

SAN FRANCISCO WATERFRONT COASTAL FLOOD STUDY, CALIFORNIA

SUB-APPENDIX B.3 – EARTHQUAKE LIFE SAFETY RISK

JULY 2026

USACE TULSA DISTRICT | THE PORT OF SAN FRANCISCO



**US Army Corps
of Engineers**



Table of Contents

Acronyms and Abbreviations.....	ii
1.0 General Methodology	1
2.0 Future Without Project Condition.....	1
2.1 Life-Safety	2
2.2 Resilience.....	2
3.0 Future With Project Condition.....	2
3.1 Life-Safety	3
3.2 Resilience.....	4
4.0 Future Without Project and Future With Project Alternative Maps.....	6
5.0 References	7

List of Tables

Table B.3-1: Approximate Quantity of Casualties and People Trapped Over Water for FWOP and FWP Alternatives.....	3
Table B.3-2: Life-Safety Scoring for FWOP and FWP Alternatives	4
Table B.3-3: Northern Waterfront Bulkhead Wharf Damage Rating	5
Table B.3-4: Embarcadero Roadway Damage Rating.....	5
Table B.3-5: Resilience Scoring for FWOP and FWP Alternatives.....	6

Attachment B 3-1: Color-coded maps demonstrating impact of seismic ground improvements in all structural alternatives and wharf replacement in Alternatives D, E, F, and G (subsequent actions).

Acronyms and Abbreviations

Acronym	Definition
FWOP	Future Without Project
FWP	Future With Project
HAZUS	Hazards United States
MHRA	Multi-Hazard Risk Assessment
PDT	Project Delivery Team
TNBP	Total Net Benefits Plan
USACE	U.S. Army Corps of Engineers

1.0 General Methodology

The Earthquake Life-Safety and Resilience metrics documented in this appendix are intended to describe the Future Without Project (FWOP) and various Future With Project (FWP) alternatives performance of waterfront structures within the study area. Construction of Coastal Defense Structures will have an incidental effect on existing and future seismic risk which will be qualitatively described and graphically represented. To avoid any potential conflicts with the language of Section 152 of the Water Resources Development Act of 2020, as amended, the Project Delivery Team (PDT) makes no attempt to quantify the number of lives at risk or seismic damages caused. However, several of the FWP alternatives will influence life-safety performance and resilience along the waterfront therefore it was considered reasonable to evaluate these benefits qualitatively in consideration of the total net benefits plan (TNBP), subsequently referred to as the Recommended Plan, approach and as part of the multi-authority and multi-hazard guidance specific to this study. Simplified scores are provided on a scale of 1 to 5, with the score of 1 indicating a poor outcome and 5 indicating a positive outcome with respect to the metric being evaluated (life-safety or resilience). This score is based upon professional judgment within the PDT. These scores will be independent of sea level rise curve, therefore do not need to be qualitatively assessed for each curve. The specific methodology for each metric and generalized rubric for scoring for each is provided in the sections below.

2.0 Future Without Project Condition

In the FWOP condition, the structures and infrastructure (transportation and utility) along the waterfront are subject to the seismic hazards of ground shaking, lateral spreading, and liquefaction. Each of these hazards can be expected to cause damage, disruption, and potential casualties, which will vary in severity relative to the magnitude of the earthquake as documented in the Port of San Francisco's Multi-Hazard Risk Assessment (MHRA) completed in 2020 and the Initial Southern Waterfront Earthquake Assessment completed in 2022. The findings of these studies were independently peer reviewed by industry leading experts in seismic risk analysis and utilized by the PDT in defining the FWOP condition related to earthquake events. It is important to highlight that the level of certainty associated with seismic risk, differs across the study area, with substantially higher level of seismic assessment completed for the northernmost 3 miles along the Embarcadero, where geotechnical exploration and non-linear geotechnical and structural analysis were completed as part of the MHRA. In contrast, the southern 4.5 miles of the study area have only been assessed through an initial assessment that relied solely on desktop evaluation of historic geotechnical reports, drawings, and use of professional judgment to identify potential seismic hazards and vulnerabilities.

An earthquake can happen at any time, and it is expected that one or more earthquake events will occur during the 100-year period of analysis, therefore it is important to consider the consequence of these events and understand how investment in a coastal storm risk reduction system will alter these consequences when designed to meet the requirements of ER 1110-2-1806 *Earthquake Design and Evaluation for Civil Works*

Projects (USACE 2024). Performance of the existing waterfront has been qualitatively scored for two metrics related to earthquake performance (1) life-safety and (2) resilience.

2.1 Life-Safety

The life-safety score is a semi-quantitative metric based upon the results of the MHRA, whereby the approximate number of casualties along the Embarcadero were estimated using a customized Hazards United States (HAZUS) approach to represent the seismic hazard to marine structures and associated superstructures. The MHRA results indicate a substantial number of casualties within the bulkhead wharf zone, and people trapped over water when landside portion of the facilities are damaged by a 225-year earthquake, therefore the FWOP condition is assumed to result in a poor outcome, scoring a qualitative rating of 1. Approximate number of casualties and people trapped over water for the FWOP and FWP alternatives are provided in **Table B.3-1**. **Table B.3-2** provides the score assigned to the FWOP and FWP alternatives with first and subsequent actions constructed.

2.2 Resilience

The resilience score is also a semi-quantitative metric based upon the result of the MHRA whereby damage to the marine structures and adjacent transportation infrastructure is estimated as a distribution across multiple damage states. The damage states range from minor damage to full collapse and are based upon the probabilistically predicted damage following the customized HAZUS approach which is a national standardized risk model. HAZUS identifies areas with high risk for natural hazards and estimates physical, economic, and social impacts of earthquakes, hurricanes, floods, and tsunamis. The MHRA results indicate substantial damage expected to occur within the bulkhead wharf zone and Embarcadero corridor from a 225-year earthquake. For the Southern Waterfront, the results presented in the Initial Southern Waterfront Earthquake Assessment were used to qualitatively score the without project performance based on professional judgment. In addition to the predicted damage, the expected downtime and impact of damage on the post-disaster response and recovery were factored in the qualitative scoring. This is important because the waterfront is specifically identified in local and regional disaster response plans as home to several critical assets and functions. For the FWOP condition, the MHRA results predict that more than 50% of the wharf structures will have major damage or will be in the collapse damage state, while more than 50% of the roadway will have at least moderate damage. This is considered to be a poor outcome, scoring a qualitative rating of 1.

3.0 Future With Project Condition

In the FWP condition, the range of alternatives will have differing levels of influence on the life-safety performance and resilience, based upon the measures and alignment selected. While all coastal storm risk reduction measures will be designed to meet the seismic performance requirements of ER 1110-2-1806 (USACE 2016), the location of these structures relative to existing coastal defenses, and scope of existing structure

replacement will vary, therefore each alternative is scored using professional judgment and information from the MHRA.

3.1 Life-Safety

The life-safety score is again semi-quantitative metric where the difference between casualties in the FWOP condition are compared to the expected casualties in the FWP condition. It is assumed that full replacement of seismically vulnerable wharf substructures, which serve as part of the existing coastal defense system, will have a positive outcome. Alternatives E, F, and G all include ground improvement and replace the existing structures with new pile supported structures or solid fill, therefore result in substantial reductions to the FWOP life-safety hazard. Alternative D also includes ground improvements and replaces the existing structures but does not construct the replacement until halfway through the 100-year period of analysis, therefore only showing an improvement with the subsequent actions. The ground improvement included with Alternative C will substantially reduce the lateral spreading and liquefaction hazard acting upon the vulnerable wharf structures but does not fully eliminate the life-safety risk therefore this alternative is assumed to have a neutral outcome (score 3).

Table B.3-1: Approximate Quantity of Casualties and People Trapped Over Water for FWOP and FWP Alternatives

Embarcadero Zone Earthquake Safety, 225-year Earthquake (Draft)			
Alternative	Occupancy over Water	Bulkhead Zone Casualties	Trapped Over Water
A (FWOP) and B	8810	295	608
C and D	8810	224	0
E, F, G	8810	161	0

Table B.3-2: Life-Safety Scoring for FWOP and FWP Alternatives

Alternative	Qualitative Metric		Notes
	First Actions	Subsequent Actions	
A – No Action (FWOP)	1 – poor outcome	1 – poor outcome	
B – Nonstructural	1 – poor outcome	1 – poor outcome	No investment in vulnerable structures that reduce earthquake life-safety risk
C – Low Curve	3 – neutral outcome	3 – neutral outcome	Reduce lateral spreading risk with ground improvement, lowered demand on wharf structure
D – Low Curve Adaptable	3 – neutral outcome	5 – positive outcome	Reduce lateral spread risk with ground improvement, same score as C at 2040; but 2090 investment in vulnerable structures, substantially reduces earthquake life-safety risk.
E – Shoreline	5 – positive outcome	5 – positive outcome	Reduces lateral spread risk with ground improvement and replaces vulnerable wharves with new structures
F – Bayward w/Gates	5 – positive outcome	5 – positive outcome	Replaces vulnerable wharves with solid ground
G - Retreat	5 – positive outcome	5 – positive outcome	Replaces vulnerable wharves with new structures

To roll up the earthquake life-safety metrics for the economics key driver matrices, the score from the first actions will be used to best captures the alternative performance related to the first actions. The Recommended Plan is expected to perform similarly to Future with Project results for Alternatives E, F or G.

3.2 Resilience

The resilience score is again a semi-quantitative metric where the difference between damage and disruption in the FWOP condition is compared to the expected damage and disruption for each of the FWP alternatives. Alternatives that replace vulnerable structures with new facilities are expected to substantially reduce damage and disruption following an earthquake, thereby score higher from the lens of earthquake resilience. As can be seen in **Table B.3-3**, when bulkhead wharf structures are fully or partially replaced by engineered fill, the expected earthquake damage is very minor, while the pile supported wharf has a range of minor to very minor damage, significantly reduced from the FWOP condition. Similarly, when ground improvements are employed below major transportation corridors such as the Embarcadero, the roadway damages

are expected to be reduced as seen in **Table B.3-4**, thus providing a post-event emergency response corridor as another measure of added earthquake resilience. These metrics focus heavily on the conditions in the Northern Waterfront (Reaches 1 and 2) and are not expected to differ substantially in the Southern Waterfront, except for the disaster response functions fulfilled at deep draft vessel berths such as Pier 94/96 or replicated at Pier 80. The maritime metrics described in *Sub-Appendix E.2: Other Social Effects Report*, quantify this maritime function, therefore this qualitative scoring has not been modified to consider differences between alternatives in the Southern Waterfront.

Table B.3-5 includes the scores assigned to the FWOP and FWP alternatives with both the first and subsequent actions constructed.

Table B.3-3: Northern Waterfront Bulkhead Wharf Damage Rating

Embarcadero Bulkhead Wharf Zone, 225-year Earthquake Damages of Wharf Zones							
Alternative		Bulkhead Wharf Structural Damage Rating					Totals
		V. Minor	Minor	Moderate	Major	Collapse	
A (FWOP) and B	Area %	117,639 11%	65,529 6%	309,985 30%	273,605 26%	271,029 26%	1,037,787 100%
C and D	Area %	189,611 18%	163,388 16%	560,068 54%	96,427 9%	28,293	1,037,787 100%
E	Area %	1,037,787 100%	0 0%	0 0%	0 0%	0 0%	1,037,787 100%
F	Area %	1,037,787 100%	0 0%	0 0%	0 0%	0 0%	1,037,787 100%
G	Area %	117,639 11%	920,148 89%	0 0%	0 0%	0 0%	1,037,787 100%

Table B.3-4: Embarcadero Roadway Damage Rating

Alternative	Roadway Damage Rating by % Area		
	Minor Area	Moderate Area	Major Area
A (FWOP) and B	33%	52%	15%
C, D, E, F, and G	83%	16%	2%

Table B.3-5: Resilience Scoring for FWOP and FWP Alternatives

Alternative	Qualitative Metric		Notes
	First Actions	Subsequent Actions	
A – No Action (FWOP)	1 – poor outcome	1 – poor outcome	
B – Nonstructural	1 – poor outcome	1 – poor outcome	No investment in vulnerable structures that reduces earthquake resilience
C – Low Curve	3 – neutral outcome	3 – neutral outcome	No investment in vulnerable structures.
D – Low Curve Adaptable	3 – neutral outcome	5 – positive outcome	2090 investment in vulnerable structures, does not mitigate near term earthquake life-safety risk.
E – Shoreline	5 – positive outcome	5 – positive outcome	Replaces vulnerable wharves with new structures, but does not address full roadway risk
F – Bayward w/Gates	5 – positive outcome	5 – positive outcome	Replaces vulnerable wharves with solid ground, but does not address full roadway risk
G - Retreat	5 – positive outcome	5 – positive outcome	Replaces vulnerable wharves with new structures and addresses full roadway risk

To roll up the earthquake resilience metrics for the economic key driver matrices, the score from the first actions will be used since it best captures the alternative performance related to the initial action. The Recommended Plan is expected to perform similarly to Future with Project results for Alternatives E, F or G.

4.0 Future Without Project and Future With Project Alternative Maps

The impact of seismic ground improvements in all structural alternatives and wharf replacement in Alternatives D, E, F, and G (subsequent actions) is demonstrated with a series of color-coded maps, which have been included as Attachment B.3-1. The color-coded maps depict the expected level of damage that would occur during a 225-year return period earthquake, similar to the 1906 earthquake that shaped San Francisco. The map series includes both the Future without Project condition as well as a set showing the Future with Project condition for Alternatives D, E, F and G. The Future with Project versions utilize professional judgment to modify the expected performance

at individual polygons for wharves, piers and roadway segments to reflect the influence of the coastal storm risk reduction plan on asset when the first actions are built to U.S. Army Corps of Engineers (USACE) seismic performance standards. The Recommended Plan is expected to perform similarly to Future with Project results for Alternatives E, F or G.

5.0 References

U.S. Army Corps of Engineers (USACE). 2024. ER 1110-2-1806 *Earthquake Design and Evaluation for Civil Works Projects*. June 29.

