Title

Mitigation of Coastal Bluff Instability in San Diego County, California/Evaluating Seacliff Morphology and Erosion Control in San Diego County Using LIDAR and GIS

Author
Ashford, Scott

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California Seagrant Project # R/OE-37
P.I.: Scott A. Ashford
Trainee: Adam P. Young

Evaluating Seacliff Morphology and Erosion Control in San Diego County Using LIDAR and GIS

In order to evaluate seacliff erosion, morphology, and erosion control, this project applied new LIDAR (LIght Detection And Ranging) technologies and advanced geographic information systems (GIS) analysis. LIDAR is the newest and most accurate technology being used to map the coastline. Both aerial and ground-based LIDAR data were analyzed during this study. This project focused on the Oceanside Littoral Cell which extends from Dana Point at the northern end, to La Jolla at the south (Figure 1).

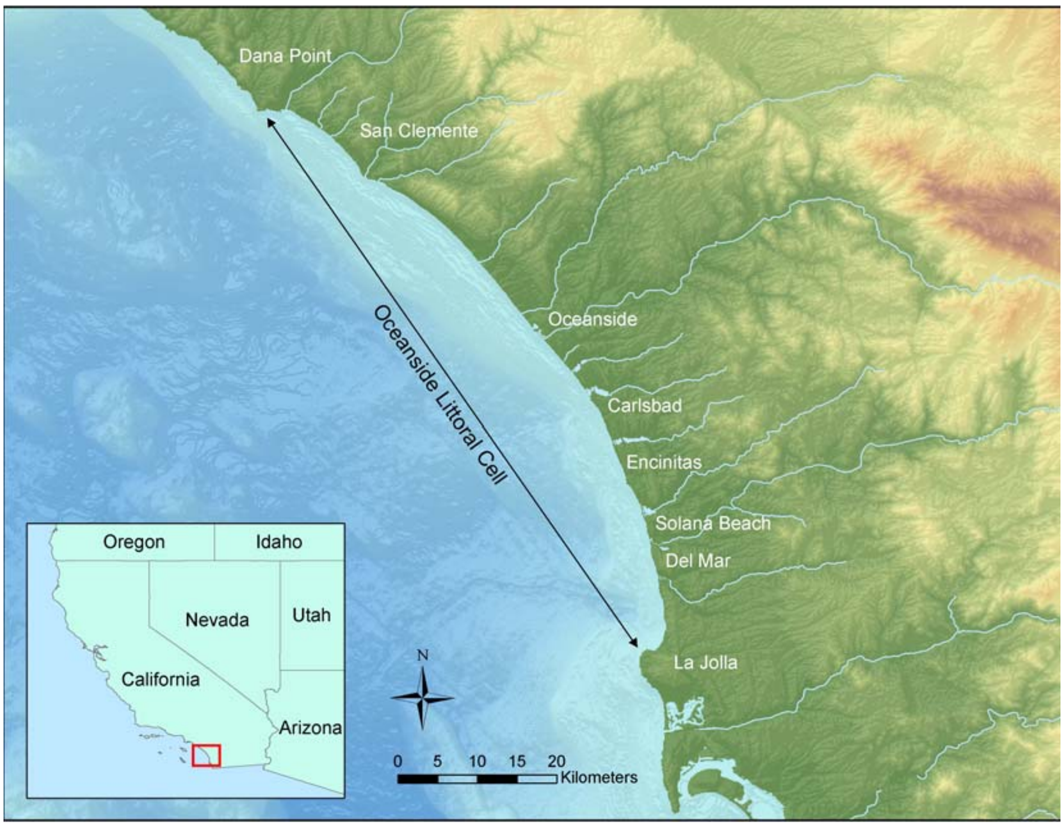

Figure 1. Study Location Map.

