

Coastal Erosion Induced Landslide in South Orange County

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ABSTRACT

Coastal erosion and sea level rise have become common issues along the coast of Southern California not only from an environmental standpoint, but also from a geotechnical standpoint. This case study presents reactivation and partial movement of an ancient landslide along the Orange County coastline due to the significant loss of sand buttressing the landslide at the beach. The landslide reactivation resulted in tension cracks that extended through a community parking lot and several residential lots above the beach. A forensic geotechnical engineering investigation was performed to characterize the subsurface soils and groundwater conditions and to monitor the landslide movements using inclinometers, piezometers, and crack monitors.

This study indicated that a portion of the neighborhood was constructed over an ancient landslide which, until recently, was essentially buttressed by beach sand deposited along the toe of the landslide. Over the last several decades, the beach sand slowly eroded until the beach was almost completely gone following a high tide event in July of 2020. The removal of beach sand that buttressed the toe of the ancient landslide led to the reduction of the slope stability safety factor to less than 1.0 triggering reactivation of a portion of the landslide. The reactivation resulted in damage to the parking lot area, underground utilities, one empty residential lot and four homes at the head scarp of the reactivated portion of the landslide as well as compromising and deforming the railroad track near the landslide toe. The beach sand depletion was confirmed through our geologic modeling and slope analyses as the triggering method for the reactivation. Temporary stabilization measures were put into place consisting of adding approximately 17,400 tons of rip-rap along the west side of the railroad that served to add weight at the toe of the active portion of landslide. The temporary stabilization measures served to temporarily halt the movement, however, high tide events triggered by hurricane Kay resulted in additional beach sand loss and landslide movement. Several more rounds of rip-rap were added while permanent stabilization measures were being developed to satisfy the multiple stakeholders. As of July 2023, permanent stabilization measures have been completed.

This case study of coastal erosion induced landsliding in southern Orange County highlights both the need for sustainable designs and future mitigation measures as well as the geotechnical challenges as the coastline erodes due to sea level rise, urban sprawl, state mandated water quality measures reducing sediment transport to the ocean, and other manmade improvements that otherwise change/impede sand deposition along the coast.

INTRODUCTION

Coastal erosion and sea level rise have become common issues along the coast of Southern California not only from an environmental standpoint, but also from a geotechnical standpoint. This paper presents a case study of coastal erosion that resulted in the partial reactivation and movement of an ancient landslide along the Orange County coastline. The reactivated landslide resulted in the damage of several homes within the Cyprus Shore Community Association and the shutdown of critical railroad infrastructure for nearly 8 months. GMU – Engineers & Geologists (GMU) performed subsurface investigations, landslide movement monitoring, and slope stability analyses to determine the likely cause of the partial ancient landslide reactivation. Based on our investigation, monitoring, and analyses, we derived a geologic model that indicated beach sand erosion was a primary factor in the reactivation. Our geologic model was utilized in the stabilization measures implemented by Orange County Transit Authority (OCTA)/Metrolink.

SITE CONDITIONS

SITE HISTORY

The site is located within an area containing an ancient landslide as mapped in the reference (1) geologic map for the San Clemente Quadrangle. The landslide is discussed in more detail below.

The existing railroad alignment was constructed in its current location in the late 1800's and, prior to development of the Cyprus Shore Community Association to the east of the railroad tracks, the site was the location of the H.H. Cotton's thoroughbred horse farm. In a 1932 historic aerial photograph a pond is visible in approximately the same location as the existing community park area. The horse farm existed within and near the subject site until at least 1960. In 1961, a grading plan was drafted to convert a portion of the southern side of the horse farm into the Cyprus Shore development. The grading for the development consisted of placing fill on top of the aforementioned ancient landslide to raise the elevations within the area.

EXISTING SITE CONDITIONS

The active landslide addressed in this case study is approximately 800 feet long as measured along the coast, and encompasses the Cyprus Shore Community Association common property, several private residential homes, and the railroad track below and to the west of the community. Existing improvements within the common area portion of the site consist of the community clubhouse, clubhouse parking lot, public restrooms, a paved beach access road, a community park with pond, a view deck over an operations and supply storage room, and City owned and maintained underground sewer lift station and associated utility house. To the south of the common area within the limits of the reactivated portion of landslide are one undeveloped single-family lot (4002 Calle Ariana) and five single-family residential lots with single-family homes and associated improvements (4004, 4006, 4008, and 4010 Calle Ariana). See Figure 1 – Geotechnical Map.

Site Cracking

GMU made an initial site visit on October 28, 2020, to observe cracking reported in the parking lot area of the Cyprus Shore Community Association clubhouse. At the time of the initial visit, the

cracking was observed to extend from the northern side of the parking lot and extended southward through the parking lot area and through the adjacent lots at 4002, 4004, and 4006 Calle Ariana. In addition, areas of the concrete curb along the paved beach access road appeared to be pulling away near the public restroom building. Generally, this cracking trended in a roughly north/south line about parallel with the top of the slope (i.e., parallel with the coastline). Cracking is shown on Figure 1.

GMU continued to monitor the cracks from October 2020 to July 2023 and observed the cracking progressively growing in width and length at a slow rate coinciding with an increase in landslide movement and limits. By the completion of the stabilization measures in July of 2023, cracking had expanded to the east, south and north. The observed cracking ranged from minor cracks at the southern end of the landslide with less than an inch of separation near residences 4010 and 4008 Calle Ariana and increased to the north with open cracks and down dropping within the vacant lot at 4002 Calle Ariana and the clubhouse parking lot area of up to about 2 feet. In addition, the residences at 4004 and 4006 Calle Ariana had significant damage to the homes and were red tagged. Further to the east, cracking was observed in Calle Ariana above (i.e., east of) the park area and within houses adjacent to the park at 3912 and 3910 Calle Ariana and 308 Avenida de las Palmera. This cracking has been observed to have up to about 1 inch separation and some down dropping of up to about two inches.