**Attachment 1 - Sub
Appendix B.3.1
Future Without Project and Future
With Project
(Alternatives E, F, G or
Recommended Plan First Action)
225-year Earthquake Damage
Maps**

Map 1: Hyde St to Pier 35

Disaster Response Assets

- Assembly Area
- Deep Draft Berth
- Embarkation/Debarkation Facility
- Emergency Operations Center
- Emergency Response Operations Facility

- Headquarters and Maintenance Facilities
- Land Transportation Facilities
- Staging Area
- Cordon Area

Structural Ratings: Building and Marine Structures

- Very Minor Damage, fully functional
- Minor Damage, accessible function may be impaired
- Moderate Damage, restricted access
- Major Damage, no access
- Collapse, partial or complete

Roadway Rating for Emergency Vehicles

- Minor Damage, functional for emergency
- Moderate Damage, use caution
- Major Damage, may not be passable

#	LOCATION	O	C	TW
1	Hyde St. Pier	19	5	3
2	Wharf J-11	2	1	1
3	Wharf J-9	9	1	1
4	Pier 47 - Scomas	114	10	113
5	SWL 302 - Al Scoma Way	53	4	13

#	LOCATION	O	C	TW
6	Pier 49 - Fisherman's Wharf	409	38	86
7	Pier 45	626	7	0
8	Pier 43 1/2 Old Portion	162	19	40
9	Pier 43 Bay Trail Link	115	0	0
10	Pier 43	41	8	0

#	LOCATION	O	C	TW
11	Pier 41 1/2	250	7	63
12	Pier 41	125	23	0
13	Pier 39 1/2	60	2	15
14	Pier 39	872	22	120
15	Pier 35 1/2	247	4	3

FWOP

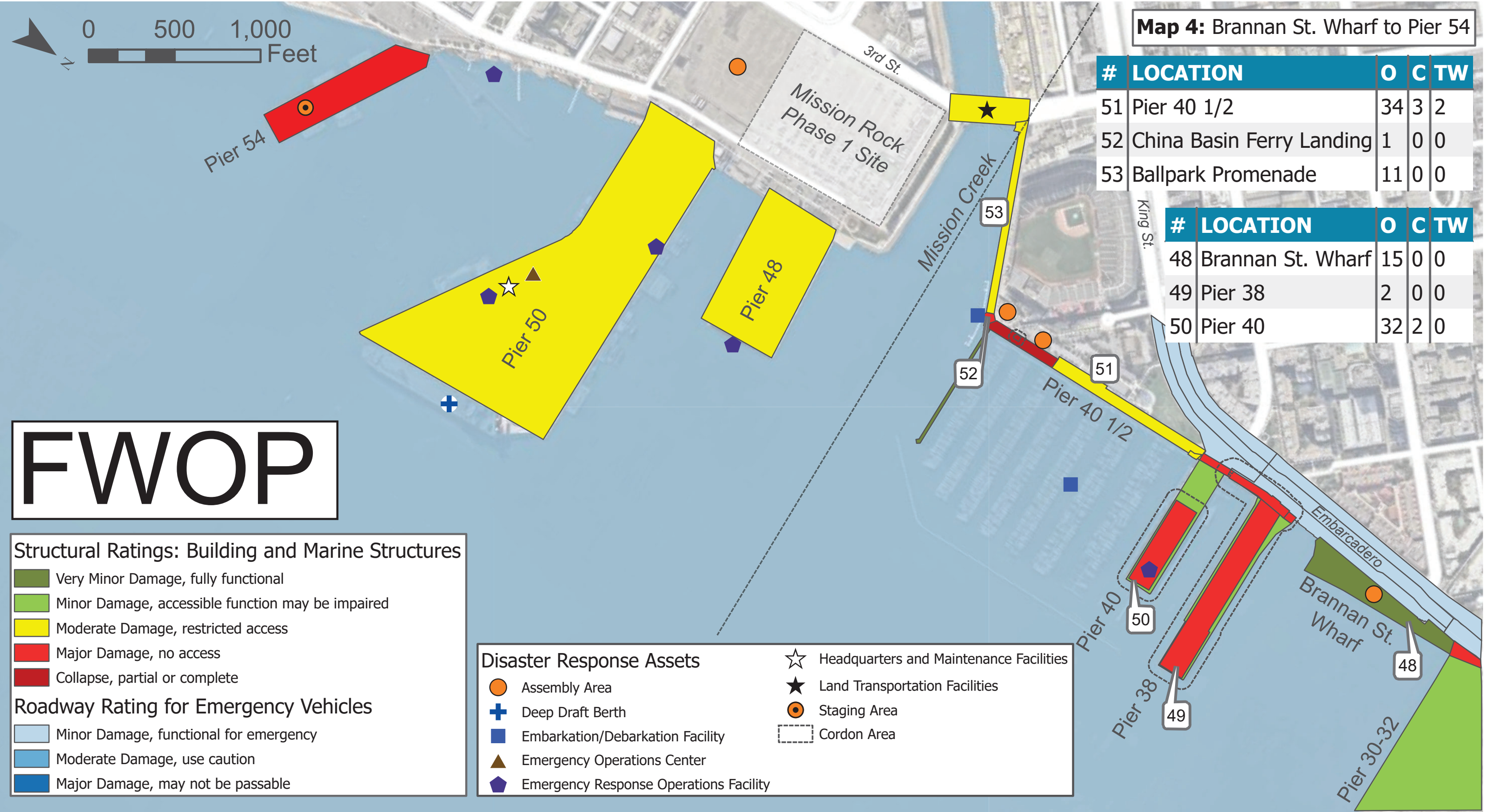


#	LOCATION	O	C	TW
26	Pier 17 1/2	10	1	0
27	Pier 17	115	4	0
28	Pier 15	1175	4	0
29	Pier 9 1/2	15	1	4
30	Pier 9	150	17	112

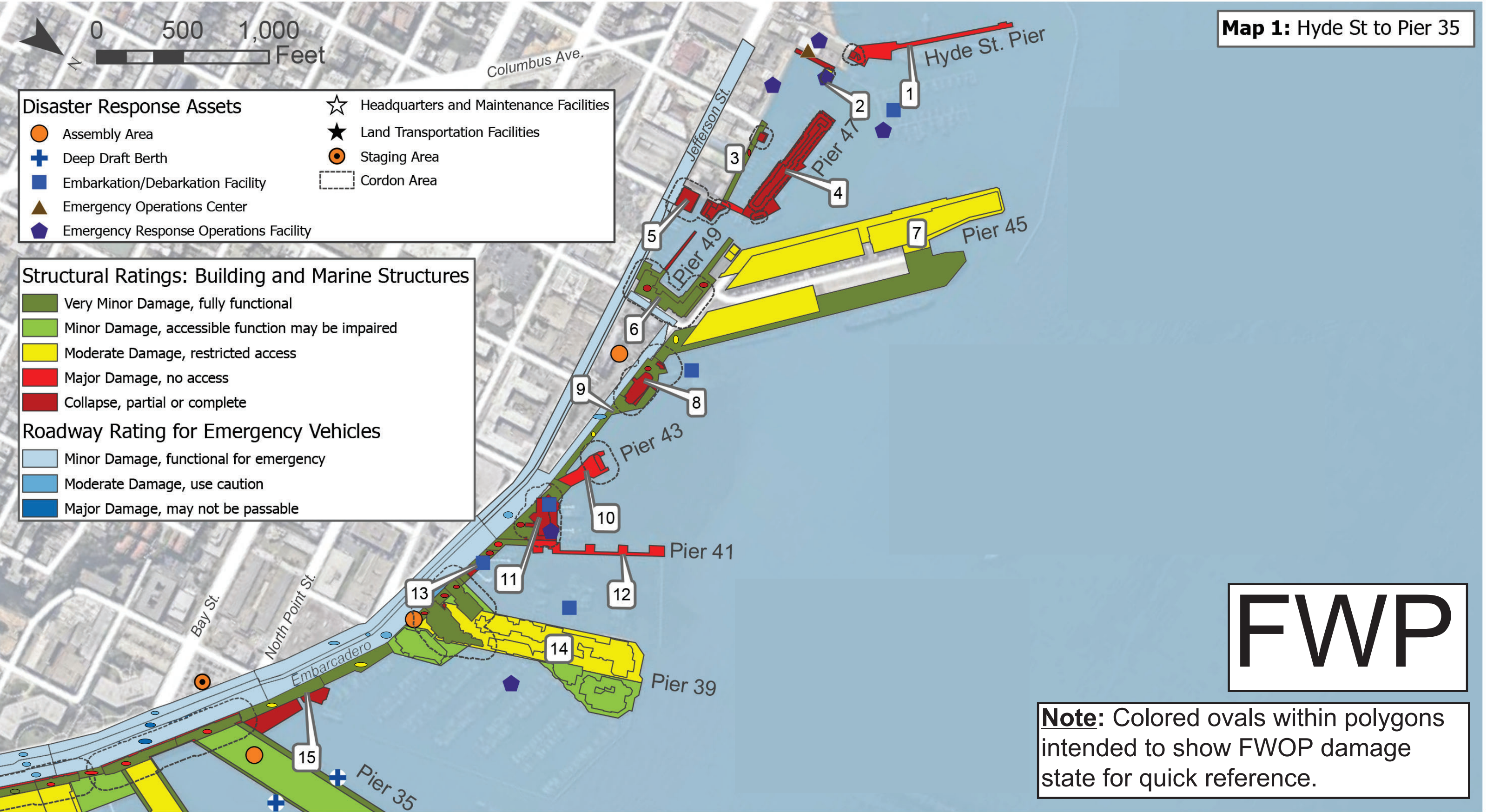
#	LOCATION	O	C	TW
21	Pier 29	77	7	0
22	Pier 27	600	7	0
23	Pier 23	78	7	0
24	Pier 19 1/2	24	1	0
25	Pier 19	48	5	0

#	LOCATION	O	C	TW
16	Pier 35	165	2	0
17	Pier 33 & 33 1/2	135	5	0
18	Pier 31 1/2	45	0	0
19	Pier 31	60	3	0
20	Pier 29 1/2	31	2	0