Aerial LIDAR

One phase of this project focused on aerial LIDAR. Two aerial LIDAR data sets were used to quantify the volumetric changes of the seacliffs from April 1998 to April 2004. The April 1998 data set was obtained from the NOAA's Coastal Services Center website (www.csc.noaa.gov). The April 2004 data set was provided by Southern California Beach Processes Study, operated by the Scripps Institution of Oceanography.

Both of these data sets were obtained in X, Y, Z format then gridded using an inverse distance weighting algorithm in ESRI ArcINFO software. The result of the gridding produced 0.5 meter resolution digital elevation models. These two grids were then subtracted from one another to produce a map that shows the change in elevation over the six year time period. Figure 2 shows a sample map of the elevation change that occurred in Solana Beach.

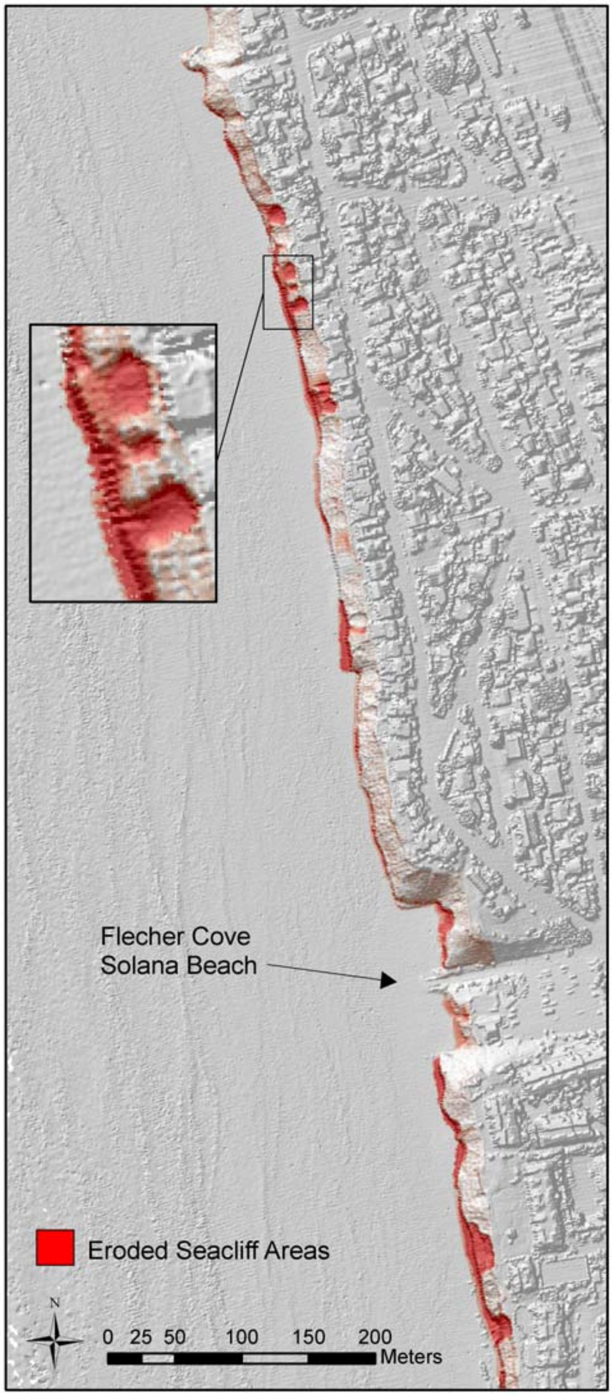

Figure 2. Areas of seacliff erosion in Solana Beach from April 1998 to April 2004.

The Oceanside Littoral Cell was divided into ten sections based on general stratigraphy and major river incisions for analysis. The eroded areas in each section were then summed to calculate a total eroded volume. The total eroded volumes were then reduced for amount of seacliff sediments that were large enough to be retained on the beach. Gullied areas in each section were identified and separated from the seacliffs so that individual analyses could be performed. Table 1 shows both the total eroded volume and volume reduced for beach sand content in each section.