Beach Erosion

It is our understanding, based on conversations with the community's representatives as well as City representatives, that the beach area immediately west of the cracking and landslide was significantly eroded following a King Tide event in July of 2020. Based on field observations, historical aerial review, and comparison of topographic maps obtained from the County of Orange, the beach appears to have lost upwards of 15 to 20 vertical feet of sand just west of the railroad tracks resulting in the loss of an approximately 115-foot-wide beach when compared to the 1950 assessor high tide map. The beach loss appears to be gradual over the last couple of decades with fluctuations in the width of the beach to the west of the Cyprus Shore Community Association (i.e., periods of sand erosion and periods of sand deposition). However, sand erosion has increasingly dominated, and almost complete loss of the beach adjacent to the railroad tracks occurred during the King Tide event of 2020. Figure 2 shows a comparison of high tide marks as well as select aerial photos.

GEOLOGIC CONDITIONS

REGIONAL GEOLOGIC SETTING

The site is underlain by an existing ancient landslide within native marine terrace materials and bedrock of the Capistrano Formation. This landslide consisted of a depressed bowl-shaped feature as seen in old topographic maps and historic aerial photographs. During the original grading of the community in the 1960's, fill was placed on top of the ancient landslide, without any recorded landslide stabilization measures, to raise the elevations and create the existing pads, streets, and slopes.

GEOLOGIC MATERIALS

The site below the Cyprus Shore Community Association is currently underlain by up to about 35 feet of previously placed artificial fill materials, overlying various depths of landslide materials derived from native terrace deposits and bedrock. The toe of the slide below the railroad tracks and to the west of the tracks is overlain by terrace deposits and beach sand deposits. The landslide materials are overlying moderately hard to hard, unoxidized, massive siltstone and claystone bedrock materials of the Capistrano Formation (See Figure 3 – Geotechnical Cross Section).

GEOLOGIC STRUCTURE

The failure surface of the reactivated portion of the landslide was observed during our subsurface investigation to be a continuous, thin, planar clay seam that dips about 5 degrees in a southwesterly direction (i.e., towards the coastline). This is generally consistent with regional geologic mapping as shown on the reference (1) published geologic map.

Geologic structure within the landslide materials is characterized by fracture and shear zones steeply dipping about 37 to 59 degrees in a southwesterly direction. Where encountered in our bucket auger drill hole, this zone was observed to be highly sheared with some sub-vertical fractures, clay along the shears, and seepage. Where observed, the bedrock materials below the ancient landslide are massive siltstone and claystone bedrock with no discernable bedding.

GROUNDWATER

Groundwater is present within the site and was encountered during our subsurface investigations. In order to determine a best fit groundwater model for our geotechnical analyses, eight of the inclinometers installed by GMU were converted to standpipe piezometers. In addition, two grout-in-place vibrating wire piezometers were installed within one of the inclinometers at depths of 15 feet Below Ground Surface (BGS) and 25 feet BGS. The groundwater was monitored on a regular basis starting in February 2021 and has continued as of the date of this case study where the inclinometers are still functional (i.e., not sheared off). The groundwater monitoring showed a static groundwater level with no significant upwards or downwards gradients. This generally indicates a static groundwater table within the landslide area. The groundwater table also appears to be controlled by sea level and is consistent across the area being monitored. The exception to this is groundwater below the park area, which is also highly influenced by rainfall. The groundwater level utilized in our geotechnical analyses is shown on our Geologic Cross Section shown in Figure 3.

SUBSURFACE INVESTIGATION

GMU performed subsurface investigations within the site in order to determine the extent and depth of the landslide, observe existing subsurface conditions, and collect samples for laboratory testing. Our investigations consisted of one (1) bucket auger boring, seven (7) hollow stem auger borings, and four (4) solid flight auger borings. The locations of the subsurface investigations are shown on the attached Figure 1 – Geotechnical Map.

Previous investigations by others have been performed for individual homeowners within the Cyprus Shore Community Association. Select previous borings are included on our Figure 1 – Geotechnical Map where the data was utilized in preparing our geologic model.

INCLINOMETER INSTALLATION

Inclinometers were installed within our hollow stem auger drill holes and solid flight auger drill holes for a total of eleven (11) inclinometers. Our inclinometer installation occurred in several stages based on observations and landslide movement. In addition, inclinometers were installed at the railroad tracks by Metrolink/OCTA geotechnical consultants. This data was shared with GMU and was utilized to confirm our geologic model.

LANDSLIDE

Ancient Landslide

The ancient landslide within the Cyprus Shore Community Association is evident by pre-development topography and confirmed during our subsurface investigation. The ancient landslide most likely originally occurred over 11,000 years ago during times of relatively high precipitation and lower sea levels. Similar landslides are a common occurrence within the Capistrano Formation bedrock in the San Clemente area.