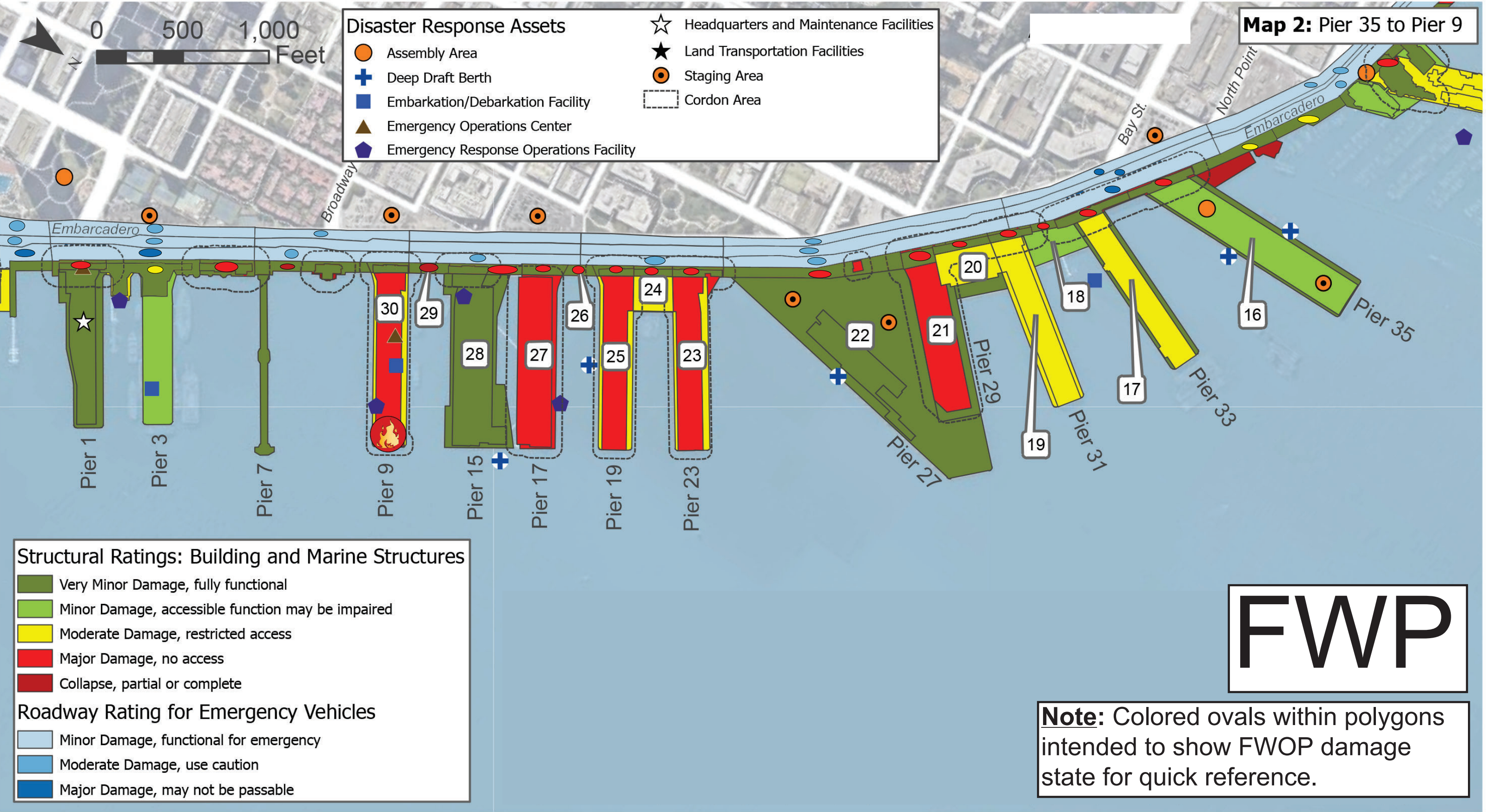




Map 1: Hyde St to Pier 35



Map 2: Pier 35 to Pier 9

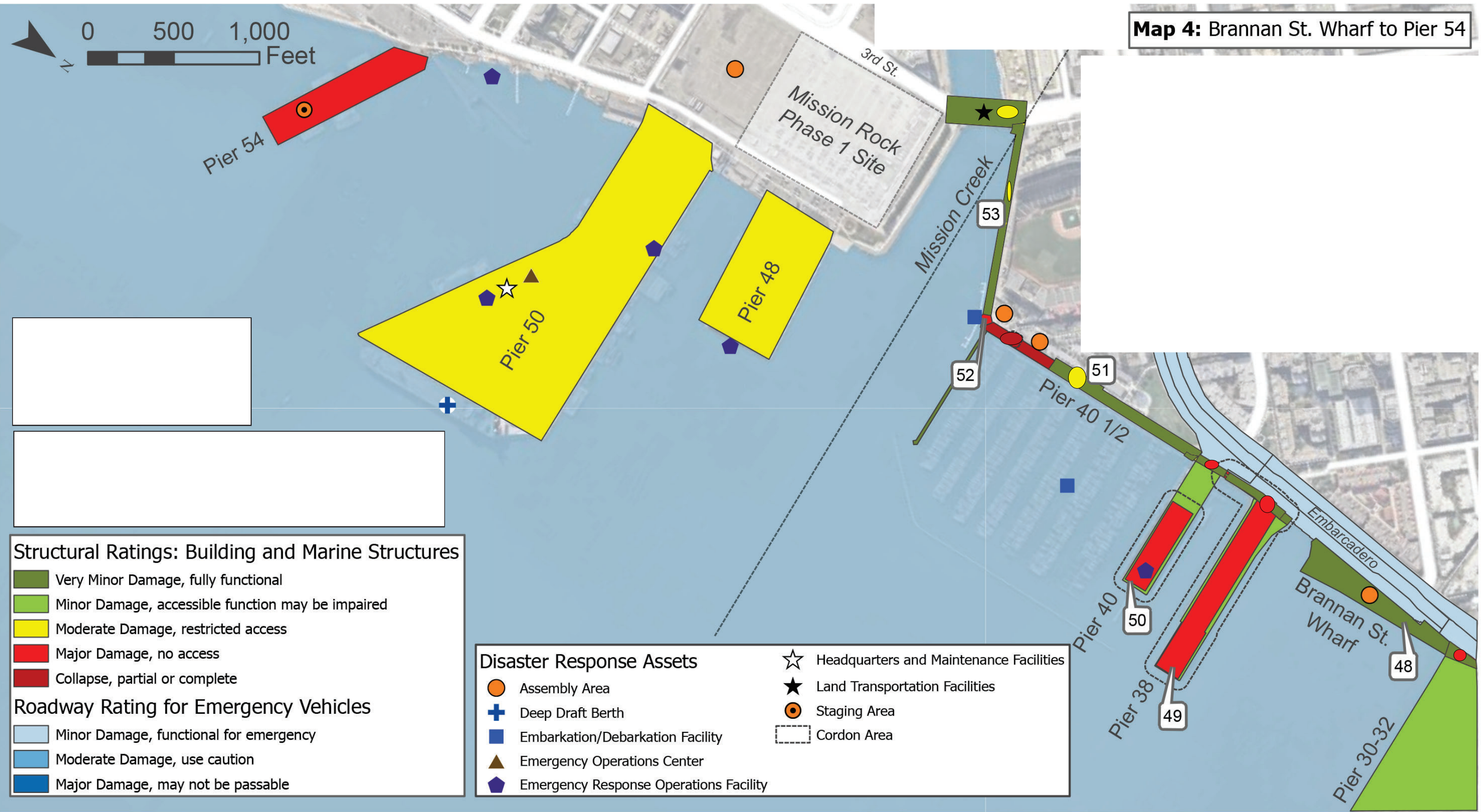


FWP

Map 3: Pier 7 to Pier 30-32



Map 4: Brannan St. Wharf to Pier 54





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Attachment 2 - Sub Appendix B.3
Review of Draft EIS and Preliminary
Seismic Analysis for Ground
Improvement Measures
San Francisco Waterfront Project
San Francisco, California

Report Prepared By:
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Report Prepared For:
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USACE Tulsa District

July 2024

Review of Draft EIS and Preliminary Seismic Analysis for Ground Improvement Measures

Table of Contents

Executive Summary	1
1. Introduction.....	11
1.1. Reference Documents.....	12
2. Seismic Performance Criteria	13
3. Alternative Waterfront Stabilization Schemes Analyzed.....	15
3.1. Selection of Sections for Seismic Analyses	15
3.2. Seismic Analysis Approach.....	16
3.3. Results of Existing Conditions Seismic Analyses.....	16
3.4. Results Seismic Analyses with Ground Improvement Measures	17
3.4.1.1 30-ft Wide DMM Panels directly Behind Current Bulkhead	17
3.4.2 Drilled Shaft Secant Walls	18
3.4.3 Slurry Wall Panels Perpendicular to the Shoreline.....	18
3.5. Analysis Results and Discussion.....	18
4. Detailed Observations and Recommendations for individual Waterfront Sub-Reaches	20
5. Conclusions and Recommendations	24

APPENDICES

- A. Numerical Analyses of Alternative Waterfront Seismic Stabilization Schemes
 - B. San Francisco Waterfront Project Observations and Recommendations for Sub-Reaches
-

List of Tables

Table ES-1. Performance Objectives and Lateral Displacement Criteria at Seawall Bulkhead, as Inferred from CH2M-ARCADIS Team Report (2021)	3
Table ES-2. Seismic Deformation Analysis Results for Existing Conditions	5
Table ES-3. Seismic Deformation Analysis Results for Compact, limited footprint Ground Improvement Schemes	7
Table 2-1. Performance Objectives and Lateral Displacement Criteria at Seawall Bulkhead, as Inferred from CH2M-ARCADIS Team Report (2021)	13
Table 3-1. Seismic Deformation Analysis Results for Existing Conditions.....	17
Table 3-2. Seismic Deformation Analysis Results for Compact Ground Improvement Schemes	19
Table 4-1. Northern Waterfront Segment Sub-Reaches – Potential Ground Improvement or Alternative Measures.....	20
Table 4-2. Southern Waterfront Segment Sub-Reaches – Potential Ground Improvement or Alternative Measures.....	22
Table A-1. Soil Properties for Young Bay Mud (YBM).....	30
Table A-2. Soil Properties for Analysis of Pier 27 and Piers 30-32	31
Table A-3. Deep Soil Mix (DSM) Properties.....	31
Table A-4. Properties of Drilled Shafts.....	32
Table A-5 Summary of Seismic Deformation Analysis Results: Pier 27	33
Table A-6. Summary of Seismic Deformation Analysis Results: Piers 30-32.....	34

List of Figures

Figure 3-1: Existing Conditions: Pier 27

Figure 3-2: Existing Conditions: Piers 30-32

Figure 3-3: Pier 27 with DMM Ground Improvement

Figure 3-4: Pier 27 with Secant Wall (10-ft Diameter)

Figure 3-5: Piers 30-32 with Secant Wall (6-ft Diameter)

Figure 3-5: Pier 27 with Reinforced Concrete Slurry Wall Ground Improvement

Figure A-1: Uniform Hazard Response Spectra for San Francisco Waterfront (VS30 = 1250 m/sec)

Figure A-2: FLAC Numerical Mesh for Pier 27 Section: Existing Conditions

Figure A-3: FLAC Numerical Mesh for Pier 27 Section: DMM Ground Improvement

Figure A-4: FLAC Numerical Mesh for Pier 27 Section: Drilled Shaft Secant Wall (10-ft Diameter)

Figure A-5: FLAC Numerical Mesh for Pier 27 Section: Slurry Wall Panels

Figure A-6: Displacement Vectors after Shaking, Pier 27: Existing Conditions

Figure A-7: Displacement Vectors after Shaking, Pier 27: With DMM Ground Improvement

Figure A-8: Displacement Vectors after Shaking, Pier 27: Drilled Shaft Secant Wall (10-ft Diameter)

Figure A-9: Displacement Vectors after Shaking, Pier 27: Slurry Wall Panels

Figure A-10: FLAC Numerical Mesh for Piers 30-32 Section: Existing Conditions

Figure A-11: FLAC Numerical Mesh for Piers 30-32 Drilled Shaft Secant Wall (6-ft Diameter)

Figure A-12: Displacement Vectors after Shaking, Piers 30-32: Existing Conditions

Figure A-13: Displacement Vectors after Shaking, Piers 30-32: Drilled Shaft Secant Wall (6-ft Diameter)

Executive Summary

This report presents review, commentary, and observations on the draft Tentatively Selected Plan (TSP) for the San Francisco Waterfront Coastal Flood Study (USACE, 2024) and results of seismic analysis at two selected locations. The main objective of the study is to evaluate ground improvements measures for the project.

The draft TSP for the San Francisco Waterfront Coastal Flood Study is described in *San Francisco Waterfront Flood Study, Draft Integrated Feasibility Report and Environmental Impact Statement*, prepared by the US Army Corp of Engineers (USACE), Tulsa District and the Port of San Francisco.

Initial review of the draft TSP showed that the very wide (up to 100-ft) ground improvement scheme for seismic stabilization proposed may not be appropriate for the dense urban environment along the Embarcadero, with tightly packed expensive infrastructure, buildings, roadways, light rail and utilities. In addition, it appears that the selected ground improvement schemes were not based on specific geo-structural seismic analysis considering the future condition of the floodwall and sea level rise. Previous seismic analyses performed by the Port of San Francisco were performed to evaluate the seismic deformations for existing conditions, and seismic measures without considering flood conditions or future sea level rise. The seismic stabilization scheme is a key, foundational component of the draft TSP, representing a major project cost and constraint.

For these reasons, as part of this review, additional geo-structural seismic analyses were performed to investigate more compact seismic stabilization schemes that are more directly focused on improving the seismic performance of the proposed floodwall itself. The findings from these seismic deformation analyses informed this review and commentary on the draft TSP.

The key observations and recommendations from the review are listed below:

a. Subsurface Data Adequacy for TSP:

The primary controlling USACE regulation governing seismic performance criteria is Engineer Regulation 1110-2-1806 “Earthquake Design and Evaluation for Civil Works Projects” (2024). As per ER 1110-2-1806, “*The PDT is required to assess the existing data adequacy, collect required data using the appropriate methods, and develop parameters for seismic analyses with higher reliability.*”

While there is adequate subsurface geotechnical information for the Northern Waterfront segment (except Aquatic Cove Park) for plan formulation study, subsurface data along the Southern Waterfront alignment is either unavailable or inadequate for planning and engineering evaluations. This is a significant risk to the project.

Three sets of maps that are generally common for planning studies should be developed for this project in the planning phase with the tentatively selected alignment. These three sets are (1) contours of existing conditions, (2) existing subsurface explorations and longitudinal subsurface profiles, and (3) maps of the project area at a reasonable scale. Currently this data is either missing or available in 1 map=5.5 miles or 3 miles scale, which are not appropriate.

The project alignment needs to be established to determine a more accurate estimate of the proposed ground improvement length. The current estimate appears to be based on geomorphology maps or plan view maps at very large scale.

We recommend development of plans and profiles with appropriate scale for the entire project alignment to identify the data gaps. A data gap analysis should be performed to identify sub-reaches with data gaps. This data gap analysis should be utilized to develop and implement a subsurface investigation program to support plan formulation study.

b. Performance Criteria for the Project:

As per definitions in ER 1110-2-1806, the proposed floodwalls and berms can be considered intermittently loaded floodwalls and levees. Performance criteria and seismic loading for a frequently loaded levee or floodwall are determined based on Table 2 of ER 1110-2-1806, whereas for intermittently loaded levee or floodwall, seismic loading (Table 2 of ER 1110-2-1806) is considered in design and evaluation. ER 1110-2-1806 requires,

- *In moderate and high seismic ground motion hazard regions (paragraph 9d), mitigation measures for non-seismic potential failure modes (PFMs) cannot increase the risk for seismic PFMs.*
- *Cost effective seismic mitigation measures will be implemented when justified based on the results of a project-specific risk assessment including considerations for post-earthquake response and repair (feasibility and cost)".*

Proposed flood control measures for the San Francisco Waterfront project are being developed considering potential sea level rise and flood due to storms. Based on the Port of San Francisco's Seismic Measures Development Report, the following criteria can be inferred as the performance criteria at the seawall bulkhead:

Table ES-1. Performance Objectives and Lateral Displacement Criteria at Seawall Bulkhead, as Inferred from CH2M-ARCADIS Team Report (2021)

Seismic Loading	Performance Objective	Lateral Displacement at Seawall Bulkhead
225-year return period	Controlled and Repairable Damage Limited Loss of Serviceability • Desired performance if spending significant money on upgrades	3/4 - ft
975-year return period	Collapse Prevention • Minimum requirement for any upgrades • Equivalent to a Building Code “MCE”	1.5 - ft

We consider that the performance criteria established by the Port of San Francisco for the project are reasonable for a high seismic region like San Francisco. However, USACE should perform an independent risk-analysis to establish performance criteria consistent with Section 9C(7) of ER 1110-2-1806 for intermittently-loaded levees and floodwalls.

Preliminary seismic analyses of compact, limited footprint ground improvement schemes for Pier 27 and Pier 30-32 meet performance criteria established by the Port of San Francisco. The preliminary seismic analyses also meet the 225-year return period criteria with the much higher loading of the 475-year return period (seismic loading for operating basis earthquake ground motion, OBE-GM, as per USACE ER 1110-2-1806).

c. Analytical Approach for the Existing Conditions by Port of San Francisco and USACE (Current Study)

Fugro performed nonlinear seismic deformations analyses for existing conditions at 16 locations along portions of the Northern Waterfront Segment for the Port of San Francisco under the Seawall Earthquake Safety Program (Fugro, 2020). Based on an evaluation of existing conditions seismic analyses, two sections were selected for seismic analyses in this study.

Pier 27: Represents geologic conditions with a relatively thicker-soft Young Bay Mud (YBM) layer under rock dike. Seismic deformations at the edge of the waterfront may be due to impacts of both potentially liquefiable hydraulic fill and soft YBM. This analysis section should be representative of most of the northern sub-reaches of the Northern Waterfront Segment (from Hyde Street Pier to Pier 29). Fugro (2020) existing conditions analysis indicates relatively higher lateral deformations at this section compared to other locations with similar geologic conditions.

Pier 30-32: Represents geologic conditions with a relatively thinner-soft YBM layer (less than 6 ft to non-existent) under the rock dike. Seismic deformations at the edge of the waterfront may be mainly due to impacts of potentially liquefiable hydraulic fill with less impact from deep-seated foundation soil-induced deformations. This analysis section should be representative of the southern portion of the Northern Waterfront Segment (south of the Ferry Building or Yerba Buena Cove area). Fugro (2020) analyses in this area have shown limited lateral deformations (meeting Port performance criteria with existing conditions).