Table 1. Summary of Average Annual Eroded Volumes

	Average Annual Volume of Totol Eroded Sediment		Average Annual Volume of Beach-Sand Content (Total Reduced for %LCD)	
Section Name	Gully (m^3/yr)	Seacliff (m^3/yr)	Gully (m^3/yr)	Seacliff (m^3/yr)
Torrey Pines	8,300	26,400	3,500	11,100
Del Mar	600	4,900	500	3,700
Solana Beach	0	8,300	0	6,200
Cardiff	0	5,800	0	4,600
Leucadia	0	5,900	0	4,700
Carlsbad	0	4,000	0	3,200
Camp Pendelton	7,600	5,500	4,100	2,900
San Onofre	16,700	57,100	11,900	40,500
Oceanside Littoral Cell*	33,200	117,900	20,000	76,900
San Clemente*	4,700	7,600	3,800	6,100
Dana Point*	0	4,500	0	3,600

* The total for the Oceanside Littoral Cells exlcudes the San Clemente and Dana Point sections

The linear rate of seacliff retreat was back calculated using the values in Table 1 and the following equation:

$R_l = V_{st} / (H_c * L_c * T)$

R_l = Linear rate of cliff face retreat
V_{st} = Total eroded volume from seacliffs
H_c = Average seacliff height
L_c = Length of seacliffs (including armored sections)
T = Time span

The results of these calculations for each section are summarized in Figure 3.

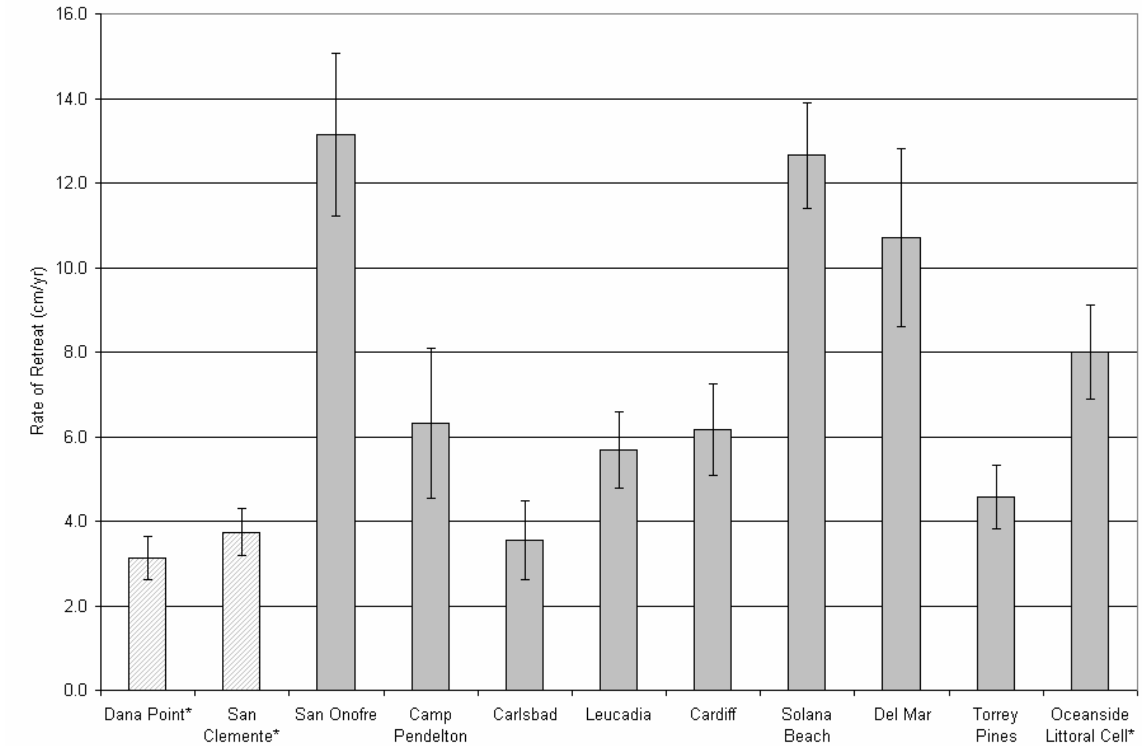

Figure 3. Summary of average annual seacliff retreat rates.

