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Rapid erosion of a small southern California beach fill

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Abstract

A winter storm eroded a small (160,000 m^3) beach fill at Torrey Pines State Beach in southern California. The fill, constructed in April 2001, was a 600-m long flat-topped berm, extending from a highway revetment seaward about 80 m, terminating in a 2-m tall, near-vertical scarp. The size distributions of the preexisting and fill beach sand were similar (median ~0.2 mm). A total of 56 cross-shore transects were surveyed between the revetment and 8 m water depth biweekly along 2.7 km of the beach centered on the fill area. During summer and fall, the incident significant wave heights measured 1 km offshore of the fill usually were below 1 m, the scarp was not overtopped, and the fill did not change greatly. The beach face alongshore of the fill accreted, consistent with the usual seasonal cycle in southern California. During a storm (3 m significant wave height) in late November, erosion began when wave uprushes overtopped the scarp and reached the relatively flat elevated fill, where the overwash flowed alongshore to initially small depressions that channeled the flow seawards. The offshore flow rapidly deepened and widened the channels, which maintained steep vertical faces and eroded by slumping. Thirty hours after the storm began, the shoreward end of the eroded channels had retreated to the highway revetment, leaving uneroded sand peninsulas protruding seawards ~50 m from the revetment and elevated ~1.75 m above the surrounding beach. Erosion of the beach adjacent to the fill was much less variable alongshore than within the fill region. During the next few days, the peninsulas eroded almost completely.

Keywords: Beach fill; Beach nourishment; Erosion; Waves; Surveying techniques; Torrey Pines Beach

1. Introduction

Beach fill placed in April 2001 at Torrey Pines State Park, located on the border between San Diego and Del Mar, CA about 6 km north of Scripps Submarine Canyon (Fig. 1), was eroded by a storm in November 2001. Depth contours for a few kilometers on either side of the nourishment are relatively straight and parallel, and waves in the fill area are not influenced by the canyon. The fill site was 1 km south of the mouth of a small lagoon in an area of low

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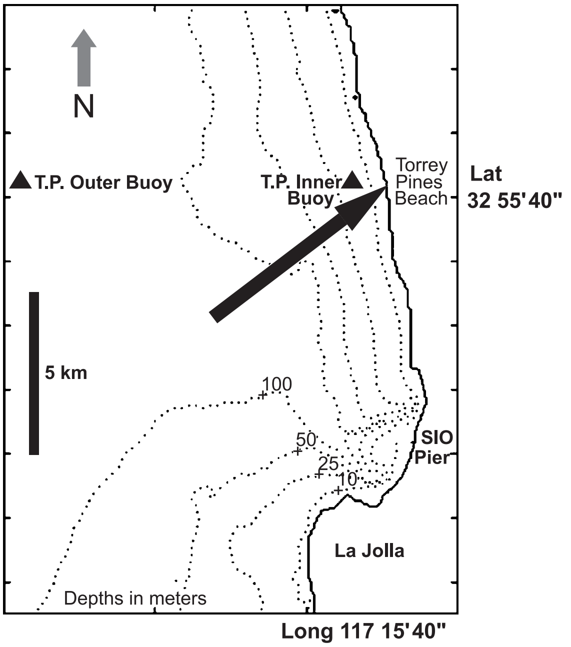

Fig. 1. Location of the Torrey Pines Beach fill (large arrow) and nearby wave measurements (triangles). Contours are depths below MSL. Submarine canyons are located on both sides of the SIO pier.

relief between 100-m high cliffs that extend for many kilometers along the coast.

During April 2001, approximately 160,000 m^3 of nourishment sand dredged from between 20 and 25 m water depth was pumped as a slurry through a submerged pipeline and discharged on the beach above mean sea level (MSL). Bulldozers contoured the fill into an approximately 600-m long flat-topped berm (Fig. 2a), extending from a highway revetment seaward ~80 m, where the shoreward face of the fill formed a 2-m tall, near-vertical scarp approximately following the MSL depth contour (Fig. 2b). Some lateral diffusion of sediment occurred during construction (Fig. 2a). The nourished length is shorter than many East Coast beach fills. For comparison, the average alongshore length of the 33 projects constructed in Florida in 1992 was about 6 km (Clarke, 1992).