The analysis approach undertaken by Fugro does not allow potentially liquefiable soils to transition to post-liquefaction residual strength of sand after liquefaction or residual strength of clay at large deformation. The approach utilizes a separate limit-equilibrium analysis to check stability of the structure.

USACE analysis approach utilizes transition to post-liquefaction residual strength of potentially liquefiable soils after liquefaction is triggered. It also utilizes transition to reduced strength based on development of large strains in the YBM. This analytical approach has successfully predicted moderate to large deformation case histories using appropriate constitutive models, liquefaction triggering relationships, post-liquefaction residual strength relationships, and clay strain-dependent strength reduction.

Due to these differences in analytical approaches, lateral displacements for existing conditions from the USACE analyses are higher than Port of San Francisco analyses. However, significant reduction in lateral displacements with proposed limited footprint ground improvement measures indicate robustness of the measures.

Table ES-2. Seismic Deformation Analysis Results for Existing Conditions

Agency and Project	Lateral Displacement at Seawall Bulkhead (ft)			Comment
	225-Years Return Period	475-Years Return Period	975-Years Return Period	
	Pier 27			
Port of San Francisco (Seawall Earthquake Safety Program)	0.97 ft	Not performed	4.1 ft	Deformations due to both potentially liquefiable fill layer and soft YBM foundation layer.
USACE (Current Study)	1.11 ft	1.52 ft	4.32 ft	
	Pier 30-32			
Port of San Francisco (Seawall Earthquake Safety Program)	0.31 ft		0.57 ft	Deformation at existing seawall bulkhead location is mainly due to liquefaction of fill soils, as foundation YBM layer is thinner. USACE analysis indicates higher displacement, as it allows transition to post-liquefaction residual strength.
USACE (Current Study)	1.29	1.58ft	4.57 ft	

d. Results of Seismic Analyses with Limited Ground Improvement Footprint:

Fugro performed nonlinear seismic deformations analyses for existing conditions at 16 locations along portions of the Northern Waterfront Segment for the Port of San Francisco under the Seawall Earthquake Safety Program (Fugro, 2020). In draft EIS (USACE, 2024), no seismic analyses were performed to support the ground improvement measures estimated for the TSPs in the draft EIS. incorporating the selected ground improvement measures and raised conditions.

PIER 27: Three ground improvement measures were considered in this section:

1. Deep Mixing Method (DMM) wall (30-ft wide perpendicular to the floodwall alignment) – landside and waterside
2. Floodwall founded on secant drilled shaft wall (10-ft diameter reinforced drilled shaft)

3. Slurry wall panels perpendicular to shoreline (4 ft thick wall 20 feet long perpendicular to shoreline and with 20 ft spacing between rows).

Analysis results indicate that all three mitigation measures result in less than 0.5 feet lateral displacement for 225-year and 475-year return period ground motions and less than 1.5 feet lateral displacement for 975-year return period at the floodwall location.

Pier 30-32: Considering that potential deformations at this section is due to potentially liquefiable fill layer, one ground improvement measure was considered in this section:

1. Floodwall founded on secant drilled shaft wall (6-ft diameter reinforced drilled shaft)

Analysis results indicate that a flood wall founded on a drilled shaft mitigation measure result in less than 0.5 feet lateral displacement for both the 225-year and the 475-year return period ground motions and less than 1.5 feet lateral displacement for 975-year return period at the floodwall location.

Table ES-3 presents results of seismic analysis with limited ground improvement footprint.

Table ES-3. Seismic Deformation Analysis Results for Compact, limited footprint Ground Improvement Schemes

Ground Improvement Measure with Limited Footprint	Lateral Displacement at Floodwall (ft)		
	225-Years Return Period	475-Years Return Period	975-Years Return Period
	Pier 27		
Deep Mixing Method (DMM) wall (30-ft wide perpendicular to the floodwall alignment) – landside	0.21 ft	0.30 ft	1.30 ft
Deep Mixing Method (DMM) wall (30-ft wide perpendicular to the floodwall alignment) – waterside	Not performed	0.32 ft	Not performed
Secant drilled shaft wall (10 ft diameter)	0.34 ft	0.47 ft	1.21 ft
Slurry wall panel perpendicular to shoreline (4 ft thick wall, 20 ft long perpendicular to shoreline, with 20 ft center to center spacing between walls – landside	0.19 ft	0.31 ft	1.46 ft
Slurry wall panel perpendicular to shoreline (4 ft thick wall, 20 ft long perpendicular to shoreline, with 20 ft center to center spacing between walls – waterside	Not performed	0.35 ft	Not performed
	Pier 30-32		
Secant drilled shaft wall (6 ft diameter)	0.27 ft	0.37 ft	0.97 ft

e. Depth of Proposed Ground Improvement Measures:

The current, very generic Deep Mixing Method (DMM) soil improvement scheme presented in the draft EIS (USACE, 2024) does not appear to be deep enough over much of the alignment. A re-evaluation of the planning level ground improvement footprint for the Northern segment (except for the Aquatic Cove Park area) can be developed considering

floodwall alignment, landside and waterside usage, subsurface conditions, rock dike depth, etc. However, limited or inadequate data is available in the southern segment.

f. Raised Ground in Landside of Floodwall:

The flood protection system can be implemented without the need for raised ground elevation on the landside. The footprint of the flood wall or berm can be designed to be limited. Extending elevated ground up to 100-ft back from the seawall is disruptive and will require utility relocations and reconstruction of infrastructure (e.g. light rail). Also, limiting the extent of ground improvement for the flood control system will reduce the need for mitigation for complex long term impacts on the existing roadway, light rail, utilities, and nearby buildings.

g. Outreach to Specialty Contractors:

Some initial engineering and analysis of seismic stabilization schemes is required, including consultation with specialty contractors. It is too great a project risk to leave this critical aspect of the project only loosely specified and described. Topics that require consultation may include, but are not limited to the presence of the rock dike on the northern segment, the potential presence of obstructions, utility relocations, construction in heavily urban environments, and ground water conditions influenced by tides. The planning of ground improvement and other seawall stabilization schemes appears to have relied on a limited number of very preliminary seismic analyses. The seismic stabilization scheme is a key, foundational component of the TSP, representing a major project cost and constraint.

h. Future Considerations for TSP Design and Analysis:

Seismic analysis performed during this study were performed to evaluate whether ground improvement measures can be implemented in a limited footprint. Engineering analyses (seismic deformation analyses) performed as part of this review support the feasibility of more compact seismic stabilization schemes more directly focused on improving the seismic performance of the floodwall itself (as shown on Table ES-2). In the design phase, the following tasks can be implemented to achieve design objectives while optimizing design measures:

1. Fugro (2020) has shown that the presence of wharfs on the waterside reduces potential of lateral deformations by about 30 to 50 percent for the 225-years and 975-years return period due to pinning effects of the existing piles. The positive impact of the waterside wharfs should be considered in design level analyses to optimize design measures.

2. Ground improvement schemes on the water side of the floodwall should be considered for sections of the alignment between the wharves. These may significantly reduce the potential disruption and impacts on utilities.
3. In the design phases, 3-dimensional analyses at critical reaches should be performed to evaluate complex soil-structure interactions due to the presence of wharfs, variable geologic conditions, and changes in ground improvement measures. It will be necessary to evaluate soil deformations in between DMM or slurry wall panels (perpendicular to the shoreline) and optimize spacings in between rows.

i. Proposed Locations for Seismic Evaluations and Analysis for Planning Study:

Nonlinear seismic deformations analyses were performed at two locations in this preliminary stage due to lack of data, selected alignment, and other project constraints. We recommend that further evaluations and analyses should be performed at the following specific areas during the planning phase:

- Aquatic Cove Park area (to select alignment and ground improvement measure)
- Ferry Building area (after flood control system alignment is available)
- Oracle Park in Mission Creek (whether any ground improvement is needed, as a recent seismic retrofit was implemented for the bulkhead wall and stadium)
- Mission Creek area (evaluate berm measures in open space adjacent to buildings – 2 sections to represent two banks of Mission Creek)
- The naturalized berm (less than 2 feet in height) in the southern segment considering performance criteria, post-earthquake repair, land use, alignment, etc. The current plan for large scale ground improvement in in this area (50 feet to 100 feet landward) should be re-evaluated (minimum of 2 sections with different geologic conditions).
- The alignment of the floodwall or berm and ground improvement alternatives at the two pier locations (Pier 80 and Piers 92-94-96) should be re-evaluated and analyzed.

The planning reaches should be broken down into more detailed sub-reaches considering land use on the waterside and the landside, geology, target elevation, etc. The current plan paints with too broad brush. Surface and subsurface conditions are too variable within the identified reaches.

Most of these proposed analysis locations are in the Southern Waterfront Segment. The Northern waterfront segment (excluding the Aquatic Cove park area) has an existing seawall and rock dike. These features (seawall and rock dike) are not present along the Southern waterfront segment (Mission Rock to Heron's Head Park), which impacts the performance of a proposed flood control system. Currently no analyses are available to evaluate the proposed flood control system in the southern segment. One partial exception to this is the Port of San Francisco analysis for Pier 80, but this is not representative of the variable surface and subsurface conditions along the 5.5 miles of southern waterfront segment.

Significant project risk currently exists due to non-availability of data or analyses at these locations or sub-reaches.

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1. Introduction

Low-lying assets and economic activity along the San Francisco Waterfront are at risk of flooding from coastal storms, extreme high tides, and sea level rise. The frequency and depth of tidal flooding along the shoreline is expected to increase as sea levels continue to rise. The San Francisco Waterfront Coastal Flood Study, CA coastal flood risk management study (SFWCFS) is authorized to investigate the feasibility of managing tidal and fluvial flooding and sea level rise along 7.5 miles of the San Francisco Waterfront, from Aquatic Park to Herons Head Park, in the City of San Francisco, San Francisco County, California.

The Tentatively Selected Plan (TSP) for the San Francisco Waterfront Coastal Flood Study is described in the report: *San Francisco Waterfront Flood Study, Draft Integrated Feasibility Report and Environmental Impact Statement*, prepared by the US Army Corp of Engineers (USACE), Tulsa District and the Port of San Francisco.

Since the San Francisco Bay Area is a very seismically active region, an important design and planning consideration is earthquake loading and potential earthquake damage to the floodwalls, levees, berms and other improvements proposed in the TSP. The waterfront area is particular susceptible to earthquake damage due to the presence of liquefiable fill and native soils, as well as the soft Young Bay Mud which underlies much of the waterfront.

This report presents review, commentary, and observations on the draft Tentatively Selected Plan (TSP) for the San Francisco Waterfront Coastal Flood Study (USACE, 2024) and results of seismic analysis at two selected locations. The main objective of the study is to evaluate ground improvements measures for the project.

Initial review of the TSP showed that, the very wide (up to 100-ft) ground improvement scheme for seismic stabilization proposed may not be appropriate for the dense urban environment along the Embarcadero, with tightly packed expensive infrastructure, buildings, roadways, light rail and utilities. In addition, it appeared that the planning of ground improvement and other seawall stabilization schemes were not based on engineering analyses. The seismic stabilization scheme is a key, foundational component of the TSP, representing a major project cost and constraint. The estimated cost of ground improvement is about \$8 billion or more. Seismic analysis to support this kind of expensive component of a project is a common practice in plan formulations studies.

For these reasons, as part of this review, additional engineering analyses were performed to investigate more compact seismic stabilization schemes that are more directly focused on improving the seismic performance of the floodwall itself. The findings from these seismic deformation analyses informed this review and commentary on the TSP.

1.1. Reference Documents

The following documents were reviewed as part of the current study:

1. Draft Integrated Feasibility Report and Environmental Impact Statement, San Francisco Waterfront Coastal Flood Study, CA, January 2024 (USACE). January 2024
2. Geotechnical Data Report, Seawall Earthquake Safety Program, San Francisco, CA. Prepared by FUGRO, for Port of San Francisco, May 07 to November 30, 2018, DRAFT
3. Geotechnical Interpretive Report, Seawall Earthquake Safety Program, San Francisco, CA. Prepared by FUGRO, for Port of San Francisco, January 31, 2020, FINAL
4. Earthquake Hazard & Geotechnical Assessment Report, Embarcadero Seawall Program, San Francisco, CA. Prepared by FUGRO, for Port of San Francisco, October 30, 2020, FINAL (REVISED)
5. Seismic Measures Development Report, Port of San Francisco Waterfront Resilience Program, Prepared by FUGRO, for Port of San Francisco, April 20, 2021, FINAL
6. Initial Southern Waterfront Earthquake Assessment, Prepared by PARSONS/RJSD AND EARTHMECHANICS for Port of San Francisco, January 2022, FINAL

Reports 2 to 5 includes geotechnical data, existing conditions analysis, and discussions on conceptual ground improvement measures.

On May 24, 2024, Port of San Francisco and their consultant (Fugro) have presented a summary of previous seismic studies to USACE. The following presentation slides were also reviewed during this study.

1. USACE Meeting – Summary of Geotechnical Evaluations for MHRA, by FUGRO
2. San Francisco Waterfront Flood Study - Ground Improvement Analyses, by Port of San Francisco
3. Deep Soil Mixed Buttresses in Fine-Grained Soil - Considerations for Performance-Based Seismic Design, by Dr. Stephen Dickenson, Principal Engineer, New Albion Geotechnical, Inc.