The volumetric rate of sand contribution to the beaches was calculated using the reduced eroded sediment volumes in Table 1 and the following equation:

$R_{vs} = (V_{st} * \%LCD) / (L_c * T)$

R_{vs} = Volumetric rate of sand contribution per length of seacliffs
V_{st} = Total eroded volume from seacliffs
%LCD = Percent of seacliff sediments with a diameter greater than the littoral cut-off diameter
L_c = Length of seacliffs (including armored sections)
T = Time span

The results of these calculations are summarized in Figure 4.

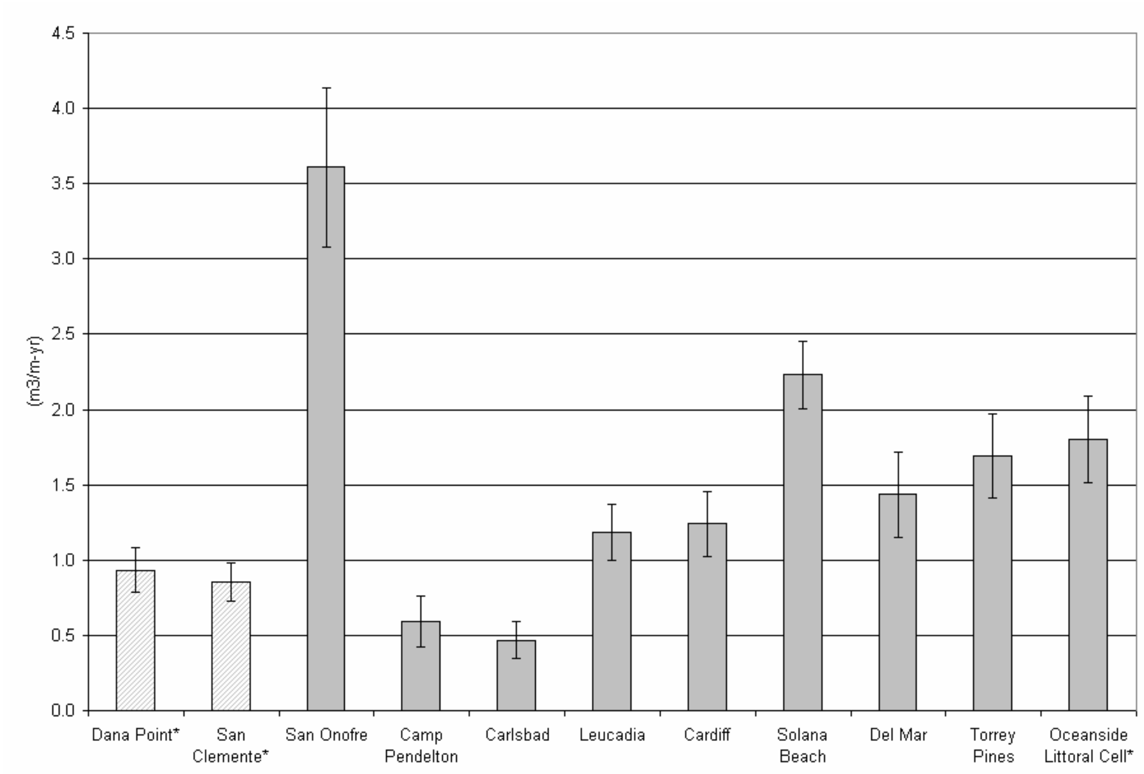

Figure 4. Summary of annual volumetric rates of sand contribution per length of seacliffs.