The ancient landslide consists of a depressed bowl-shaped feature that now underlies the railroad track, Cyprus Shore Community Association park, pond, clubhouse, and clubhouse parking lot, as well as portions of residential streets, and all or portions of approximately 18 residential lots. The ancient landslide was composed of multiple arcuate back scarps up to about 35 feet high with a graben forming the existing park and pond area. The base of the ancient landslide is at about sea level (i.e., 0 MSL elevation) along the toe and extends easterly below the railroad at an angle of about 5 degrees with a relatively steep back scarp. The approximate limits of the ancient landslide are shown on the Figure 1 – Geotechnical Map.

Available online historic aerial photos dating back to 1932 were reviewed for the subject area. The available aerial photos did not exhibit evidence of any major movement within the ancient landslide since at least 1932. However, some surficial and localized failures can be observed in historic aerial photographs prior to development of the Cyprus Shore Community Association.

Based on our document review, there have been reports of distress to homes within the area of the ancient landslide within the past. However, this distress was attributed to fill settlement. To the best of our knowledge, there have not been any reports of deep-seated landslide movement within the Cyprus Shore Community Association with lateral displacement prior to the reactivation of a portion of the ancient landslide as reported in October of 2020.

Recent Reactivated Portion of Ancient Landslide (Active Landslide)

Cracking within the Cyprus Shore Community Association originally reported in October of 2020 is associated with the reactivation of a portion of the ancient landslide extending from

approximately 200 feet north of the community's public restroom to about 4010 Calle Ariana. As discussed in more detail below, GMU inclinometer data confirmed the landslide movement was occurring at a depth of about 0 to 6 MSL with the toe of the failure at the coastal interface where beach erosion and wave action is occurring. The limits of the initial reactivation are shown on Figure 1 – Geotechnical Map and Figure 3 – Cross Section.

As the landslide movement progressed, the active portion of landslide expanded to the east and to the north encompassing the park area, portions of Calle Ariana, and portions of Avenida de las Palmeras. The expansion of the landslide is consistent with our geologic model and predictions made by our slope stability analyses. The limits of the secondary reactivation are shown on Figure 1 – Geotechnical Map and Figure 3 – Cross Section.

Slope Inclinometer and Slope Movement

Eleven slope inclinometers were installed within the subject site to monitor slope movement and to help determine the reactivated landslide geometry. The locations of GMU's slope inclinometers are shown on the Figure 3 Geotechnical Map and the following Table 1 summarizes movement location as of the date of this case study. In addition, the slope inclinometers are continuing to be monitored as of the date of this case study.

Table 1 – Slope Inclinometer Movement Location

Slope Inclinometer Number	Date of First Reading	Depth of Movement (Feet BGS)	Elevation of Movement (MSL)
SI-1 (20-330-00) ⁽¹⁾	11/10/2020	24	31
SI-1 (20-330-00) ⁽¹⁾	11/10/2020	50-52	3 to 5
SI-2 (20-330-00)	11/10/2020	48-50	8 to 10
SI-3 (20-330-00) ⁽²⁾	2/17/2021	26-30	2 to -2
SI-4 (20-330-00) ⁽³⁾	2/17/2021	24-26	4 to 6
SI-5 (20-330-00) ⁽⁴⁾	10/19/2021	40	20
SI-6 (20-330-00)	5/9/2022	32	29
SI-7 (20-330-00) ⁽⁵⁾	10/27/2022	--	--
SI-8 (20-330-00)	10/27/2022	32	28
SI-9 (20-330-00) ⁽⁶⁾	10/27/2022	30	13
SI-1 (21-119-00) ⁽⁷⁾	6/15/2021	52-48	5
SI-1 (21-116-00)	6/15/2021	16	40

Notes: (1) Inclinometer sheared off as of September 13, 2021; (2) Inclinometer sheared off as of September 20, 2021; (3) Inclinometer sheared off as of September 8, 2021; (4) Inclinometer being monitored with in-place equipment owned and maintained by Metrolink; (5) Inclinometer installed to monitor for future sewer improvements, does not penetrate the landslide; (6) Inclinometer experienced settlement; (7) Inclinometer last read September 14, 2021

Based on the results of our inclinometer monitoring, the reactivated failure plane, noted as movement within the inclinometers, is at an elevation of about 0 to 6 feet MSL near the toe of the

landslide and moves upward easterly towards the back scarp at about the angle of the observed failure surface in our bucket auger boring (i.e., about 5 degrees).

The movement observed at about 24 feet BGS within SI-1 (20-330-00) was the original backscarp of the initial reactivated portion of the ancient landslide prior to the expansion of the landslide limits. This movement was occurring along the sheared zone observed in our bucket auger boring. The movement observed at about 16 feet within SI-1 (21-116-00) is at the southern backscarp of the landslide.

STABILITY ANALYSES

STABILITY MODEL

Slope stability analyses were performed utilizing Slope/W utilizing the Morgenstern & Price stability method on select cross sections through the active landslide. Our geologic and groundwater model is based on data obtained during our subsurface investigation as well as review of historic aerial photographs and available documents. For the purpose of this case study discussion, we are utilizing our Cross Section 1-1' as a representative section. Section 1-1' is shown in Figure 3.

Groundwater

As previously discussed, a static groundwater level was interpreted and shown on the Figure 3 – Geotechnical Cross Section 1-1'. The level shown on the section was modeled in the stability analyses.

Shear Strength Model

Shear strengths used for our stability analyses are based on: 1) laboratory testing performed on undisturbed and remolded samples obtained during our recent site exploration, and 2) shear strength data in the vicinity of the site from similar geologic materials. The following Table 2 presents the design shear strengths used in our analyses.