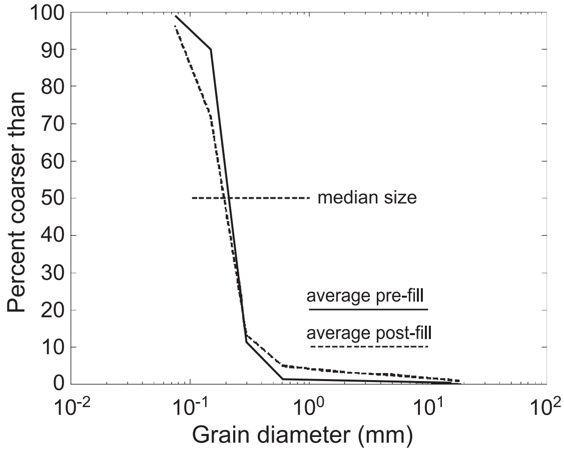

Fig. 3. Percent of sediment coarser than a size versus grain diameter.

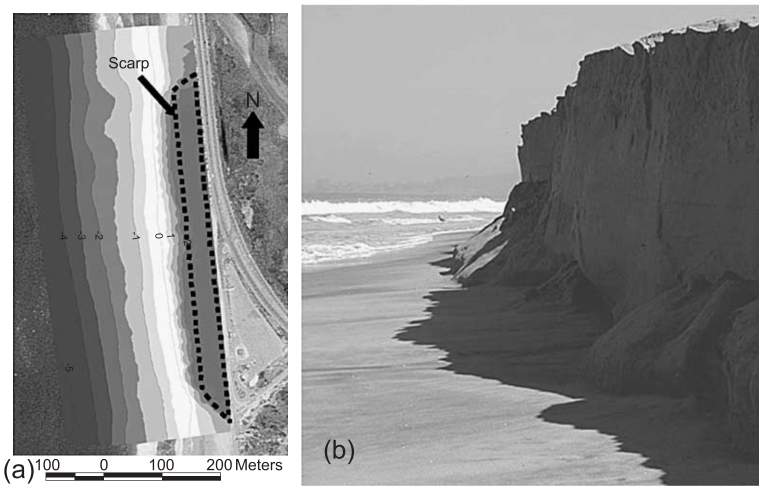

Fig. 2. (a) Configuration of the newly completed beach fill, 30 April 2001. Contours are depths relative to MSL. The elevated fill is indicated with a dashed curve. (b) Photograph of the seaward edge of the fill showing the 2-m high scarp.

2. Size distribution

The average size distributions of 27 surficial sand samples collected from 1 m above MSL to 4 m depth immediately prior to the nourishment were similar to distributions of the fill material (sampled at 24 locations within the fill). The median size is about 0.2 mm, with the fill material having a slightly broader size distribution (including about 5% coarse shell hash, Fig. 3). The fill material meets engineering standards as an acceptable source for this beach (Dean, 1974).

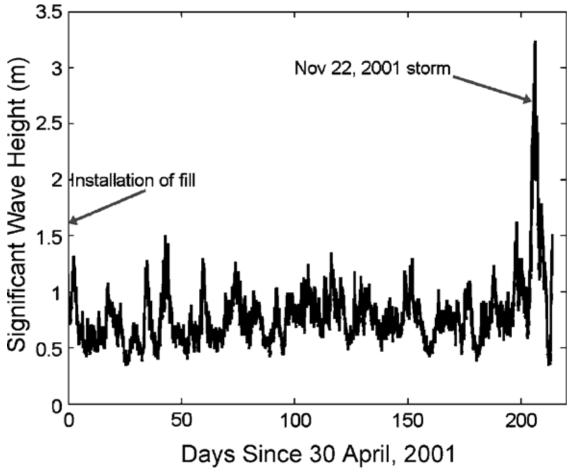

Fig. 5. Significant wave height at Torrey Pines Inner Buoy (20 m water depth) versus time.