2. Seismic Performance Criteria

Establishing seismic performance criteria is a key, necessary step in the planning process for the San Francisco Waterfront Project. As per the definitions in ER 1110-2-1806, the proposed floodwall and berms can be considered as intermittently loaded floodwalls or levees. Performance criteria and seismic loading for frequently loaded levees or floodwalls are determined based on Table 2 of ER 1110-2-1806, whereas for intermittently loaded levees or floodwalls, seismic loading (Table 2 of ER 1110-2-1806) is considered in design and evaluation. ER 1110-2-1806 requires,

- *In moderate and high seismic ground motion hazard regions (paragraph 9d), mitigation measures for non-seismic potential failure modes (PFMs) cannot increase the risk for seismic PFMs.*
- *Cost effective seismic mitigation measures will be implemented when justified based on the results of a project-specific risk assessment including considerations for post-earthquake response and repair (feasibility and cost)".*

The proposed flood control measures for the San Francisco Waterfront project are being developed considering potential sea level rise and flooding due to storms. Based on the Port of San Francisco's Seismic Measures Development Report, the following criteria can be inferred as the performance criteria at the seawall bulkhead:

Table 2-1. Performance Objectives and Lateral Displacement Criteria at Seawall Bulkhead, as Inferred from CH2M-ARCADIS Team Report (2021)

Seismic Loading	Performance Objective	Lateral Displacement at Seawall Bulkhead
225-year return period	Controlled and Repairable Damage Limited Loss of Serviceability • Desired performance if spending significant money on upgrades	3/4 - ft
975-year return period	Collapse Prevention • Minimum requirement for any upgrades • Equivalent to a Building Code "MCE"	1.5 - ft

We consider that these performance criteria established by the Port of San Francisco for the project are reasonable for a high seismic region like San Francisco. However, USACE should perform an independent risk-analysis to establish performance criteria consistent with Section 9C(7) of ER 1110-2-1806 for intermittently-loaded levees and floodwalls.

Considering the USACE Operating Basis Earthquake Ground Motion (OBE-GM) for Critical project features is the 475-year return period, seismic analyses for the current report were performed for 475-year return period, in addition the 225-year and 975-year return periods.

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3. Alternative Waterfront Stabilization Schemes Analyzed

The draft TSP, especially for the Northern Waterfront, proposes a very wide ground improvement scheme, extending up to 100-ft inland from the seawall. In addition, it appears that the selected ground improvement schemes were not based on specific geo-structural seismic analysis considering the future condition of the floodwall and sea level rise. Previous seismic analyses performed by the Port of San Francisco were intended to evaluate seismic deformations of existing conditions, and seismic measures without considering flood conditions or future sea level rise. The seismic stabilization scheme is a key, foundational component of the draft TSP, representing a major project cost and constraint.

For these reasons, as part of this review of the draft TSP, additional engineering analyses were performed to investigate more compact seismic stabilization schemes more directly focused on improving the seismic performance of the floodwall itself. The findings from these seismic deformation analyses then informed this review the TSP.

3.1. Selection of Sections for Seismic Analyses

Analyses were performed for two cross-sections: the first representing subsurface conditions at Pier 27 and the second section representing subsurface conditions at Piers 30-32. Existing conditions for these cross sections are shown in Figures 3-1 and 3-2. The sections were selected to represent average or typical conditions along a section of the alignments. The Pier 27 section is representative of conditions over much of Reach 2, excluding the Pier 3 and Ferry Building area where the Young Bay Mud is much thicker. The Piers 30-32 section is representative of conditions over much of the northern portions of Reach 3, from the Bay Bridge to Mission Creek. Surface and subsurface geometry for both cross sections were provided by Fugro based on their recent seismic deformation analyses of existing conditions (Fugro, 2020).

Even though Pier 3 and Ferry Building area in Yerba Buena Cove area may be critical due to the presence of thick YBM, no analysis section was selected in this area. Our understanding is that alignment of floodwall is yet to be determined in this area due to the presence of historic buildings.

It should be noted that both analysis sections were selected within Northern Waterfront Segment where there is adequate geotechnical data available. For the Southern Waterfront, the geotechnical data required to perform more detailed seismic analysis is not currently available or documented. There are significant differences between the Northern and Southern Waterfront Segments due to factors such as target raise elevation, presence or absence of rock dike, thickness of hydraulic fill, land use, etc.

3.2. Seismic Analysis Approach

Nonlinear, seismic deformation analyses were performed with the computer code FLAC, Version 8.0 (Itasca, 2016), a program widely used for seismic analyses of embankment dams, waterfront retaining structures (e.g. wharves, quays, etc.), pile foundations and other analyses involving the dynamic response of soil and rock. Analysis details, including technical approach, input earthquake ground motions, structural properties as well as liquefaction modeling are described in Appendix A. Seismic analyses were performed for both existing conditions and with potential ground improvement measures.

3.3. Results of Existing Conditions Seismic Analyses

For existing conditions, the USACE FLAC analyses can be compared with recent analyses for Fugro (2020). Fugro performed nonlinear seismic deformations analyses for existing conditions at 16 locations along portions of the Northern Waterfront Segment for the Port of San Francisco under the Seawall Earthquake Safety Program (Fugro, 2020).

Note that there are differences in the analysis approach of Fugro (2020) and the USACE analyses for the current study. The analysis approach used by Fugro does not allow potentially liquefiable soils to transition to post-liquefaction residual strength of sand after liquefaction or residual strength of clay at large deformation. The approach utilizes a separate limit-equilibrium analysis to check stability of the structure.

In contrast, in the USACE analysis approach, liquefiable soils transition to post-liquefaction residual strength after liquefaction is triggered. The USACE analyses also include transition to reduced shear strength with large strains in the YBM. This analytical approach has successfully predicted moderate to large deformation case histories using appropriate constitutive models, liquefaction triggering relationships, post-liquefaction residual strength relationships, and clay strain-dependent strength reduction.

Due to these differences in analytical approaches, lateral displacements for existing conditions from the USACE analysis are higher than those from the Port of San Francisco analysis. Nevertheless, the USACE analyses presented here (Section 3.5) demonstrate that the proposed compact ground improvement schemes are successful in greatly reducing seismic displacements.

For existing conditions, permanent shaking-induced horizontal displacements for the Pier 27 and Piers 30-32 analyses are listed in Table 3-1. Additional analysis results can be found in Appendix A.

Table 3-1. Seismic Deformation Analysis Results for Existing Conditions

Agency and Project	Lateral Displacement at Seawall Bulkhead (ft)			Comment
	225-Years Return Period	475-Years Return Period	975-Years Return Period	
	Pier 27			
Port of San Francisco (Seawall Earthquake Safety Program)	0.97 ft	Not performed	4.1 ft	Deformations due to both potentially liquefiable fill layer and soft YBM foundation layer.
USACE (Current Study)	1.11 ft	1.52 ft	4.32 ft	
	Pier 30-32			
Port of San Francisco (Seawall Earthquake Safety Program)	0.31 ft		0.57 ft	Deformation at existing seawall bulkhead location is mainly due to liquefaction of fill soils, as foundation YBM layer is thinner. USACE analysis indicates higher displacement, as it allows transition to post-liquefaction residual strength.
USACE (Current Study)	1.29	1.58 ft	4.57 ft	

3.4. Results Seismic Analyses with Ground Improvement Measures

Three ground improvement measures or schemes were analyzed for Pier 27 and one ground improvement scheme was analyzed for Pier 30-32. Description of these ground improvement schemes are presented below.

3.4.1.1 30-ft Wide DMM Panels directly Behind Current Bulkhead

The first seismic stabilization scheme analyzed was 30-ft wide Deep Mixing Method (DMM) panels, installed directly behind the existing seawall. The following assumptions were used for the DMM panels:

- Unconfined compressive strength of 400 psi
- Area replacement ratio of 50 percent

- Depth of wall 10-feet below the bottom of the YBM layer

A cross section illustrating the DMM panel scheme for Pier 27 is shown in Figures 3-3. Engineering properties used for analyses of the DMM are listed in Table A-3.

In the project design phases, more detailed analyses, including 3D analyses, should be performed to evaluate the performance of the DMM panels and interaction with the soils in between panels, tensile yielding of the DMM panels, impacts of the waterside wharfs (pile pinning effects), etc. Structural details such as shorter floodwall sections, etc. can be developed based on detailed design-level analyses.

3.4.2 Drilled Shaft Secant Walls

The 2nd seismic stabilization scheme analyzed was a structural solution consisting of a secant wall consisting of 6-ft diameter drilled shafts, at 6-ft spacing (Piers 3-32), or 10-ft diameter drilled shafts at 10-ft spacing (Pier 27). Note that in practice, the secant walls would require some gaps so as not to impede groundwater flow. Cross sections illustrating the drilled shaft secant wall scheme are shown in Figure 3-4 (Pier 27) and Figure 3-5 (Piers 30-32). Structural properties used for the drilled shafts are listed in Table A-4.

3.4.3 Slurry Wall Panels Perpendicular to the Shoreline

A 3rd seismic stabilization scheme analyzed was a structural solution consisting of 20-ft long reinforced concrete slurry wall panels oriented perpendicular to the shoreline. The scheme modeled consisted of 4-ft wide panels, at a 20-ft spacing along the shoreline. A cross section illustrating the slurry wall panel scheme for Pier 27 is shown in Figure 3-6. The 20-ft long slurry wall panels can be narrower than the 30-ft long DMM panels, as there is less concern about tensile yielding. In a sense the slurry walls can be thought of much stronger, stiffer DMM panels with tensile reinforcing.

3.5. Analysis Results and Discussion

For the ground improvement schemes, permanent shaking-induced horizontal displacements for the Pier 27 and Piers 30-32 analyses are listed in Table 3-2. Additional analysis results can be found in Appendix A.

Analysis results indicate that flood wall founded on any of three ground improvement measures in Pier 27 result in less than 0.5 feet lateral displacement for 225-year and 475-year return period ground motions and less than 1.5 feet lateral displacement for 975-year return period at the floodwall location. Analysis results indicate that the flood wall founded on secant drilled shaft measures for Piers 30-32 result in less than 0.5 feet lateral displacement for both the 225-year and 475-year return period ground motions and less than 1.5 feet lateral displacement for 975-year return period at the floodwall location.

Table 3-2 presents results of seismic analysis with a compact, limited ground improvement footprint.

Table 3-2. Seismic Deformation Analysis Results for Compact Ground Improvement Schemes

Ground Improvement Measure with Limited Footprint	Lateral Displacement at Floodwall (ft)		
	225-Years Return Period	475-Years Return Period	975-Years Return Period
	Pier 27		
Deep Mixing Method (DMM) wall (30-ft wide perpendicular to the floodwall alignment) – landside	0.21 ft	0.30 ft	1.30 ft
Deep Mixing Method (DMM) wall (30-ft wide perpendicular to the floodwall alignment) – waterside	Not performed	0.32 ft	Not performed
Secant drilled shaft wall (10 ft diameter)	0.34 ft	0.47 ft	1.21 ft
Slurry wall panels perpendicular to shoreline (4 ft thick wall, 20 ft long perpendicular to shoreline, with 20 ft center to center spacing between walls – landside	0.19 ft	0.31 ft	1.46 ft
Slurry wall panels perpendicular to shoreline (4 ft thick wall, 20 ft long perpendicular to shoreline, with 20 ft center to center spacing between walls – waterside	Not performed	0.35 ft	Not performed
	Pier 30-32		
Secant drilled shaft wall (6 ft diameter)	0.27 ft	0.37 ft	0.97 ft-

The seismic deformation analysis results support the feasibility of more compact seismic stabilization schemes more directly focused on improving the seismic performance of the floodwall itself.

4. Detailed Observations and Recommendations for individual Waterfront Sub-Reaches

A review of the existing information, as presented in the draft TSP and EIS and supporting reports (Section 1.1) was performed to evaluate the existing land use, subsurface conditions, and proposed ground improvement and other mitigation measures in the draft TSP and EIS (USACE, 2024).

For the Northern Waterfront, a total of four sub-reaches were identified (sub-reaches North 1 to 4). Two of these sub-reaches were further sub-divided into two segments (sub-reaches North 1 and 2). Comments and observations on these Northern Waterfront sub-reaches are listed in Table 4-1. Appendix B provides additional details, discussion and plan views of these sub-reaches. It should be noted that the potential ground improvement schemes or other alternative measures listed in Column 3 of Table 4-1 were developed based on comparing subsurface conditions of two sections (Pier 27 and Piers 30-32) (Chapter 3) with similar conditions (where data is available). In Sub-Reaches North 1A, no data is available, and the proposed measure is an alternative for consideration. Further evaluation will be required after additional site data is collected.

Table 4-1. Northern Waterfront Segment Sub-Reaches – Potential Ground Improvement or Alternative Measures

Sub-Reach Target Raise Elevation and Current Ground Improvement Plan in Draft EIS (USACE, 2024)	Land Use	Discussions on Potential Ground Improvement or Other Alternative Measures
Sub-Reach North – 1 North Beach 5,000 feet Raise to El. 15.5 ft (~5 ft. raise) Ground Improvement 50 ft. x 50 ft.	North 1A: Aquatic Cove Park area (~1000-1200 feet length), ground elevation rises towards inland (Ghirardelli Square)	Low height curb wall at park area (away from shoreline such as along city streets) and flood gate or other closure structure at both ends may be more appropriate.)
	North 1B: North Beach – Hyde Street Pier to Taylor Street	Floodwall on Drilled Shaft and No or Very Limited Additional Landward Ground Improvement, as the landward area is very limited with presence of buildings and streets.
	North 1C: Taylor Street to North of Pier 29	Smaller Ground Improvement Footprint 30 feet (width) x 65 to 75 feet (depth) ~4000 feet

Sub-Reach Target Raise Elevation and Current Ground Improvement Plan in Draft EIS (USACE, 2024)	Land Use	Discussions on Potential Ground Improvement or Other Alternative Measures
	Wharves and piers (Pier 39, Fisherman's wharf, etc.)	
Sub-Reach North – 2 Yerba Buena Cove to Bay Bridge 6,500 feet	North 2A: Pier 29 to Pier 15 (~2500 feet area). Shallower Fill + YBM than Ferry building area.	Smaller Ground Improvement Footprint 30 feet (width) x 65 to 75 feet (depth) ~2500 feet
Raise to El. 15.5 ft (~5 ft. raise) Ground Improvement 100 ft. x 100 ft.	North 2B: Ferry Building Area (Pier 9 to Ferry Building area).	Alignment of floodwall is under considerations. Ground improvement plan should be developed after alignment is selected.
Sub-Reach North – 3 Rincon Point to Bay Bridge 2,000 feet Raise to El. 15.5 ft (~5 ft. raise) Ground Improvement 50 ft. x 50 ft.	North 3: South of Ferry Building to Bay Bridge (~2000 feet). Shallower Fill + YBM than Ferry building area. Park area.	Floodwall on Drilled Shaft and No Additional Landward Ground Improvement
Sub-Reach North – 4 South Beach 4,000 feet Raise to El. 13.5 ft (<2 ft. raise) Ground Improvement 50 ft. x 50 ft.	North 4: South of Bay Bridge to Mission Creek (AT&T Park). Wharfs, park, and parking lot area.	<u>Alternative 1:</u> Floodwall on Drilled Shaft and NO Additional Landward Ground Improvement. <u>Alternative 2:</u> Shoreline raise integrated with erosion protection and No Additional Landward Ground Improvement (damage expected during earthquake).