Table 2 – GMU Shear Strength Parameters

Geologic Material	Phi (degrees)	Cohesion (psf)	Strain Conditions
Artificial Fill (Qaf)	28	260	Ultimate
Beach Sand	30	0	Peak/Ult.
Terrace Deposits involved in Landslide (Qls - Qtr)	29	175	Ultimate
Terrace Deposits (Qtr)	29	175	Ultimate
Bedrock involved in Landslide (Qls - Tc)	25	230	Ultimate
Recent Landslide Plane (Clay Seam)	16	0	Residual (Stark et al. 2013)
Continuous Jointing in Landslide Materials (Joint)	29	0	FS
Capistrano Formation (Tc)	21	1,420	Peak

* FS= Fully Softened

STATIC STABILITY MODEL VERIFICATION

A static stability analysis was performed using: 1) the above discussed shear strength parameters and static groundwater table, 2) landslide boundaries determined from the slope inclinometer readings and ground cracking, etc., and 3) existing beach sand conditions at the toe. Our stability analysis indicated a safety factor of 1.0 and verified that the shear strengths used in our slope stability analysis are representative of site conditions.

TEMPORARY STABILIZATION ANALYSES

In September of 2021, the landslide movement began to increase following additional King Tide events that removed additional sand from the beach along the toe of the active landslide. During this time, the initial active landslide began moving rapidly resulting in the down dropping of the parking lot area and the shearing off of four of the inclinometers. GMU performed temporary stability calculations to determine several potential temporary stabilization measures. One potential temporary stabilization measure consisted of rip-rap being placed at the toe of the landslide on the west side of the railroad tracks to add weight to the toe of the landslide in order to temporarily slow or stop the landslide movement. The results of our temporary stability analyses are shown in Figure 4 and indicated that rip-rap placed at the toe would raise the safety factor to 1.2. This recommendation was reviewed by the railroad's Geotechnical Consultants and was implemented as discussed below. An aerial photo showing the rip-rap placed is included in Figure 2.

FAILURE CAUSATION ANALYSES

Historical air photo analyses indicated that upwards of 15 to 20 feet of beach sand had been eroded from the toe of the ancient landslide resulting in the loss of up to a 115-foot-wide sand beach. To evaluate the effect of beach sand erosion on the subject landslide reactivation, beach sand was modeled in the analyses. Modeling beach sand back into the analyses (i.e., placing upwards of 15 to 20 feet of beach sand back) indicates static safety factors of approximately 1.8, providing a stable condition. Erosion of the beach sand resulted in a reduction of the static safety factor to 1.0 for the reactivated landslide. This indicates that the beach sand had buttressed the slope, and had it been in place at the toe of the ancient landslide, the reactivated landslide would have been stable. Conversely, the erosion of the beach sand led to the current landslide. These analyses also indicate that our model adequately predicts the observed failure mechanism. In addition, our analysis predicted that the active landslide could expand should enough movement occur, which was verified by additional movement as observed in our inclinometers and field observations. The results of our active landslide analyses for cross section 1-1' are shown in Figure 5.

STABILIZATION

CHALLENGES

This case study was met with several struggles beyond the geotechnical challenges to stabilize a landslide along the coast in order to save existing infrastructure. Some of the other challenges included multiple parties being impacted, constraints due to its location, and multiple jurisdictional

agencies. However, the biggest hurdle to overcome on this project was California Coastal Commission (CCC) regulations. Due to CCC strict regulations about what is considered an “existing structure” as well as the verbiage included in Coastal Development permits, the CCC would not allow the homeowners and the Cyprus Shore Community Association to stabilize the landslide under an emergency stabilization measure. Furthermore, the CCC would not approve the placement of the rip-rap as an emergency stabilization measure. However, since the loss of beach meant the railroad track was bordered by water, and not beach, this area now fell under the jurisdiction of the Army Corp of Engineers, who approved the temporary stabilization. This hurdle would require other entities (i.e., OCTA/Metrolink) to take the lead role in stabilization of the landslide.

TEMPORARY STABILIZATION MEASURES

In September of 2021, the landslide movement began to accelerate following another King Tide event, which resulted in more beach sand erosion, and emergency temporary stabilization measures needed to be implemented to prevent catastrophic failure of the slope. Based on the results of our geotechnical studies, it was determined that the landslide triggering mechanism was the removal of the beach sand that was buttressing the toe of the landslide. In order to slow down the movement, adding weight back to the toe was the best short term option.

OCTA/Metrolink began the placement of approximately 12,000 tons of rip-rap in September 2021. The rip-rap placement temporarily stopped the landslide movement. Temporary stabilization measures were again implemented to slow the landslide movement in December 2021 after another King Tide event and in September of 2022 after Hurricane Kay. Adding rip-rap to the toe of the landslide (i.e., west of the existing railroad tracks) within the area where sand was previously eroded resulted in the slowing of landslide movement as shown in Figure 6. This further supports our failure causation model indicating that erosion of the beach sand led to the current landslide.

PERMANENT STABILIZATION MEASURES

Permanent stabilization measures were implemented by OCTA/Metrolink starting in November of 2022. The stabilization is based on our geologic model and results of our testing, monitoring, and analyses and was designed by OCTA/Metrolink Geotechnical Engineers of Record. The permanent stabilization consisted of the installation of 220 tie-back anchors with total lengths of about 133 feet (93 feet unbonded and about 40 feet bonded). The tie-backs were installed in two rows with tie-backs in each row connected by a grade beam. The tie-back stabilization was considered a suitable solution as it would: 1) serve to stabilize the active portion of landslide while causing minimal disruption to homeowners, 2) not result in any loss of use of private and community property, and 3) be completely buried upon completion to keep the aesthetics of the coastline. As of the date of this case study, the permanent stabilization has been completed and the slope inclinometers indicate little to no movement.

