Mitigating Geotechnical Challenges Associated with Marshland Restoration in the San Diego Bay

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Abstract. Coastal marshes provide many benefits to local communities, including increased habitat, coastal protection, and recreational use. The Otay River Estuary Restoration Project (ORERP) aims to restore disturbed marsh wetlands for the benefit of fish, birds, and other coastal species native to habitats at the south end of San Diego Bay. The project involves the excavation of material from the San Diego Bay National Wildlife Refuge floodplain and the transport and placement of that material in an existing solar salt pond (Pond 15) to establish and restore tidal marshland.

This paper addresses the geotechnical challenges associated with the earthwork involved in the ORERP and the use of Rocscience software in the development of the design. The challenges with restoring marshland within Pond 15 lay in the earthen berm separating San Diego Bay from the hypersaline water within the salt pond. To construct tidal marshland within Pond 15, the pond must first be drained of brine before fill can be placed and a portion of the perimeter berm removed to safely expose the restored marsh to the bay's tides. Draining the brine will change the conditions that influence the stability of the perimeter berm of Pond 15. If the berm were to fail, brine would flow into bay waters, resulting in adverse impacts to bay habitats and associated wildlife. To address the potential impacts associated with berm failure, geotechnical analyses were performed to develop guidance for all phases of the restoration project. To mitigate risks of berm instability, Slide2 was used to iteratively assess berm enhancements, as well as different approaches to pond draining, so that acceptable factors of safety would be achieved during and after construction.

Keywords: Slope stability · restoration · factors of safety · berm failure

1 Introduction

The Otay River runs through southern San Diego County, California, and forms an estuary where it meets San Diego Bay (Bay). At the mouth of the river is a series of salt ponds separated from the Bay by earthen berms. There are more than 20 salt ponds operated by South Bay Salt Works, which has been in operation for more than 100 years,

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that harvest salt from Bay water. Due to the hypersaline water and remote location, this region has become a favorite nesting area for 94 species of migratory birds, of which 7 are endangered or threatened (Yu 2008). The land is currently managed by the U.S. Fish and Wildlife Service as a national wildlife refuge (Fig. 1).

Poseidon Water, LLC, has recently developed a desalination plant in Carlsbad, California, to desalinate sea water as a resource for fresh drinking water. Poseidon developed a Marine Life Mitigation Plan as part of the requirements to obtain a Coastal Development Permit from the California Coastal Commission for developing the desalination plant. Poseidon has set forth to create, restore, and enhance coastal wetlands to benefit native wildlife and plant species within the southern portions of San Diego Bay Wildlife Refuge to provide mitigation for impacts associated with construction and operation of the desalination plant. As part of this mitigation requirement, the Otay River Estuary Restoration Project (ORERP) was developed to restore a former salt pond and an active salt pond to salt marsh habitat. The overall marsh restoration project includes creation of

Fig. 1. Otay River Estuary Location Map

125 acres of salt marsh at two different locations as well as the removal and management of the hypersaline water currently in Pond 15.

Marsh restoration can be complicated and involve challenging environments with little room for error. Typically, restoration projects require placement of material on soft surface in marine environments where soil stability can be quite low. This poses numerous geotechnical challenges, including slope-stability issues, consolidation issues, and, with any project in a seismically active region, potential for liquefaction.

2 Salt Marsh Restoration Overview

The restoration for this project involves several interrelated elements. It consists of the excavation of soils from the San Diego Bay Wildlife Refuge floodplain area, a former salt pond, and placement of those soils into Pond 15 to create 90.9 acres of subtidal habitat, intertidal mudflat, intertidal salt marsh, transitional marsh, and upland habitat. It is anticipated that Pond 15 will be partially or fully dewatered during construction. Due to potential instabilities created by dewatering the pond, additional fill to buttress berms will be placed to improve berm stability. Approximately 310,000 cubic yards of material is being excavated from the floodplain area, with 260,000 cubic yards of this material being transported to Pond 15 and placed as fill material using land-based methods, including bulldozers, scrapers, and excavators. Finally, the berms will be breached to provide tidal connections to the Bay. The project also includes other restoration elements, particularly within the floodplain, that are not the subject of this geotechnical study.