3. Monitoring program

The fill and adjoining beach segments were surveyed with high resolution in space and time using Global Positioning System (GPS) surveying techniques. The shallowest portion of each cross-shore transect was surveyed during low tide with a GPS-equipped all-terrain vehicle (Fig. 4b) and a manually pushed cart (Fig. 4a) used in the swash zone and to cross the steep scarp face. Subaqueous surveys were conducted at high tide using a similar GPS system

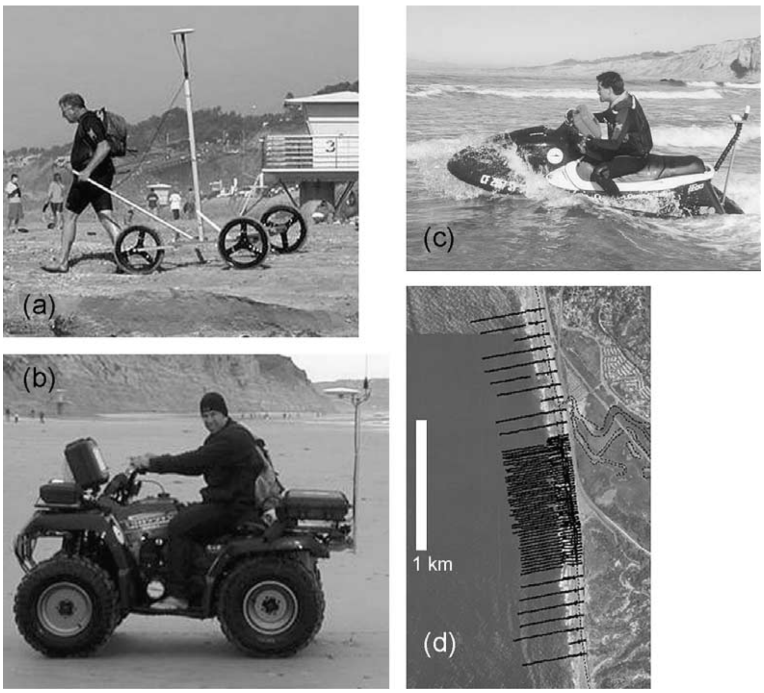

Fig. 4. GPS-equipped survey vehicles. (a) Cart, (b) all-terrain vehicle, (c) wave-runner and (d) typical survey vehicle tracks (black curves) superposed on an aerial photograph of the fill area and adjacent coastline.