CONCLUSIONS

In 2020, cracking appeared along the top of a manufactured fill slope in the Cyprus Shore Community Association. This cracking was associated with the reactivation of a portion of an

ancient landslide that underlies a portion of the community. It was hypothesized that the landslide reactivation was due to the erosion of beach sand that buttressed the toe of the landslide. This hypothesis was confirmed both by our slope stability analysis as well as the temporary halting of the landslide movement by the placement of rip-rap along the toe of the slope west of the railroad tracks.

This case study has implications for the future of the California coastline as it relates to beach erosion, sand replenishment, and development. It highlights both the need for sustainable designs and future mitigation measures as well as the geotechnical challenges as the coastline is eroded due to sea level rise, urban sprawl reducing sediment transport to the ocean, and other manmade improvements that otherwise change/impede sand deposition along the coast. In addition, it highlights the need for reform to coastline rules and regulations in order to address erosion and protection of existing infrastructure.

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- William A. Ayer, Grading Plan for Tract No. 4202, "Cyprus Shore", San Clemente, California, dated August 1961.
- Select Historic Aerial Photographs: UCSB Library FrameFinder
Select Historic Aerial Photographs: Nearmap

GEOTECHNICAL LEGEND

Qlsr	RECENT ACTIVE LANDSLIDE MATERIALS
Qaf	ARTIFICIAL FILL
Qls	ANCIENT LANDSLIDE MATERIALS, CIRCLED WHERE BURIED
DH-3 (20-330-10)	BUCKET AUGER BORING BY GMU GEOTECHNICAL, INC.
DH-10 SI-9 (60-010-00)	HOLLOW STEM AUGER BORING AND SLOPE INCLOINOMETER BY GMU GEOTECHNICAL, INC.
B-4 (1-5-2)	BUCKET AUGER BORING BY JOHN A. SAYERS * ASSOCIATES.
B-2 (5-2)	HOLLOW STEM AUGER BORING BY EARTH LOGICS CONSULTANT GROUP.
B-2 (1 * A)	HAND AUGER BORING BY PETER & ASSOCIATES.
B-2 (1 * A)	SOLID FLIGHT AUGER BORING BY PETER & ASSOCIATES.
B-1 (1 * A)	BUCKET AUGER BORING BY PETER AND ASSOCIATES.
	CRACKING AND/OR SEPARATION
	ORIGINAL GRADING DESIGN CUT/FILL LINE
	LIMITS OF ANCIENT SLIDE BASED ON ORIGINAL TOPOGRAPHY
	LIMITS OF ACTIVE SLIDE
	LIMITS OF SECONDARY ACTIVE SLIDE
	GEOTECHNICAL CROSS SECTION