Based on the airborne LIDAR data, seacliffs and gullies yielded 76,900 m^3/yr and 20,000 m^3/yr of beach-sediment, respectively, during the study period (Table 1). The majority of the beach-sediment from both the seacliffs and gullies originated from the San Onofre section. The volumetric rate of beach-sediment yield per length of shoreline ranged from 0.47 (Carlsbad) to 3.61 (San Onofre) m^3/m-yr with a weighted average of 1.80 m^3/m-yr for the entire Oceanside Littoral Cell (Figure 4). Figure 5 shows that the linear rate of seacliff face retreat ranged from 3.1 to 13.2 cm/yr with a weighted average for the littoral cell of 8.0 cm/yr. The highest seacliff face retreat rates were found in the Del Mar, Solana Beach, and San Onofre sections, which were all greater than 10 cm/yr.

Ground-Based LIDAR

Ground-based LIDAR was collected semi-annually starting in the fall of 2003 along bluffs in the Cities of Encinitas, Solana Beach, and Del Mar. Ground-based LIDAR has very high resolution with centimeter level accuracy. The ground-based LIDAR was collected by mounting the LIDAR scanner on top of vehicle for mobility (Figure 5). This innovative setup permitted data collection to move at a pace of 1.5 km/hr.


Figure 5. Mobile ground-based LIDAR setup.

Because the ground-based LIDAR is collected perpendicular to the cliff face, the entire seacliff is captured, including over vertical topography like seacaves and notches. These formations are essential to evaluate the role of marine erosion at the base of the seacliff. Figure 6 shows an example of the complex geometric surfaces that can be modeled using the ground-based technique.

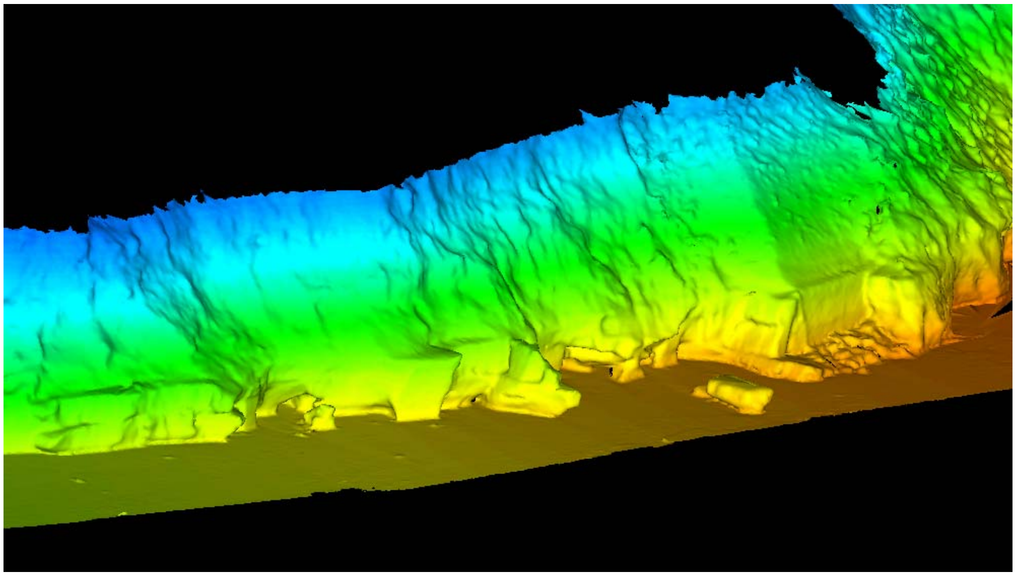
Figure 6. Ground-based surface modeling in Solana Beach.

Ground-based LIDAR can also be used to evaluate volumetric changes in the seacliffs as well as in depth analysis of cliff failures. Figure 7 shows a modeled cliff failure in Solana Beach that occurred on September 28, 2004.