For the Southern Waterfront, a total of three sub-reaches were identified (sub-reaches South 1 to 3). Sub-Reach South 1 was further sub-divided into three segments (A, B and C). Comments and observations on these Southern Waterfront sub-reaches are listed in Table 4-2. Appendix B provides additional details, discussion and plan views of these sub-reaches.

It should be noted that potential ground improvement or other alternative measures in Column 3 of Table 4-2 were not developed based on any analysis. Neither the Port of San Francisco nor USACE has performed seismic analyses as part of the flood control project. A set of simplified seismic analyses at Pier 80 was performed by the Port of San Francisco, which may need further evaluation, once alignment of the proposed project is developed. For the majority of the Southern Waterfront, no data is available or properly documented. These discussions on proposed measures are conceptual alternatives for consideration. Further evaluations and analyses will be required after data collection is performed.

Table 4-2. Southern Waterfront Segment Sub-Reaches – Potential Ground Improvement or Alternative Measures

Sub-Reach Target Raise Elevation and Current Ground Improvement Plan in Draft EIS (USACE, 2024)	Land Use	Discussions on Potential Ground Improvement or Other Alternative Measures
Sub-Reach South-1 Mission Creek ~7,000 feet Raise to El. 13.5 ft Naturalized shoreline (<2 ft. raise) Ground Improvement 50 ft. x 50 ft.	South-1A Oracle Park (~1000 feet)	Limited shoreline work may be needed, if recent bulkhead wall retrofit and foundation work for AT&T park meet project objectives for SFWP.
	South-1B North Mission Creek Bank (~3000 feet)	Naturalized shoreline berm for 1.5 ft SLR Alternative 1: No ground improvement may be needed, if project allows post-seismic repair based on risk-assessment, as cost of naturalized shoreline berm of 1.5 ft repair may not be significant. Seismic analysis will be required to assess damage potential. Alternative 2: Limited ground improvement based on location, type, and consequence of flood control measure.
	South-1C South Mission Creek Bank (wider park area) (~3000 feet)	
Sub-Reach South-2 Mission Creek to Islais Creek ~7,700 feet Raise to El. 13.5 ft Naturalized shoreline (<2 ft. raise)	Pier 48 to Potrero Point (~3000 feet) Islais Creek (~4,700 feet)	Naturalized shoreline raise for 1.5 ft SLR. Alternative 1: No ground improvement may be needed, if project allows post-seismic repair based on risk-assessment, as cost of naturalized shoreline berm of 1.5 ft repair may not be significant. Seismic analysis will be required to assess damage potential.

Sub-Reach Target Raise Elevation and Current Ground Improvement Plan in Draft EIS (USACE, 2024)	Land Use	Discussions on Potential Ground Improvement or Other Alternative Measures
Ground Improvement 50 ft. x 50 ft.		Alternative 2: Limited ground improvement based on location, type, and consequence of flood control measure.
Sub-Reach South-3 Piers ~14,800 feet Raise to El. 13.5 ft Curb Wall (<2 ft. raise) Ground Improvement 100 ft. x 100 ft.	Pier 80 (~6,300 feet) Pier 92-94-96 (~8,500 feet)	Curb wall at a distance from edge to reduce need for extensive ground improvement. Different types of ground improvement measures should be evaluated.

5. Conclusions and Recommendations

Based on a review of the draft TSP, supporting reports, and new seismic analyses performed specifically for this review, the following conclusions and recommendations are made:

a. Subsurface Data Adequacy for TSP:

While there is adequate subsurface geotechnical information for the Northern Waterfront segment (except for Aquatic Cove Park) for plan formulation study, subsurface data along the Southern Waterfront alignment is either unavailable or inadequate for planning and engineering evaluations. This is a significant risk to the project.

We recommend development of plans and profiles with appropriate scale for the entire project alignment to identify the data gaps. A data gap analysis should be performed to identify sub-reaches with data gaps. This data gap analysis should be utilized to develop and implement a subsurface investigation program to support plan formulation study.

b. Performance Criteria for the Project:

As per definitions in ER 1110-2-1806, the proposed floodwalls and berms can be considered intermittently loaded floodwalls and levees. Performance criteria and seismic loading for frequently loaded floodwalls and levees are determined based on Table 2 of ER 1110-2-1806, whereas for intermittently loaded floodwalls or levees, seismic loading (Table 2 of ER 1110-2-1806) is considered in design and evaluation. ER 1110-2-1806 requires,

- *In moderate and high seismic ground motion hazard regions (paragraph 9d), mitigation measures for non-seismic potential failure modes (PFMs) cannot increase the risk for seismic PFMs.*
- *Cost effective seismic mitigation measures will be implemented when justified based on the results of a project-specific risk assessment including considerations for post-earthquake response and repair (feasibility and cost)".*

We consider that the performance criteria established by the Port of San Francisco for the project are reasonable for high seismic region like San Francisco. However, USACE should perform an independent risk-analysis to establish performance criteria consistent with Section 9C(7) of ER 1110-2-1806 for intermittently-loaded levees and floodwalls.

c. Potential Limited or Compact Footprint of Ground Improvement Measures

Fugro performed nonlinear seismic deformations analyses for existing conditions at 16 locations along portions of the Northern Waterfront Segment for the Port of San Francisco under the Seawall Earthquake Safety Program (Fugro, 2020). In draft EIS (USACE, 2024), no seismic analyses were performed to support the ground improvement measures estimated

for the TSPs in the draft EIS with incorporating the selected ground improvement measures and raised conditions.

PIER 27: Three ground improvement measures were considered in this section:

1. Deep Mixing Method (DMM) panels (30-ft wide perpendicular to the floodwall alignment) – landside and waterside
2. Floodwall founded on secant drilled shaft wall (10-ft diameter reinforced drilled shaft)
3. Slurry wall panels perpendicular to the shoreline (4 ft wide panels, 20 feet long perpendicular to shoreline and with 20 ft center to center spacing between panels).

Analysis results indicate that all three mitigation measures result in less than 0.5 feet of lateral displacement for both 225-year and 475-year return period ground motions and less than 1.5 feet lateral displacement for the 975-year return period at the floodwall location.

Pier 30-32: Considering that potential deformation at this section is due primarily to the potentially liquefiable fill layer, only a single ground improvement measure was considered in this section:

1. Floodwall founded on secant drilled shaft wall (6-ft diameter reinforced concrete drilled shaft)

Analysis results indicate that flood wall founded on the drilled shaft mitigation measure results in less than 0.5 feet lateral displacement for both 225-year and 475-year return period ground motions and less than 1.5 feet lateral displacement for the 975-year return period at the floodwall location.

d. Depth of Proposed Ground Improvement Measures:

The current, very generic Deep Mixing Method (DMM) soil improvement scheme in draft EIS (USACE, 2024) does not appear to be deep enough over much of the alignment. A re-evaluation of the planning level ground improvement footprint for the Northern segment (except Aquatic Cove Park area) can be developed considering floodwall alignment, landside and waterside usage, subsurface conditions, rock dike depth, etc. However, limited or inadequate data is available in the southern segment.

e. Raised Ground in Landside of Floodwall:

The flood protection system can be implemented without the need for raised ground elevation on the landside. The footprint of the flood wall or berm can be designed to be limited. Extending elevated ground up to 100-ft back from the seawall is disruptive and will

require utility relocations and reconstruction of infrastructure (e.g. light rail). Also, limiting ground improvement for the flood control system will reduce the need for mitigation for complex long-term impacts on the existing roadway, light rail, utilities, and nearby buildings.

f. Outreach to Specialty Contractors:

Some initial engineering and analysis of seismic stabilization schemes is required, including consultation with specialty contractors. It is too great a project risk to leave this critical aspect of the project only loosely specified and described. Topics that require consultation may include, but are not limited to the presence of the rock dike on the northern segment, the potential presence of obstructions, utility relocations, construction in heavily urban environments, and ground water conditions influenced by tides. The planning of ground improvement and other seawall stabilization schemes appears to have relied on a limited number of very preliminary seismic analyses. The seismic stabilization scheme is a key, foundational component of the TSP, representing a major project cost and constraint.

g. Future Considerations for TSP Design and Analysis:

Engineering analyses (seismic deformation analyses) performed as part of this review support the feasibility of more compact seismic stabilization schemes more directly focused on improving the seismic performance of the floodwall itself (as shown on Table ES-2). In the project design phase, the following tasks can be implemented to achieve design objectives while optimizing design measures:

4. Fugro (2020) has shown that the presence of wharfs on the waterside reduce potential of lateral deformations by about 30 to 50 percent for the 225-year and 975-year return periods due to pinning effects of the existing piles. The positive impact of the waterside wharfs should be considered in design level analyses to optimize design measures.
5. Ground improvement schemes on the water side of the floodwall should be considered for the sections of the alignment between the wharves. These may significantly reduce potential disruption and impacts on utilities.
6. In the design phase, 3-dimesional analyses at critical reaches should be performed to evaluate complex soil-structure interactions due to presence of wharfs, variable geologic conditions, and change in ground improvement measures. It will be needed to evaluate conditions in between DMM or slurry wall rows (perpendicular to the shoreline) and optimize spacings in between rows.

h. Proposed Locations for Seismic Evaluations and Analysis for Planning Study:

Nonlinear seismic deformations analyses were performed at two locations in this preliminary stage due to lack of data, selected alignment, and other project constraints. We recommend that further evaluations and analyses should be performed at the following specific areas during the planning phase:

- Aquatic Cove Park area (to select alignment and ground improvement measure)
- Ferry Building area (after flood control system alignment is available)
- Oracle Park in Mission Creek (whether any ground improvement is needed, as recent seismic retrofit implemented for bulkhead wall and stadium)
- Mission Creek area (evaluate berm measures in open space adjacent to buildings – 2 sections to represent two banks of Mission Creek)
- The naturalized berm (less than 2 feet in height) in the southern segment considering performance criteria, post-earthquake repair, land use, alignment, etc. The current plan for large scale ground improvement in this area (50 feet to 100 feet landward) should be re-evaluated (minimum of 2 sections with different geologic conditions).
- The alignment of the floodwall or berm and ground improvement alternatives at the two pier locations (Pier 80 and Piers 92-94-96) should be re-evaluated and analyzed.

The planning reaches should be broken down into more detailed sub-reaches considering land use on the waterside and the landside, geology, target elevation, etc. The current plan paints with too broad brush. Surface and subsurface conditions are too variable within the identified reaches.

Most of these proposed analysis locations are in the Southern Waterfront Segment. The Northern waterfront segment (excluding the Aquatic Cove park area) has an existing seawall and rock dike. These features (seawall and rock dike) are not present along the Southern waterfront segment (Mission Rock to Heron's Head Park), which impacts the performance of a proposed flood control system. Currently no analyses are available to evaluate the proposed flood control system in the southern segment. One partial exception to this is the Port of San Francisco analysis for Pier 80, but this does not represent the variable surface and subsurface conditions of the 5.5 miles of southern waterfront segment.

Significant project risk currently exists due to non-availability of data or analysis at these locations or sub-reaches.

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Appendix A

Numerical Analyses of Alternative Waterfront Seismic Stabilization Schemes

A.1. Introduction

Nonlinear, seismic deformation analyses were performed with the computer code FLAC, Version 8.0 (Itasca, 2016), a program widely used for seismic analyses of embankment dams, waterfront retaining structures (e.g. wharves, quays, etc.), pile foundations and other analyses involving the dynamic response of soil and rock. The seismic analyses were nonlinear, time-domain seismic deformation analyses, often called Response History Analyses (RHA).

Analyses were performed for two cross-sections: the first section representing subsurface conditions at Pier 27 and the second section representing subsurface conditions at Piers 30-32. These sections were presented in the main report in Figures 3-1 through 3-9.

A.2. Seismic Loading and Input Ground Motions

Input ground motion time histories were those developed by CH2M Hill (2020) in their site specific, probabilistic seismic hazard study. In that study, ground motions were developed for rock conditions, with a V_{s30} (time weighted average shear wave velocity) of 4,100 feet per second (1250 m/s), for average return periods of 43, 100, 225 and 975 years.

For the current study, an additional return period of 475 years was considered, using UHS response spectra obtained for the project site using the USGS seismic hazard tool. To approximate the response spectra for a V_{s30} of 1250 m/sec, the response spectra for Site Class B ($V_{s30} = 1080$ m/sec) and Site Class AB ($V_{s30} = 1500$ m/sec) were averaged. The CH2M Hill (2020) acceleration time history for the 225-year return period was then scaled to the USGS spectrum using a factor of 1.2: the average ratio of the 475-year to 225-year spectra between periods of 0.01 and 1.0 seconds.

Seismic deformation analyses were run for return periods of 225-, 475- and 975-years. The response spectra for these return periods are shown in Figure A-1. At each return period, analyses were run for a single input time history, the time history found to produce the largest displacements in the analyses of Fugro CH2M Hill (2020).

A.3. Technical Approach

Soils were modeled with a linear-elastic/perfectly plastic Mohr-Coulomb constitutive model. The initial static stress state was computed by simple gravity turn on. After establishing initial stresses, stress-dependent shear strength was installed following the SHANSEP approach using the soil layer properties and undrained shear strengths listed in Tables A-1 and A-2. The small-strain shear modulus G_{max} for each soil layer was computed as a multiple of the undrained shear strength, as listed in Table A-1. The shear wave velocity at the base of the model (Bedrock) was 4100 ft/sec (1250 m/sec), the value used by Fugro CH2M Hill (2020) when developing the input ground motions. This is necessary for correct application of the input ground motions, as described below.

A.4. Soil and Structural Properties

Soil properties for the seismic deformation analyses were adapted from the properties developed by Fugro (2018), Fugro (2020a) and Fugro (2020b), and are shown in Tables A-1 and A-2. Properties used for Deep Soil Mix (DSM) ground improvement are listed in Table A-3 while structural properties used for reinforced concrete drilled shafts are listed in Table A-4. Reinforced concrete properties used for the slurry wall analyses are the same as those used for the drilled shafts, as listed in table A-4.