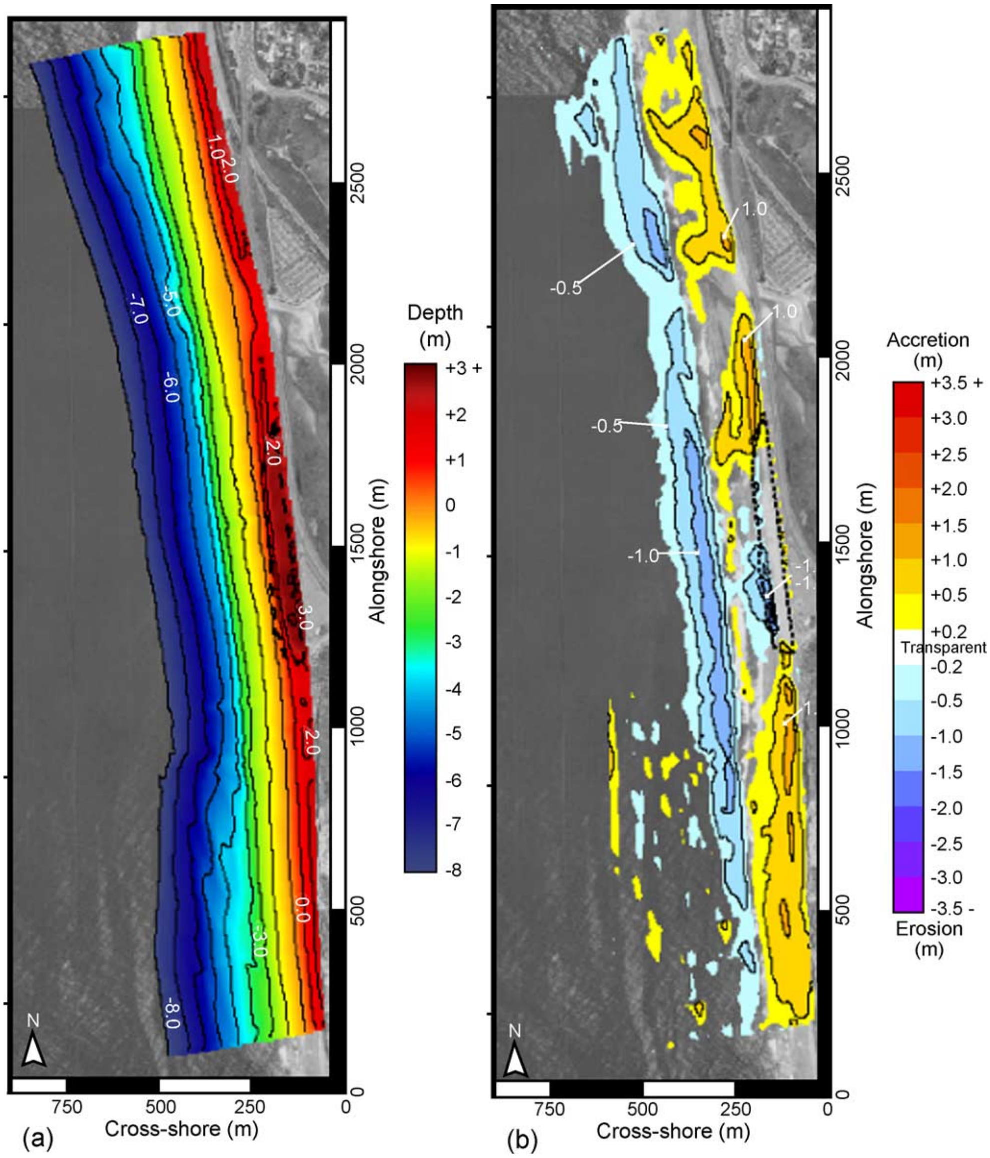

Fig. 6. (a) Bathymetry measured on 17 November 2001 along a 2700-m long strip centered on the initially nourished region (black dashed curves). Contours are depth in meters relative to MSL, and the contour interval is 1 m. (b) Changes in bathymetry between 27 April 2001 and 17 November 2001. The contour interval is 0.5 m. Changes less than 0.2 m are not shown. Color scales are to the right of each panel.

mounted on a wave-runner equipped with an acoustic depth sounder (Fig. 4c). To allow surveying of predetermined transect lines, the real-time position of the all-terrain vehicle and wave-runner were displayed on onboard screens. Approximately, biweekly surveys (depending on tide and wave conditions) were begun just prior to the fill construction in April 2001 and collected through the storm in November 2001, with less frequent surveys until March 2003. Approximately, shore normal (locally) transect lines were established at 20-m alongshore intervals for a 700-m long reach encompassing the fill and at 100-m alongshore intervals for 1000 m on either side of it (Fig. 4d). The 56 survey

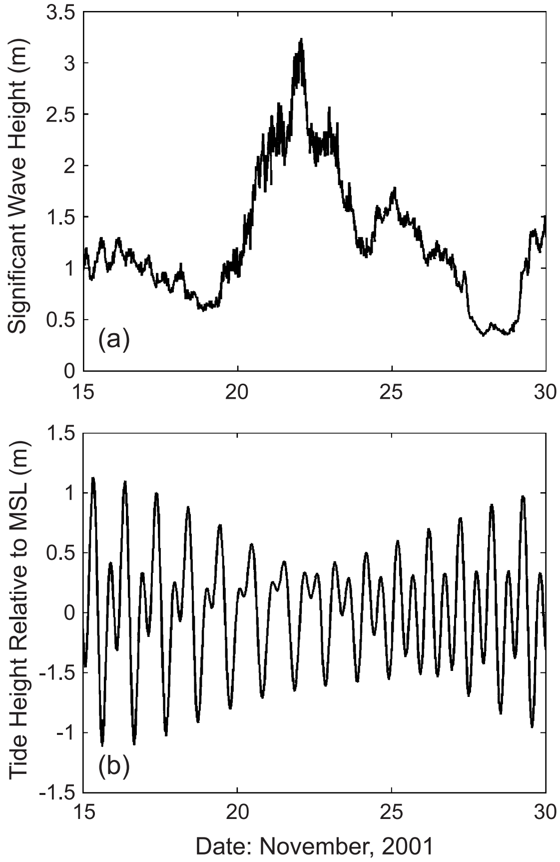

Fig. 7. (a) Significant wave height and (b) tidal elevation at Torrey Pines versus time.

transects extended seawards from the backing cliffs or revetment to about 8 m water depth.

Wave conditions were monitored with Datawell directional buoys located offshore of the nourishment location in 20 and 550 m water depths (Fig. 1). Tidal vertical ranges were about 1.0 (neap) and 2.5 m (spring) (e.g., Fig. 7b).