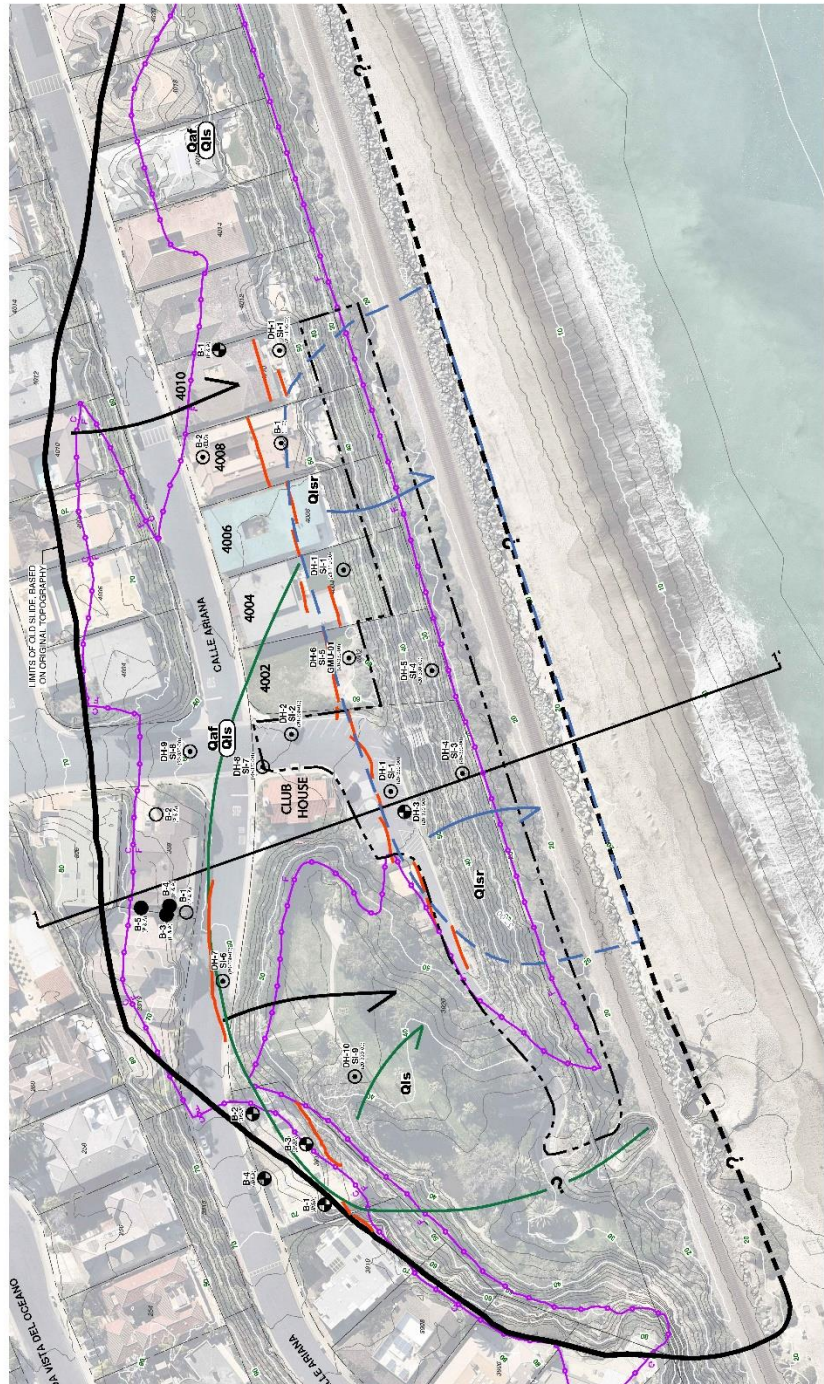


Figure 1. Geotechnical Map



Figure 2a. September 2020

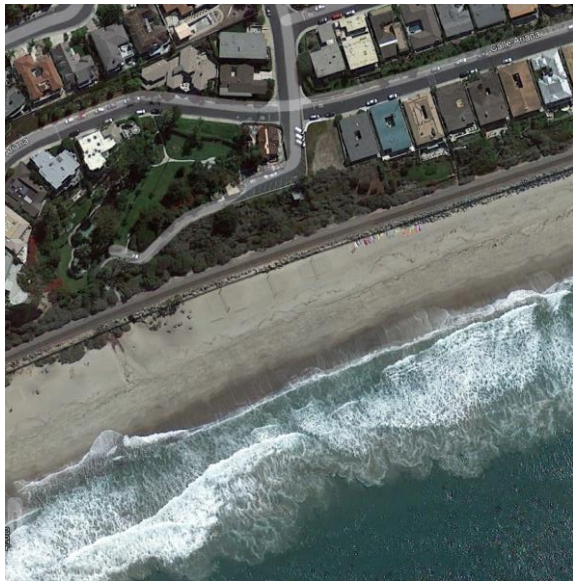


Figure 2b. April 2013

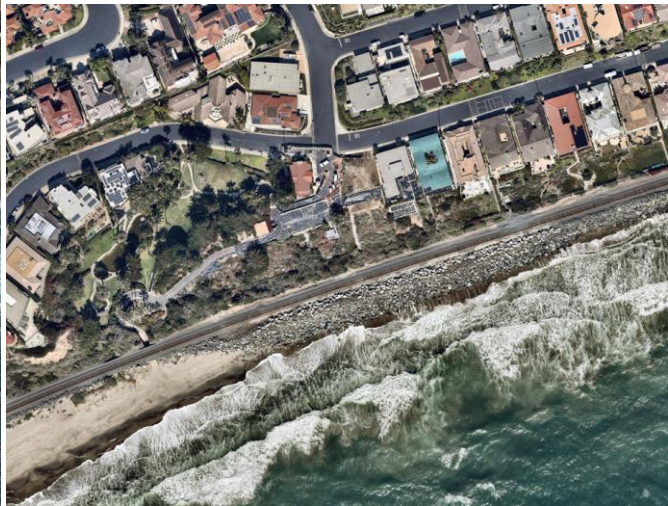


Figure 2c. May 2022

Figure 2. Aerial photograph comparisons a) high tide lines overlain on September 2020 aerial photograph, b) Google Earth imagery dated April 2013 showing an approximately 150 foot wide beach area to the west of the tracks, c) Aerial photograph taken May 2022 showing a section of recently placed rip-rap on the western side of the railroad track.