Table A-1. Soil Properties for Young Bay Mud (YBM)

Location	Total Unit Weight (pcf)	OCR	S_u/σ'_{vo}	Shear Wave Velocity (ft/sec)	Small Strain Stiffness, G_{max}
Water Side	Depth < 25 ft: 87+0.62 depth	1.1	0.3	$V_s = 18 S_u^{0.475}$ Dickenson (1994)	$G_{max} = \rho V_s^2$
Land Side		0-20 ft: OCR = 3	0.67		
		> 20 ft: OCR = 1.5	0.38		

Notes:

(1) YBM is modeled with a sensitivity of 4. Shear strength reducing with plastic shear strain, reaching 25% of its original value at a plastic shear strain of 60%

Table A-2. Soil Properties for Analysis of Pier 27 and Piers 30-32

Soil Layer	Total Unit Weight (pcf)	Shear Wave Velocity (ft/sec)	Small Strain Stiffness, G_{max}	S_u/σ'_{vo}	Drained Friction Angle (deg.)	$(N_1)_{60-cs}$
Fill	120	-	$1628 p_{atm} \left(\frac{p}{p_{atm}} \right)^{0.5}$	-	33	15
Rock Dike	130	-	$1628 p_{atm} \left(\frac{p}{p_{atm}} \right)^{0.5}$	-	45	-
YBM Sand	120	-	$1628 p_{atm} \left(\frac{p}{p_{atm}} \right)^{0.5}$	-	33	10
ULS Sand	135	-	$5202 p_{atm} \left(\frac{p}{p_{atm}} \right)^{0.5}$	-	33	-
ULS Clay	120	650	-	0.54	-	-
OBM	116	800	-	0.39	-	-
LLS	135	1900	-	-	34	-
Rock	140	4100	-	-	-	-

Table A-3. Deep Soil Mix (DSM) Properties

Unconfined Compressive Strength – UCS (psi)	Cohesion (psi)	Tensile Strength (psi)	Young's Modulus (ksi)	Replacement Ratio
400	200	60 ⁽¹⁾	140 ⁽²⁾	0.5 ⁽³⁾
Notes: (1) Tensile strength is taken as 15% of UCS (Kitazume and Terashi, 2017) (2) Youngs Modulus is estimated as 350 UCS (Kitazume and Terashi, 2017) (3) In the 2D numerical analysis the DSM properties presented here are scaled down according to the replacement ratio				

Table A-4. Properties of Drilled Shafts

Diameter (ft)	Unit Weight (pcf)	f'_c (psi)	Young's Modulus (ksi)	Area (ft ²)	Moment of Inertia ⁽¹⁾ (ft ⁴)	Yield Moment ⁽²⁾ (kip-ft)
6	150	5000	5.8(10) ⁵	28.3	64	1.53(10) ⁴
10	150	5000	5.8(10) ⁵	78.5	491	7.07(10) ⁴
Notes: (1) For the dynamic numerical analysis, the moment of inertia is reduced by 50% to account for cracking (2) The yield moment is provided as a rough index of moment capacity. This parameter is not used in the analysis, as the drilled shafts are modeled as linear elastic.						

A.5. Modeling of Liquefiable Soils

Liquefiable soils were analyzed with the Roth cycle counting model (Dawson and Mejia, 2012, Dawson et al., 2001). The model consists of a Mohr-Coulomb (linear elastic and perfectly plastic) soil model coupled with an empirical pore-pressure generation scheme. Pore pressure is generated in response to shear stress cycles, following the cyclic-stress approach of Seed (Seed et al., 1976; Seed, 1979). This approach is the basis of the widely used Simplified Procedure for liquefaction analysis.

The pore-pressure generation scheme is fully integrated with the dynamic analysis, as pore pressures are continuously updated for each element in response to shear stress cycles. As effective stresses decrease with increasing pore pressure, permanent deformation due to plastic strain is accumulated. As effective stress decreases the shear strength drops to the post-liquefaction residual strength.

Analyses were performed using the Cetin et al. (2018) median liquefaction triggering relationship and the Weber et al. (2015) 33rd percentile post-liquefaction residual strength relationship.

The constitutive model, liquefaction triggering relationships, and residual strength relationships employed in the FLAC analyses were selected based on demonstrated predictive ability to estimate deformations in a well-documented pair of seismic performance case histories of the Lower San Fernando Dam and the Upper San Fernando Dam during the 1971 San Fernando Earthquake (Chowdhury et al., 2018).

A.6 Modeling of Seismic Stabilization Schemes

Drilled shafts secant walls were modeled as linear elastic beam elements connected directly to the soil mesh, using the structural properties listed in Table A-4.

Deep Soil Mix (DSM) ground improvement zones were modeled in the 2D model with a linear-elastic/perfectly plastic Mohr-Coulomb constitutive model, with DSM properties scaled according to the replacement ratio (50% for all analyses) using the unscaled DSM properties listed in Table A-3.

The slurry wall panels (perpendicular to the shoreline) were modeled as linear elastic, with stiffness scaled down according to the panel thickness (4-ft) and panel spacing (20-ft) along the shoreline. Reinforced concrete properties used are those listed in Table A-4.

A.7. Analysis Results for the Pier 27 Cross Section

FLAC numerical meshes for existing conditions and the for the 3 seismic stabilization schemes are shown in Figures A-2 through A-5. Permanent shaking-induced displacement vectors, for the 475-year return period, are shown in Figures A-6 through A-10 for existing conditions and the for the 3 seismic stabilization schemes. Computed horizontal displacements of the floodwall are summarized in Table A-5 For the 225-year, 475-year and 975-year return periods. Also listed in the Table A-5 are seawall displacements from FLAC analyses performed for the Port of San Francisco as part of the Seawall Earthquake Safety Program (Fugro, 2020).

Table A-5 Summary of Seismic Deformation Analysis Results: Pier 27

Description	Horizontal Displacement of Floodwall (ft)		
	225-Year RP	475-Year RP	975-Year RP
Existing Conditions (Port of San Francisco Analyses)	0.97		4.1
Existing Conditions (Current USACE Analyses)	1.11	1.52	4.32
30-ft Wide DMM Panels (Land Side)	0.21	0.30	1.30
30-ft Wide DMM Panels (Water Side)		0.32	
Reinforced Concrete Secant Pile Wall (10-ft Diameter Shafts)	0.34	0.47	1.21
20-ft Wide Reinforced Concrete Slurry Wall (Land Side)	0.19	0.31	1.46
20-ft Wide Reinforced Concrete Slurry Wall (Water Side)		0.35	

A.8. Analysis Results for the Piers 30-32 Cross Section

FLAC numerical meshes for existing conditions and the for the drilled shaft seismic stabilization scheme are shown in Figures A-10 and A-11. Permanent shaking-induced displacement vectors, for the 475-year return period, are shown in Figures A-12 and A-13

for existing conditions and the drilled shaft seismic stabilization scheme. Computed horizontal displacements of the floodwall are summarized in Table A-6 for the 225-year, 475-year and 975-year return periods. Also listed in the Table A-6 are seawall displacements from FLAC analyses performed for the Port of San Francisco as part of the Seawall Earthquake Safety Program (Fugro, 2020).

Note that the Piers 30-32 section, the USACE analyses show much higher displacements for existing conditions than those reported for the Port of San Francisco analyses. The reason for these differences is primarily that different liquefaction models used for the fill material. In the USACE analysis, liquefiable materials are allowed to transition to residual strength during shaking, while in the Port of San Francisco analyses, residual strength is only considered after shaking has finished. As can be seen in Figure A-12, the larger displacements in the USACE analyses are produced by a toppling deformation of the seawall produced by shallow deformation of the liquefied fill behind the seawall.

Table A-6. Summary of Seismic Deformation Analysis Results: Piers 30-32

Description	Horizontal Displacement of Floodwall (ft)		
	225-Year RP	475-Year RP	975-Year RP
Existing Conditions (Port of San Francisco Analyses)	0.31		0.57
Existing Conditions (Current USACE Analyses)	1.29	1.58	4.57
Reinforced Concrete Secant Wall (6-ft Diameter Shafts)	0.27	0.37	0.97

A.9. Discussion

The seismic deformation analysis results support the feasibility of more compact seismic stabilization schemes more directly focused on improving the seismic performance of the floodwall itself. For Pier 27, all three schemes result in horizontal floodwall displacements of less than 0.5 feet for the 475-year return period and less than 1.0 feet for the 975-year return period. For Piers 30-32, the drilled shaft secant wall scheme result in horizontal floodwall displacements of less than 0.5 feet for the 475-year return period and less than 1.0 feet for the 975-year return period.

The Pier 27 analyses indicate that the slurry wall panel scheme is the most efficient structural option, providing much greater stiffness than drilled shafts for a comparable volume of reinforced concrete.

Based on these analysis results alone, it would appear that performance of the DSM scheme is roughly equivalent to that of the slurry wall scheme. However, there may be some concerns regarding tensile yielding of the unreinforced DSM panels. For the slurry wall

panels this is less of a concern, reducing project risk. This issue and many other design and performance issues should be addressed through more extensive modeling analyses (including 3D analyses) during the design stage of the project.