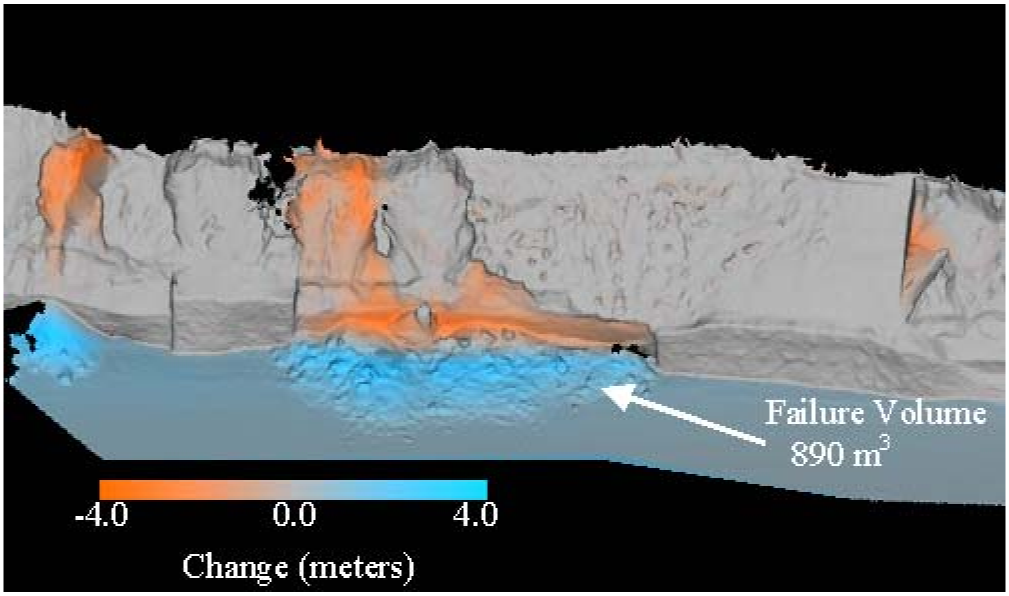

Figure 7. Major seacliff failure in Solana Beach.

Using the three dimensional failure surface highly accurate profiles can be extracted for detailed failure analysis. Figure 8 shows a typical profile through the failure area.

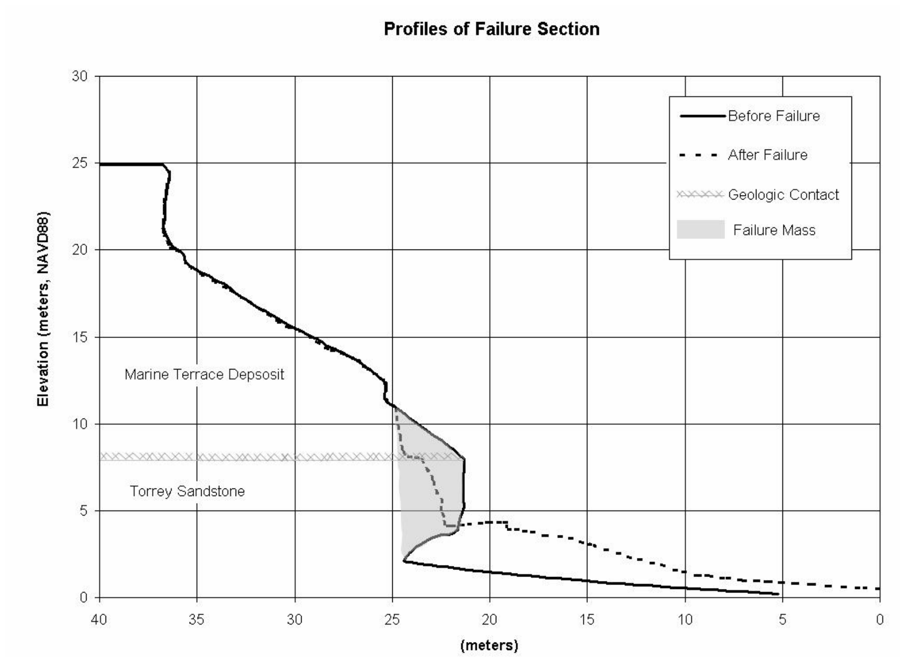

Figure 8. Before and after profiles of the Solana Beach cliff failure.