3 Existing Site Conditions

Pond 15 is currently being used for solar evaporation of seawater by the South Bay Salt Works Company. The floodplain area was developed and used for salt production but has not been in use for more than a decade. The existing salt ponds are separated from the Bay by earthen perimeter berms. It is believed that these perimeter berms were constructed using dredged material placed on top of the original marsh. Considering the age of the existing berms, these features are assumed to not have been engineered, but rather built adaptively in the field for the expansion and operation of the facility.

3.1 Data for Design

A dual-phase geotechnical investigation was performed to collect and characterize subsurface conditions for each of the ORERP's planned work elements described previously. Eleven soil borings and five cone penetrometer tests were performed through the berm to support slope stability modeling and consolidation and bearing capacity calculations (Fig. 2).

Within Pond 15, four main lithological units were observed, listed as follows from the ground surface downward: fill material, sediment, interbedded silt and clay marine deposits, and Bay Point Formation. Fill material in the upper subsurface and perimeter berms consisted of gravely, silty sand. The mudline of the pond comprised very soft

Fig. 2. Subsurface Investigation Map Within Pond 15. Aerial photograph provided by Esri streaming service

to soft silts and clays. Marine deposits underlaying sediment consisted of interbedded finer-grained silts and clays with layers of sand. Bay Point Formation soils consisted of dense sands and gravels deep in the subsurface. A site photograph of the existing berm prior to berm improvements is shown in Fig. 3.

4 Geotechnical Engineering Methods and Challenges

To support the restoration design, several geotechnical analyses were performed, including slope-stability evaluations of the existing perimeter berm and berm improvements, as well as supporting seismic evaluations, consolidation settlement, and bearing capacity calculations. The focus of this paper is the use of Slide2 software (Rocscience 2021) to perform a limit equilibrium analysis for slope stability and potential seismic deformation. Analyses were conducted to evaluate a variety of water table and buttress geometries that provide sufficient stability to the Pond 15 perimeter berm. Soil engineering properties of the existing berm fill, underlying soil units, and the proposed berm were established

Fig. 3. Site photograph of existing Berm 15

through field-collected data and laboratory-tested soil samples generated during the geotechnical field investigations.