4. Prestorm performance of fill

During approximately 7 months following completion of the fill, the significant wave height seaward of the surf zone ranged between about 0.4 and 1.5 m and usually was less than 1 m (Fig. 5), typical for the summer–fall season. During this period, changes to the bathymetry adjacent to the fill area were consistent with the seasonal cycle in southern California (Aubrey, 1979), with as much as 1.3 m accretion above MSL and 1.3 m erosion between 2 to 5 m depth (Fig. 6). The accretion on the adjacent beach face reduced the superelevation of the fill. Water levels and wave energies were elevated sufficiently to wet the surface of the fill only once or twice, and the fill region was unchanged except for approximately 20 m shoreward retreat of the steep seawards-facing scarp of the fill near the southern end of the fill (where the blue contour overlies the dashed black curve in Fig. 6b). Alongshore transport, sometimes important to the evolution of fills with relatively short alongshore extent such as Torrey Pines (Dean and Yoo, 1992), did not affect the fill. The region directly offshore of the fill (2 to 5 m depths) eroded about 1 m, similar to the adjacent regions, but this sand was blocked from coming ashore by the fill so it moved either alongshore or offshore.

5. Erosion during the November storm

The incident wave significant wave height reached 2 m about 0700 (PST) on 21 November 2001, peaked at 3.2 m at about 1200 on 22 November and dropped below 2 m around 1400 on 23 November (Fig. 7a). At the height of the storm, the peak wave period was 16 s. Tides were neap (about 1 m range, Fig. 7b).

During this 3-day period, the fill and the adjacent beach face both eroded substantially. Erosion in the nourished region was not uniform alongshore. Visual observations indicate that, at high tide, wave uprushes overtopped the steep scarp and reached the relatively flat elevated fill. The water on top of the fill flowed alongshore to initially small depressions that channeled the flow seawards. The offshore flow rapidly deepened and widened the channels. By the peak of the storm (~1300 on 22 November), the shoreward end of the eroded channels had retreated almost to the highway revetment (Fig. 8a). Sand peninsulas, located between the channels, were elevated roughly 1.75 m above the surrounding beach and protruded seawards roughly 50 m from the highway revetment. The average alongshore spacing of the peninsulas was about 50 m. After the channels were well-developed, incoming waves rushed up the embayments, and the peninsulas eroded by slumping, both on the seaward face (Fig. 8b) and within the embayments. By the following day, the cross-shore extent of the peninsulas was reduced to about 25 m. Only small remnant peninsulas remained 1 week later, and the bathymetry was more uniform alongshore (Fig. 9a). Scarps and channels did not form in the adjacent unnourished regions. The maximum accretion (1.5 m relative to immediately before the storm, Fig. 9b) occurred offshore and just to the south of the original fill, consistent with transport of the fill material by waves (from the north) during the storm.

Along the 2.7-km long surveyed reach, about 391,000 m^3 of sand was eroded from the beach face, and about 308,000 m^3 was accreted offshore. The 20% volume deficit is equivalent to a 0.06-m thick sand layer distributed over the 2.5 km long by 0.5 km wide study area, roughly comparable to the survey accuracy.

6. Modeling the erosion

Given the prestorm bathymetry along a transect bisecting the fill area and driven with the observed waves, the U.S. Army Corps of Engineers numerical model SBEACH (Larson and Kraus, 1989) failed to predict the observed evolution of the beach. Although

Fig. 8. Photographs (looking south) at the storm peak (1300 PST, 22 November 2001) showing (a) erosion occurred as a series of embayments and (b) steep-faced scarps eroded by slumping (indicated with an arrow) that was visible during wave downwash.

