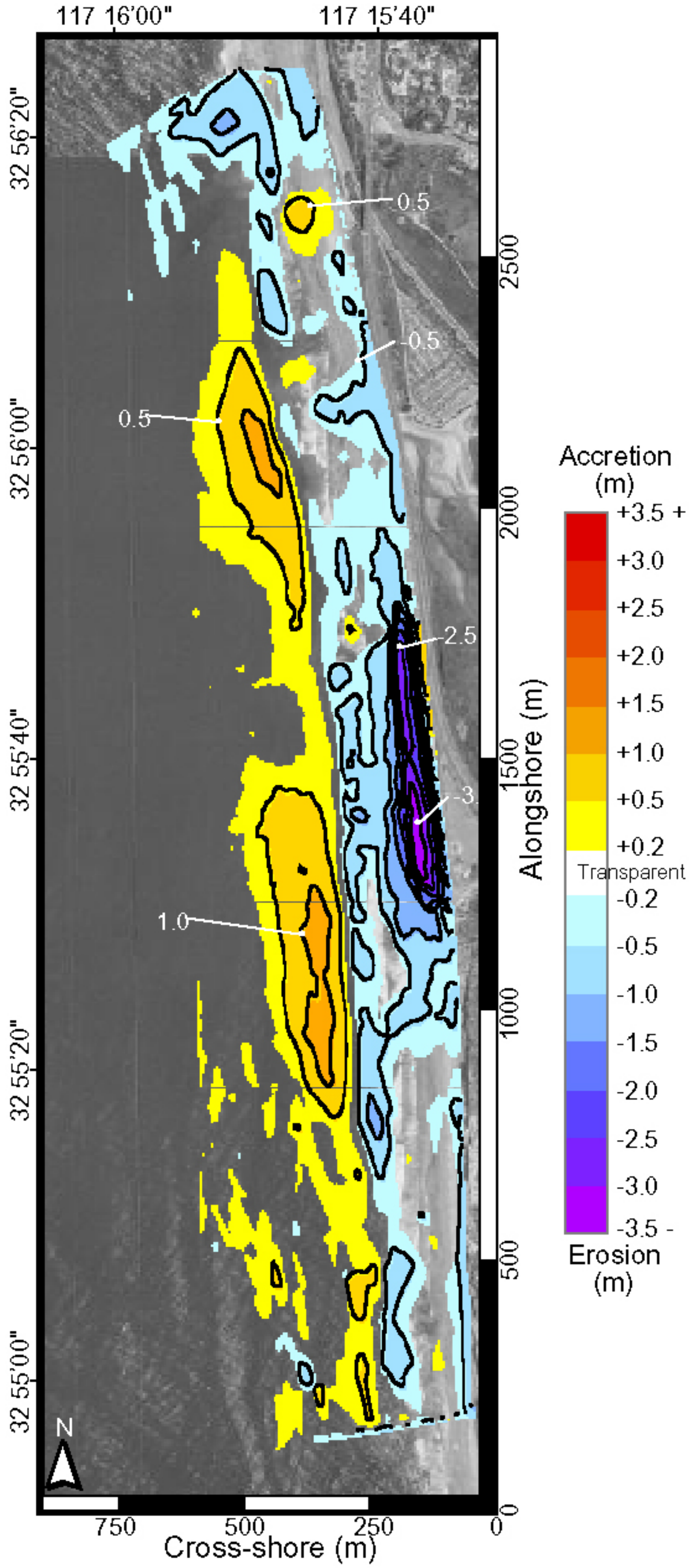


Figure 17. Plot of elevation differences between the 17 November and 30 November (immediate pre- and post-storm) surveys.


Figure 18. Summer beach at the site of the fill in 2002, the year following the storm