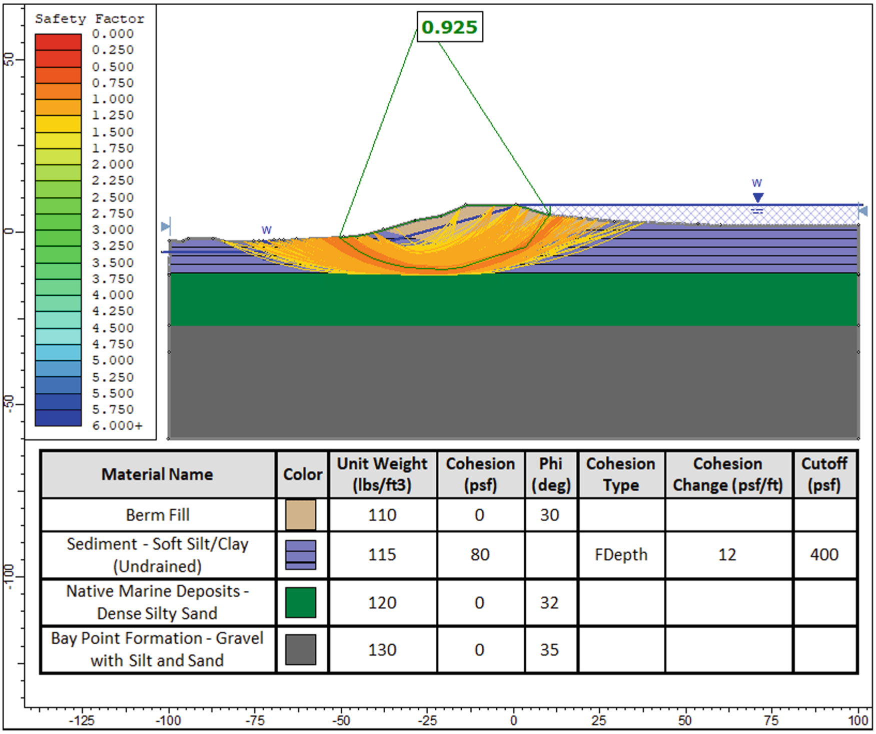
4.1 Static Stability of Perimeter Berm

The primary geotechnical concern for the restoration project is the stability of the perimeter berm separating Pond 15 from the Bay. Pond 15's western berm bordering the Bay is designed to have the tallest unsupported exterior perimeter slopes, with an average elevation difference of 12 feet from the crest of the berm to the bottom of the pond. A geologic cross section was developed to evaluate the stability of the existing slope and proposed design slopes. The location of the geologic cross section was determined based on a review of existing survey data; the locations for critical areas were selected based on the steepest berm slopes adjacent to soft, cohesive soils.

Multiple scenarios were evaluated to capture changes in water elevation that would occur during temporary dewatering for construction. Existing condition scenarios were evaluated assuming the surface water elevation of Pond 15 to be +6 feet North American Vertical Datum of 1988 (NAVD88) and assuming the mean higher high water (MHHW) elevation of +5.3 feet NAVD88 for San Diego Bay. A second set of scenarios representing possible conditions during construction assumed the MHHW elevation for the Bay and the pond interior to be dewatered to different water levels. The final scenario represented post-construction conditions, with slopes inside the pond perimeter regraded to 4H:1V (horizontal to vertical ratio) while the pond was breached and tidally connected to the

Bay (i.e., water levels on the interior and exterior of the pond were equal). The potential instability surface with the lowest factor of safety (FOS) was identified for each scenario under short-term (undrained) and long-term (drained) conditions. Resulting FOSs were compared to U.S. Army Corps of Engineers guidance target FOSs for engineered slopes: 1.3 for short-term conditions and 1.5 for long-term conditions (USACE 2003). Two methods of limit equilibrium analysis were used: Spencer (1967) and Morgenstern and Price (1965). Figure 4 shows an example model used in this study to assess slope stability during full dewatering of the existing perimeter berm around Pond 15.

The results of the modeling indicated that there was potential for global failure of the berm with an unacceptable FOS during temporary dewatering of Pond 15. Under dewatered conditions, modeled factors of safety were as low as 0.8 for undrained scenarios and 1.2 for drained conditions. These low FOSs are largely due to the loss in lateral support provided by ponded water against the berm slope and the low shear strength of the soft, underlying silty clay layer. Additional iterations of modeling for various water levels indicated a direct relationship between water level and FOS (i.e., the lower the water level, the lower the FOS). Following regrading after pore pressures equilibrate and the tidal connection of the pond, the stability is expected to improve to FOSs of 1.5 for undrained slopes and 1.8 for drained sloped, which are above the minimum recommended values.



Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)	Cohesion Type	Cohesion Change (psf/ft)	Cutoff (psf)
Berm Fill	🟫	110	0	30			
Sediment - Soft Silt/Clay (Undrained)	🟦	115	80		FDepth	12	400
Native Marine Deposits - Dense Silty Sand	🟩	120	0	32			
Bay Point Formation - Gravel with Silt and Sand	⬛	130	0	35			

Fig. 4. Example Model Scenario for Dewatered Berm. Slope-stability analysis of the Pond 15 Berm

4.2 Seismicity and Potential for Damage During a Seismic Event

The project is located in a region characterized by numerous known fault zones, including the Newport-Inglewood-Rose Canyon fault zone and the La Nación fault zone (3 miles east of San Diego). Other faults in the vicinity include the Florida Canyon and Texas Street faults immediately north of San Diego, the Coronado Bank fault zone (14 miles southwest), the Oceanside fault (17 miles southwest), and the San Diego Trough fault zone (23 miles southwest). Historic significant earthquakes experienced in the San Diego region include the following (Earthquake Track 2023):

- 7.5 magnitude in Frazier Park, California, United States, in 1952
- 7.2 magnitude in Delta, Baja California, Mexico, in 2010
- 6.8 magnitude in Fraccionamiento del Valle, Baja California, Mexico, in 1956
- 6.7 magnitude in Lakeland Village, California, United States, in 1918

A seismic evaluation for the site was conducted using the U.S. Geological Survey's (USGS's) Unified Hazard Tool, available online from USGS (2018). For the project, a 10% probability of occurrence in 50 years (475-year return period) was selected as the design seismic event because this return period is most commonly used for design. Based on observed soil conditions, the site soil classification was determined to be Class E. For these conditions, the USGS Unified Hazard Tool calculated an applicable peak ground acceleration for the site to be 0.338 gravity. Figure 5 shows the USGS hazard curve for Site Class E soils for a 475-year return-period seismic event.