These profiles show a well developed notch of 2-3 meters deep at the base of the cliff formed by marine erosion processes. This failure occurred when the notch grew to a sufficient depth where the gravitational forces overcame the shear strength of the rock. This high detailed failure geometry can be used to develop eminent failure criteria and identify hazardous areas and future seacliff failures. The failure profiles can also be used in slope modeling software to evaluate the stresses within the seacliff prior to failure. An example of stress conditions in the seacliff under static loading is shown in Figure 9.

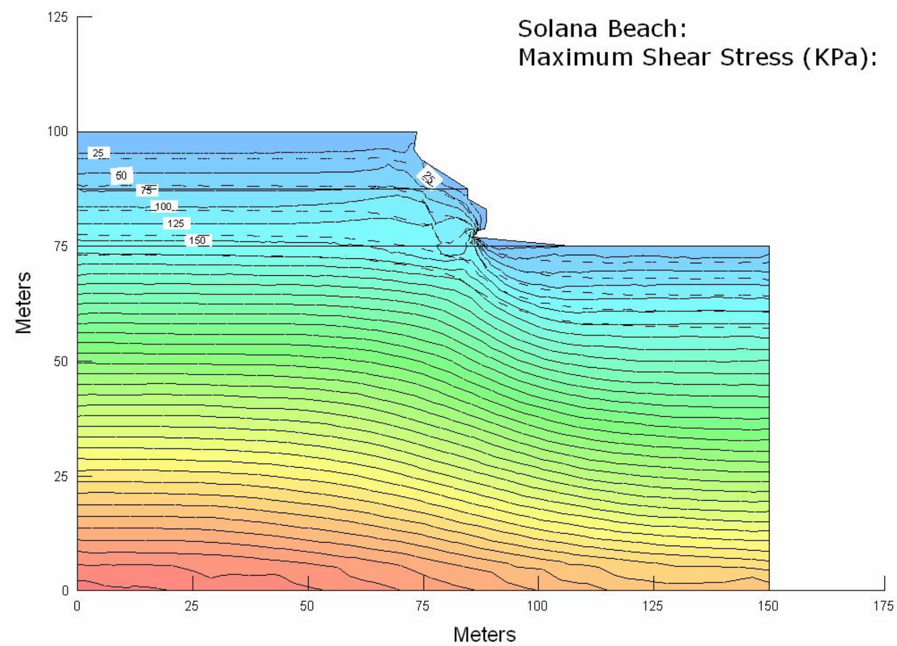

Figure 9. Theoretical shear stresses prior to the Solana Beach failure.

Slope modeling software can also be used to evaluate different types of erosion control methods and they affect the stress conditions within the seacliff. Figure 10 shows the stress distribution changes with the use of soldier piles and tie-backs.