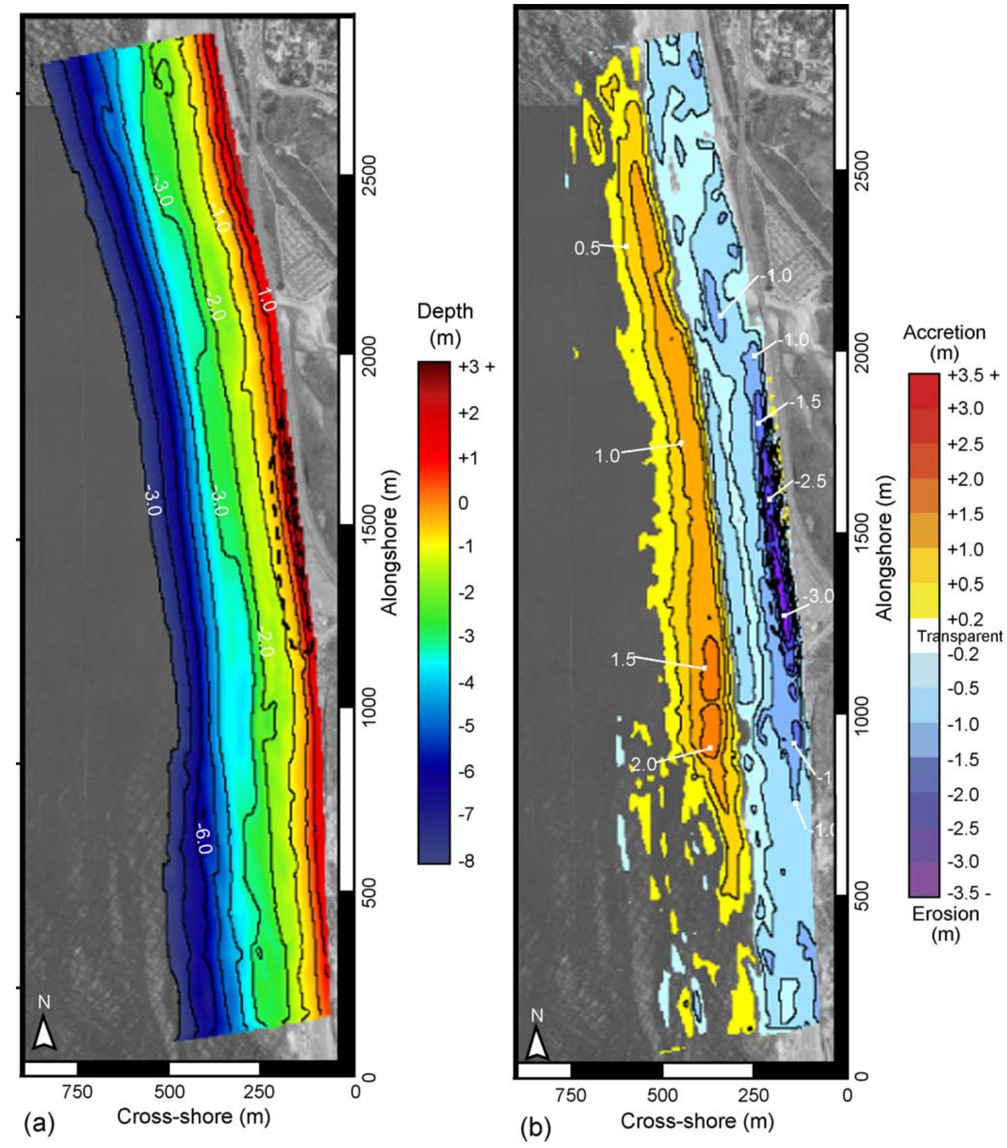

Fig. 9. (a) Bathymetry measured on 30 November 2001 (1 week after the storm) along a 2700-m long strip centered on the initially nourished region (black dashed curves). Contours are depth in meters relative to MSL, and the contour interval is 1 m. (b) Changes in bathymetry between 17 and 30 November 2001. Contour interval is 0.5 m. Format is similar to Fig. 6.

the adjustable parameters were tuned to force maximum erosion, erosion was severely underpredicted possibly because slumping of the steep-fronted scarps is not accounted for in SBEACH, which has been calibrated with smoother profiles. A research version of the Delft3D model also failed to predict the storm erosion of the beach nourishment (Reniers, 2002).

Although similar patterns of alongshore variable scarp erosion have been observed in some Florida nourishments (Bodge, 2002), other nourishments do not exhibit scarping nor alongshore variability. The conditions conducive to formation of scarps and quasi-periodic peninsulas are unknown. There was no obvious alongshore variation in fill porosity or size, and the fill was bulldozed into place similarly at all alongshore locations.

7. Conclusions

A 160,000 m^3 beach fill eroded during a storm with 3-m high waves. The erosion began when waves overtopped the scarp, reaching the flat top of the fill, and flowed alongshore to depressions that channeled water seawards. The offshore flow enlarged the depressions, which maintained steep vertical sides by slumping sediment, eventually forming peninsulas about 1.75 m higher than the neighboring beach. Over the next few days, the peninsulas eroded completely. Two models, SBEACH and a research version of Delft3D, failed to predict the observed erosion.

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