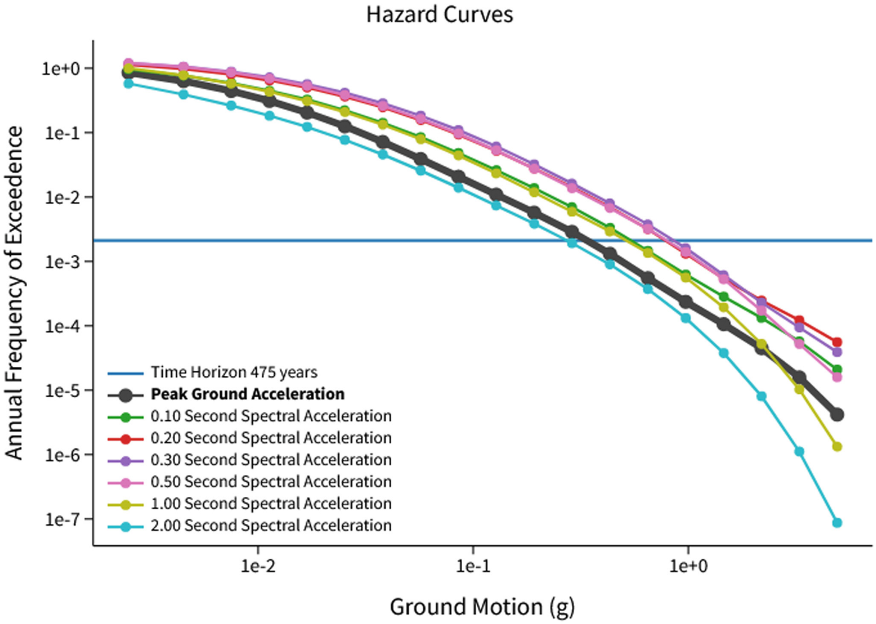


Fig. 5. USGS Hazard Tool Seismic Hazard Curves[1] for the Site

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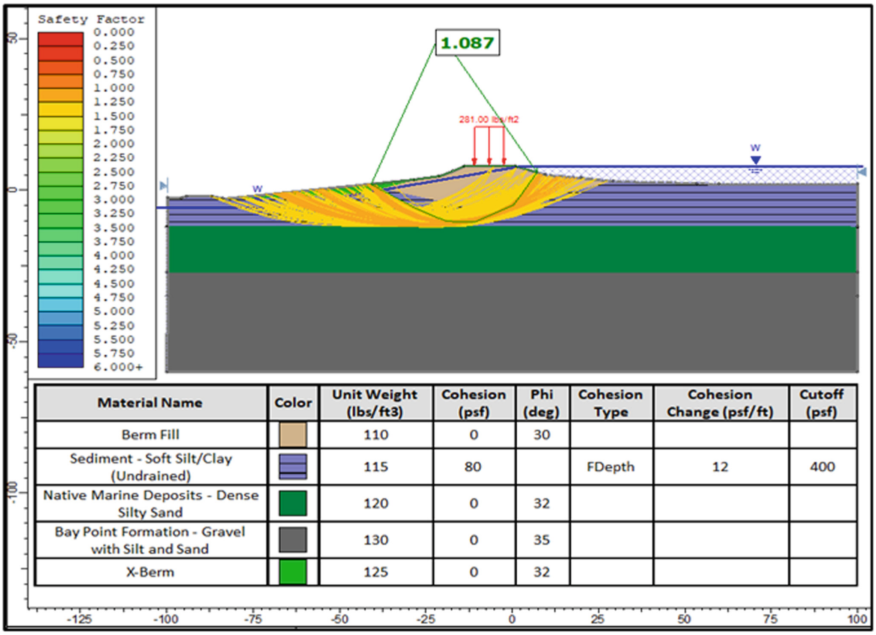
[1] Available at: https://earthquake.usgs.gov/hazards/interactive/

An estimation of the slope deformation following a design seismic event was evaluated using Slide2 in conjunction with the USGS Seismic Landslide Movement Modeled Using Earthquake Records (SLAMMER) software (Jibson et al. 2014). To conduct the deformation analysis, a seismic yield acceleration scenario was evaluated using Slide2. By iteratively applying seismic loads to the slopes, the site critical seismic yield acceleration was determined to be 0.1 gravity (the acceleration corresponding to an FOS of 1.0). Based on these parameters, SLAMMER provided a range of estimated deformations between 1 inch and 5 inches, with an average of 3.5 inches as a result of the design seismic event.