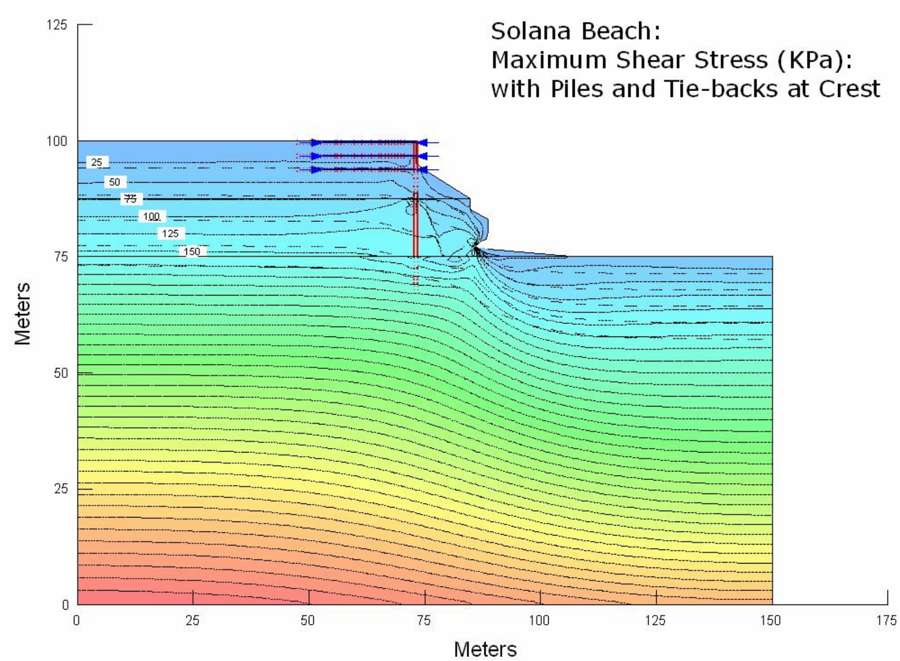

Figure 10. Theoretical stress distribution with erosion control measures.

Summary:

In summary, this project evaluated the applications of both aerial and ground-based LIDAR for use in seacliff morphology studies. Both types of LIDAR are applicable in solving different problems. Aerial LIDAR is superior for surveying large stretches of coastline, while ground-based LIDAR is more applicable to site specific in-depth failure analysis. Each technique provides new valuable insight into the coastal system and the problems associated with seacliff erosion. Current work is now underway to integrate these two types of data for a more complete understanding of coastal morphology. Figure 11 shows a preliminary example of merging the aerial and ground-based LIDAR surfaces. In the future, these surfaces could also merging bathymetric LIDAR and high resolution photography into a complete coastal model.

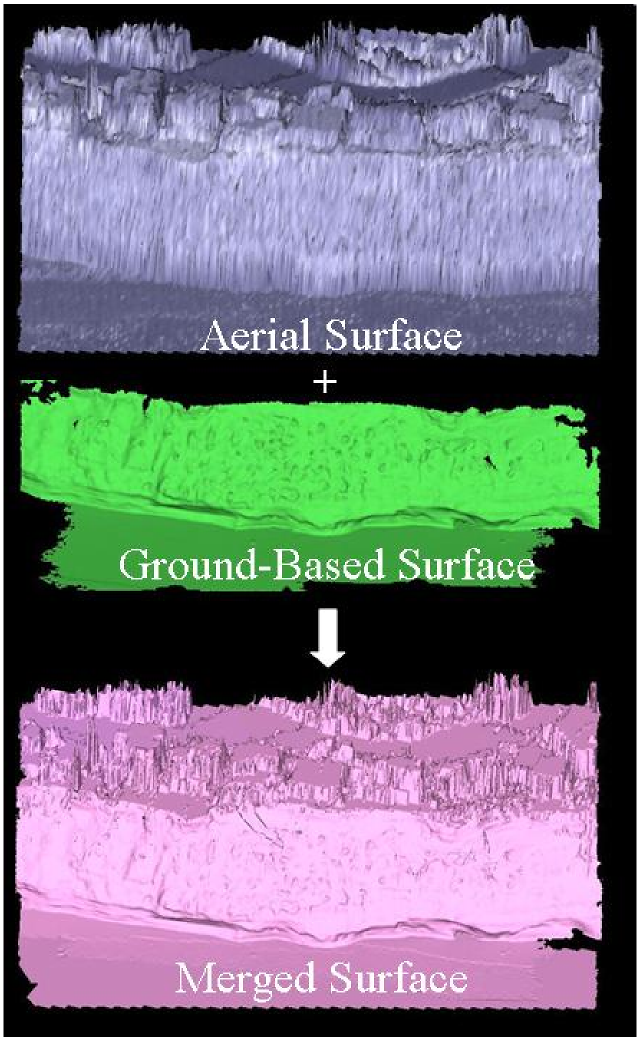

Figure 11. Merging aerial and ground-based LIDAR surfaces.