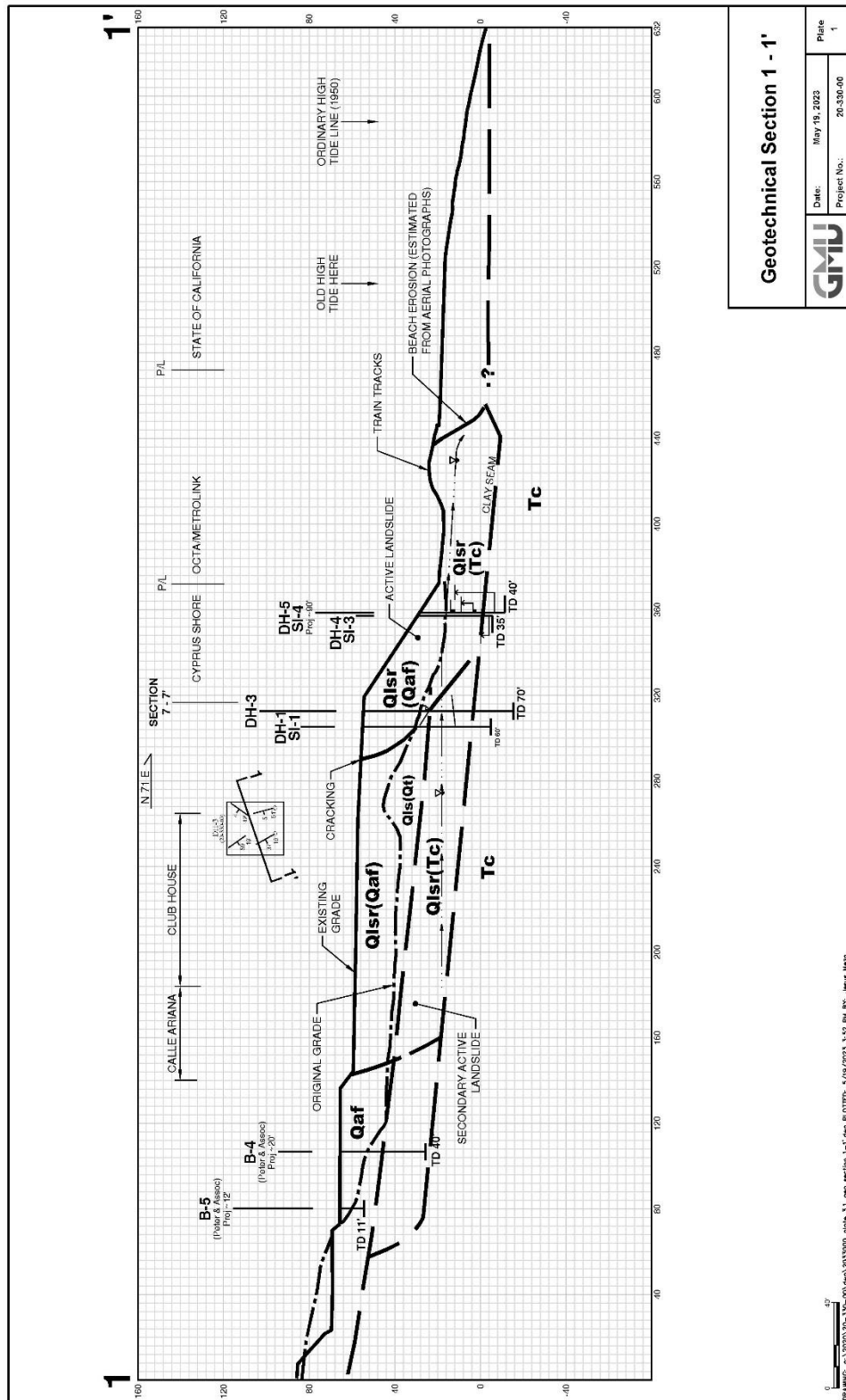


Figure 3. Select Geotechnical Cross Section

Project No. 20-330-00
Section 1-1'
August 2021

Adding Rip-rap to Beach Side of the Tracks

Temporary Analysis, Run 7.0
Horz Seismic Coef.: 0
Slip Surface Option: Fully-Specified
Recent Landslide Failure Surface
Rip-rap = 245 sq. ft.

Color	Name	Model	Unit Weight (pcf)	Cohesion (psf)	Phi (°)
Red	Clay Seam	Mohr-Coulomb	115	0	16
Pink	Joint	Mohr-Coulomb	120	0	29
Green	Qaf	Mohr-Coulomb	120	260	28
Orange	Qls (Qtr)	Mohr-Coulomb	120	175	29
Yellow	Qls (Tc)	Mohr-Coulomb	120	230	25
Light Orange	Qtr	Mohr-Coulomb	120	175	29
Grey	Rip rap	Mohr-Coulomb	150	0	50
Brown	Tc	Mohr-Coulomb	125	320	21

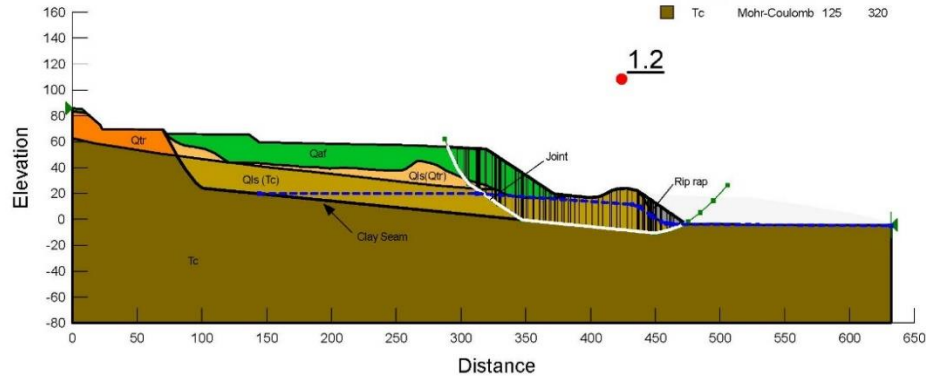


Figure 4. Results of temporary stability analysis

Project No. 20-330-00
Section 1-1'
August 2021

Static Analysis, Run 2.2
Horz Seismic Coef.: 0
Slip Surface Option: Fully-Specified
Pre-existing Condition (i.e., no beach sand erosion)
Recent Landslide Failure Surface

Color	Name	Model	Unit Weight (pcf)	Cohesion (psf)	Phi (°)
Yellow	Beach Sand	Mohr-Coulomb	100	0	30
Red	Clay Seam	Mohr-Coulomb	115	0	16
Pink	Joint	Mohr-Coulomb	120	0	29
Green	Qaf	Mohr-Coulomb	120	260	28
Orange	Qls (Qtr)	Mohr-Coulomb	120	175	29
Yellow	Qls (Tc)	Mohr-Coulomb	120	230	25
Light Orange	Qtr	Mohr-Coulomb	120	175	29
Brown	Tc	Mohr-Coulomb	125	1,420	21