5 Adaptive Management for Slope Stabilization

Because stability of the perimeter of the berm around Pond 15 is one of the main concerns of the project, Slide2 was used to adaptively design improvements to the designed slopes. Following initial slope modeling predicting instabilities of the as-built design, stabilization methods were developed, which included the implementation of a toe buttress along the outer edge of the dike area. This was designed to shallow the interior slope angle of the overall berm to a 10H:1V slope in such a way to minimize increased loading along the existing berm. The resulting buttress alignment, roughly 30 feet wide and 5 feet thick, as shown in the model scenario in Fig. 6, resulted in FOSs of 1.1.

The implementation of the buttress increased modeled FOSs from 0.9 to 1.1. The "wedge" of fill material was placed along the western dike in stages, beginning from the



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Bay Point Formation - Gravel with Silt and Sand	⬛	130	0	35			
X-Berm	🟩	125	0	32			

Fig. 6. Example Model Scenario with Berm Improvements. Slope-stability analysis of the Pond 15 berm following buttressing

toe side of the berm and building back toward the berm crest, and installed fully before dewatering took place. While an FOS of 1.1 is not a good indicator for long-term stability of the berm, the modeling was performed to predict stability during construction, while the pond was dewatered and loaded with construction equipment. Following completion, loads would be removed, and the water level of the pond would be subject to the tides of the Bay, providing increased lateral resistance and stability to the new berm. Construction commenced in late 2022, and following the installation of the buttress and dewatering of most of the pond, no significant dike instabilities were observed. The construction of the restoration project will continue in the dry pond until the restored marsh is exposed to the Bay.

6 Conclusions

The restoration of wetland marsh area within a salt pond as part of the ORERP posed many significant geotechnical challenges, namely involving stability of the perimeter dike separating the pond from the Bay. The project involved first dewatering an existing salt pond to construct wetland marsh before ultimately breaching the perimeter berm and opening the restored marsh to tidal influence. Following a geotechnical field investigation, a targeted slope-stability evaluation was performed using Rocscience Slide2 software to evaluate berm stability during dewatering. Initial slope-stability modeling indicated that the perimeter berm was at risk with a low FOS of 0.9. To mitigate risk of instability, adaptive improvements were designed to increase the berm stability via placement of an interior buttress of material, increasing the FOS of the berm from 0.9 to 1.1, allowing short-term dewatering to be carried out successfully.

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References

Earthquake Track Homepage, https://earthquaketrack.com, last accessed 2023/02/14.
Jibson, R.W., Rathje, E.M., Jibson, M.W., Lee, Y.W.: SLAMMER—Seismic Landslide Movement Modeled Using Earthquake Records (Version 1.1). U.S. Geological Survey Techniques and Methods Book 12, Chapter B1. (2014).
Morgenstern, N.R., Price, V.E.: The analysis of the stability of general slip surfaces. Geotechnique 15(1), 79–93 (1965).
Spencer, E.: A method of analysis of the stability of embankments assuming parallel inter-slice forces. Geotechnique 17(1):11–26 (1967).
Rocscience: Slide2 – 2-D Limit Equilibrium Slope Stability for Soil and Rock Slopes, User's Guide. Rocscience Software, Inc., Toronto, Ontario, Canada (2021).
USACE (U.S. Army Corps of Engineers): Slope Stability. EM 1110-2-1902 (2003).

USGS (U.S. Geological Survey) Online earthquake hazard maps and design ground motions, https://earthquake.usgs.gov/hazards/designmaps/ (2018).

Yu, L.: "The Hidden Salt Ponds of Chula Vista." Voice of San Diego (2008).