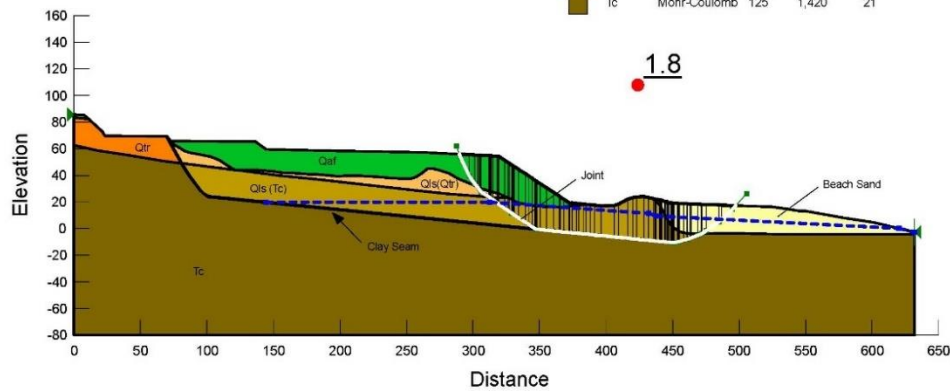


Figure 5a. Results of stability analyses: Pre-existing condition before beach sand was eroded through initial re-activated portion of landslide.

Project No. 20-330-00
Section 1-1'
August 2021

Static Analysis, Run 2.4
Horz Seismic Coef.: 0
Slip Surface Option: Fully-Specified
Existing Condition
Recent Landslide Failure Surface

Color	Name	Model	Unit Weight (pcf)	Cohesion (psf)	Phi (°)
Clay Seam	Clay Seam	Mohr-Coulomb	115	0	16
Joint	Joint	Mohr-Coulomb	120	0	29
Qaf	Qaf	Mohr-Coulomb	120	260	28
Qls (Qtr)	Qls (Qtr)	Mohr-Coulomb	120	175	29
Qls (Tc)	Qls (Tc)	Mohr-Coulomb	120	230	25
Qtr	Qtr	Mohr-Coulomb	120	175	29
Tc	Tc	Mohr-Coulomb	125	1,420	21

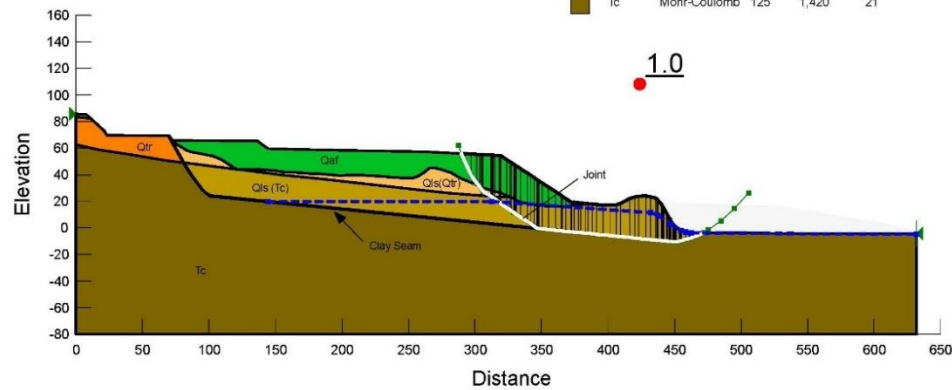
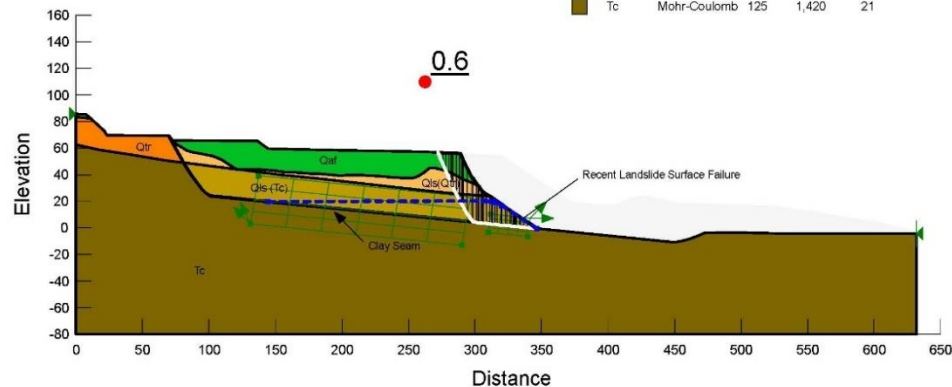


Figure 5b. Results of stability analyses: After beach sand is eroded though initial re-activated portion of landslide

Project No. 20-330-00
Section 1-1'
September 2021

Static Analysis, Run 2.5.1
Horz Seismic Coef.: 0
Slip Surface Option: Block
After Recent Landslide Failure Condition
Ancient Landslide Failure Surface

Color	Name	Model	Unit Weight (pcf)	Cohesion (psf)	Phi (°)
Clay Seam	Clay Seam	Mohr-Coulomb	115	0	16
Qaf	Qaf	Mohr-Coulomb	120	260	28
Qls (Qtr)	Qls (Qtr)	Mohr-Coulomb	120	175	29
Qls (Tc)	Qls (Tc)	Mohr-Coulomb	120	230	25
Qtr	Qtr	Mohr-Coulomb	120	175	29
Tc	Tc	Mohr-Coulomb	125	1,420	21



5c. Results of stability analyses: Condition if full failure of initial reactivated failure occurs.