DRAFT

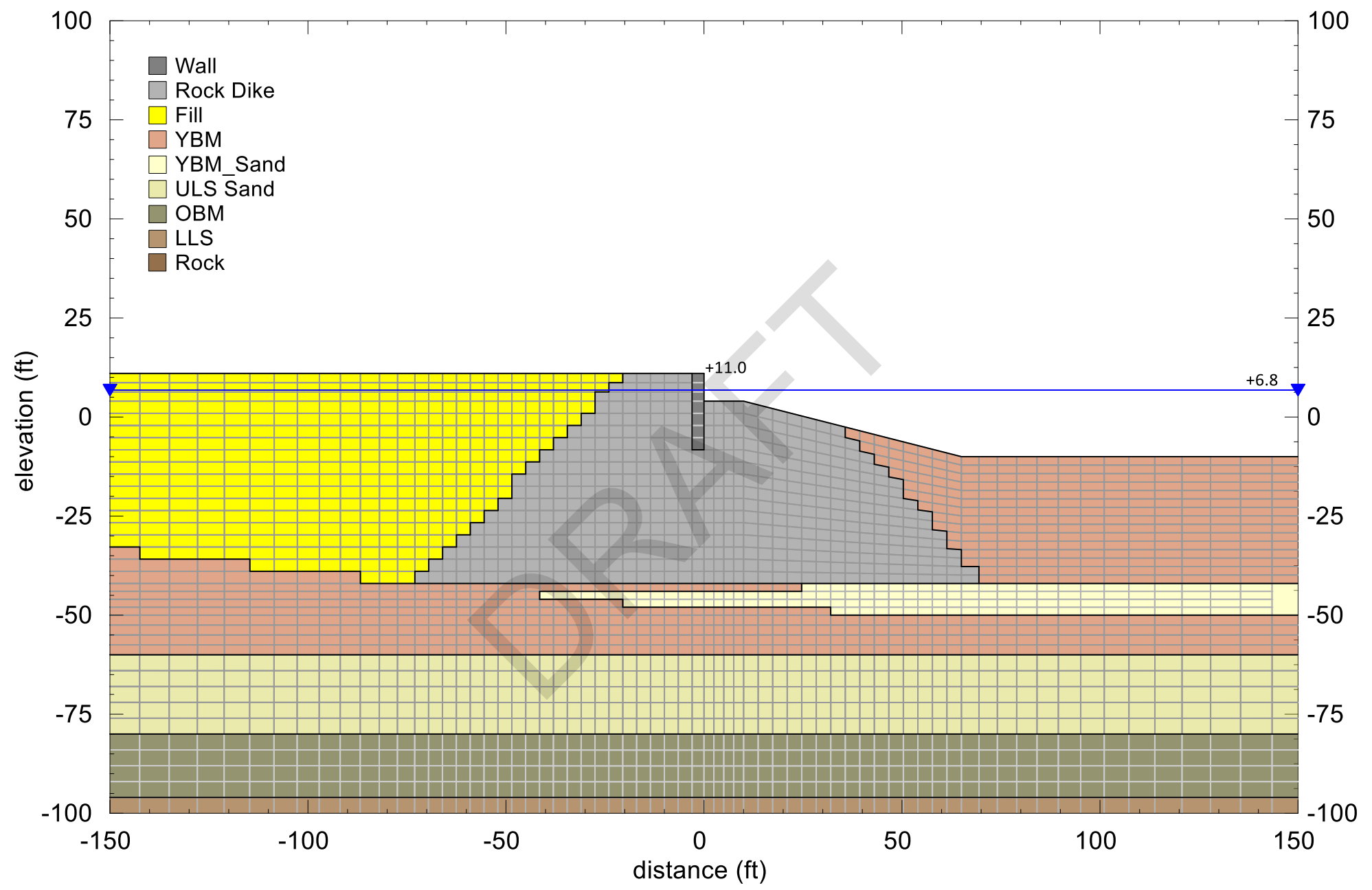


Figure 3-1: Existing Conditions: Pier 27

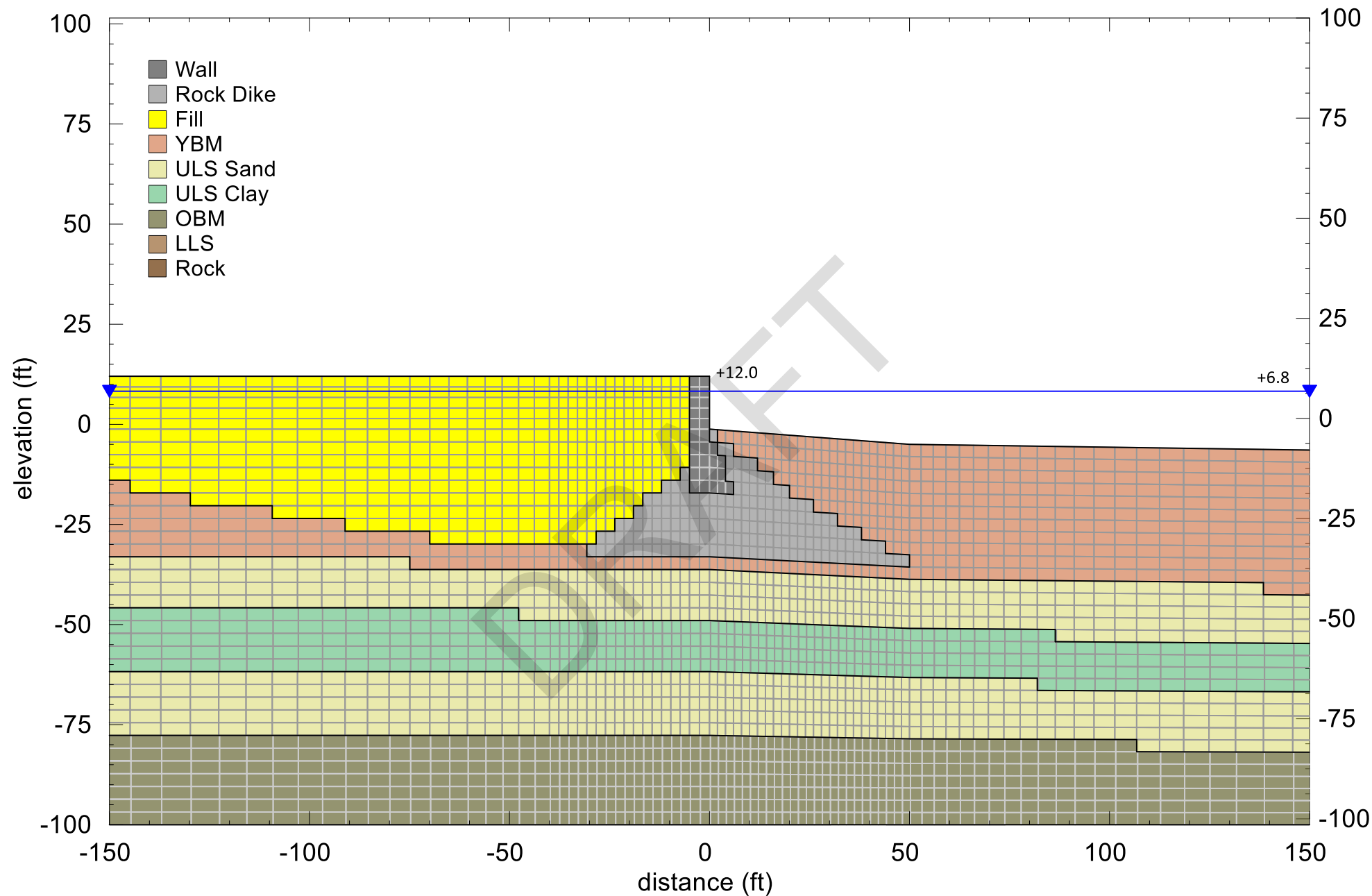


Figure 3-2: Existing Conditions: Piers 30-32

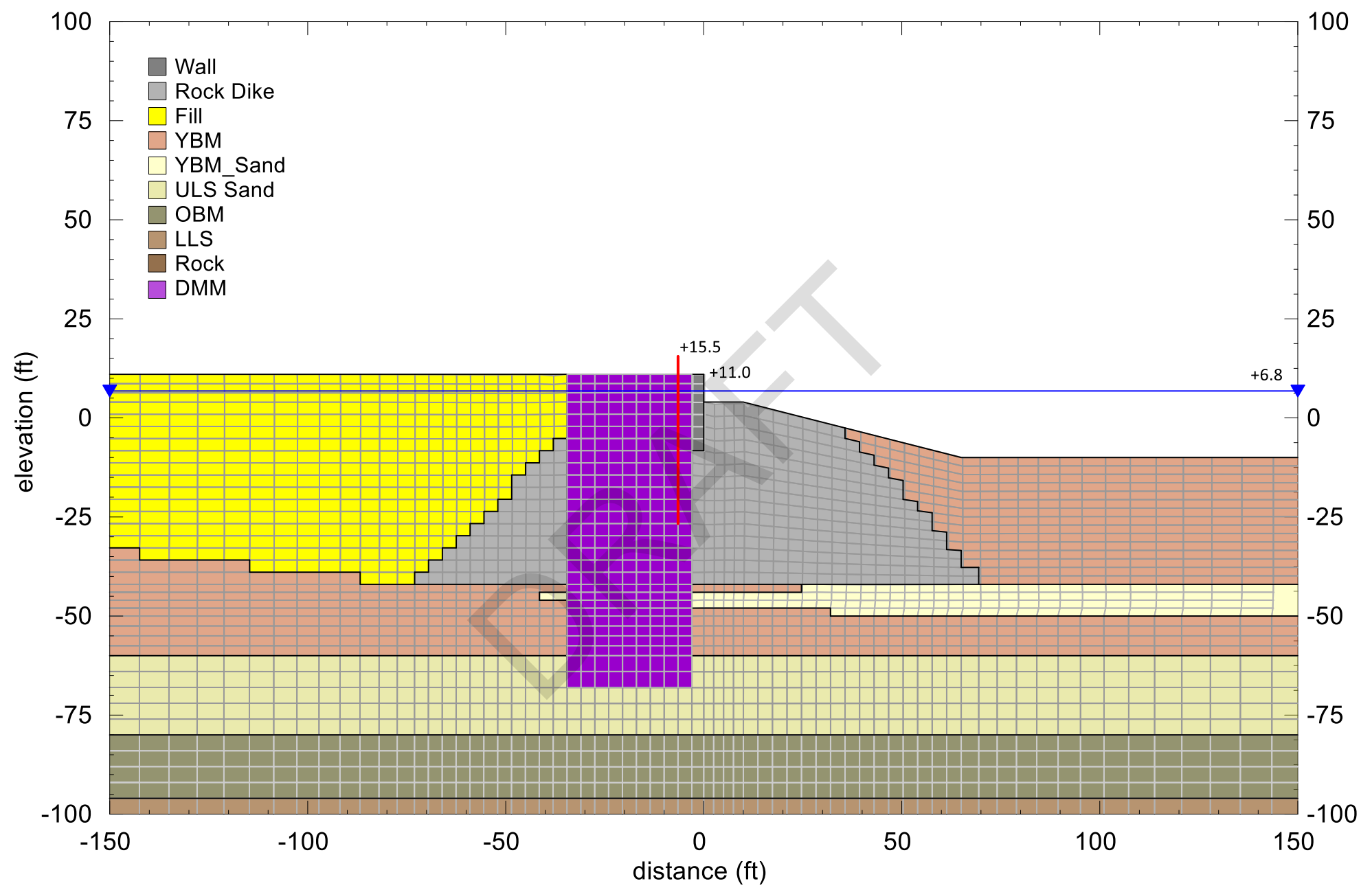


Figure 3-3: Pier 27 with DMM Ground Improvement

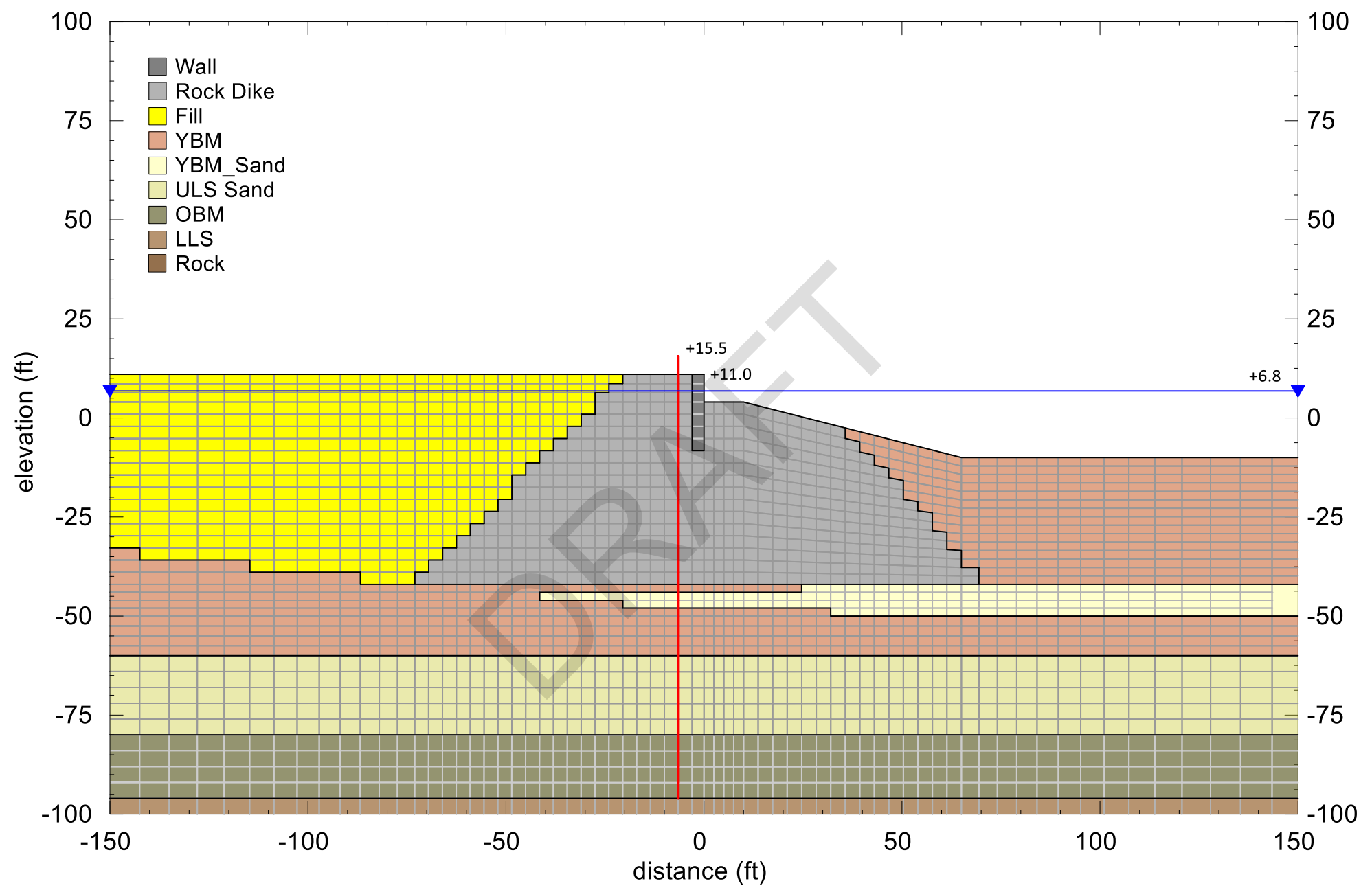


Figure 3-4: Pier 27 with Secant Wall (10-ft Diameter)

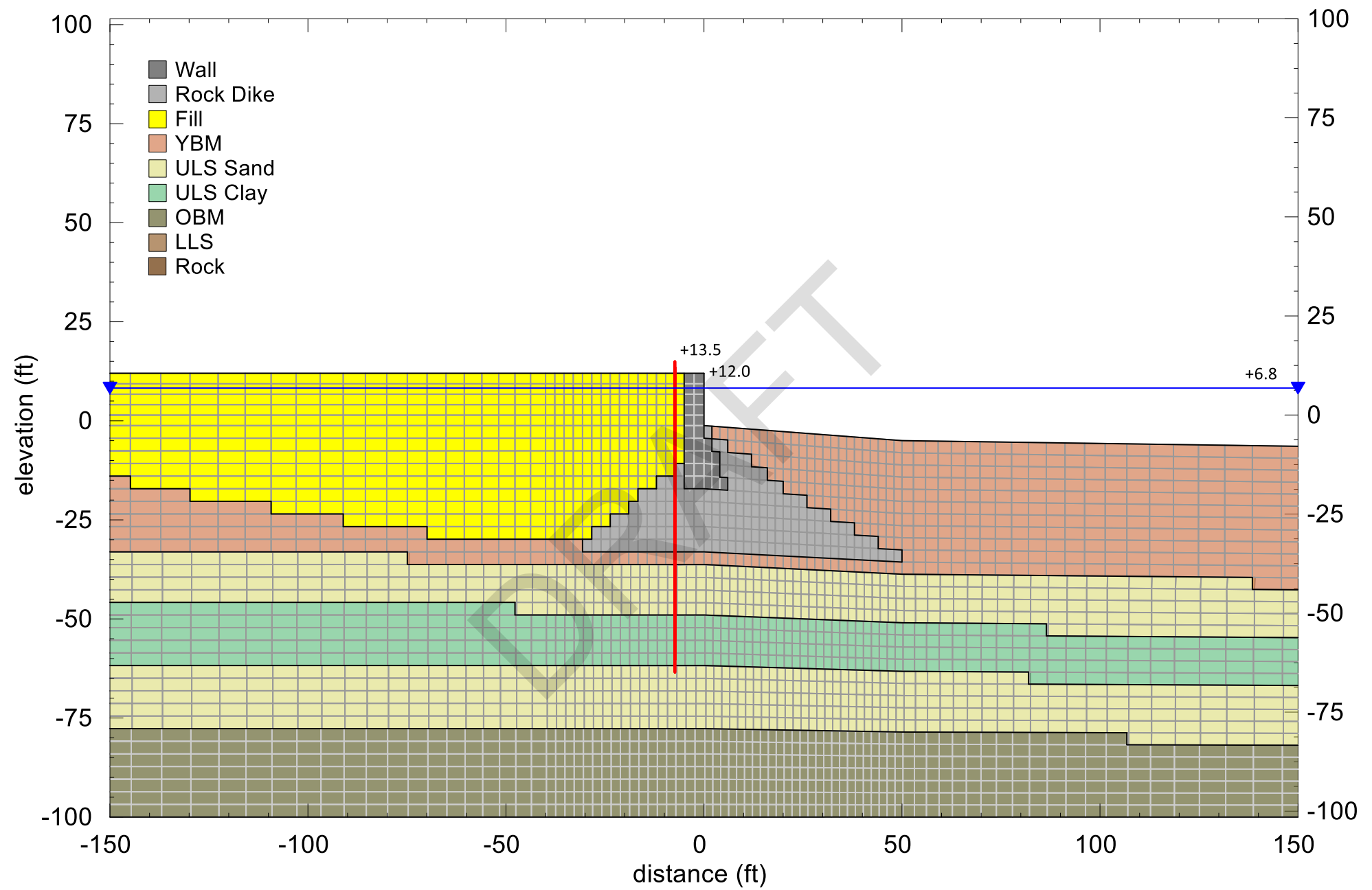


Figure 3-5: Piers 30-32 with Secant Wall (6-ft Diameter)

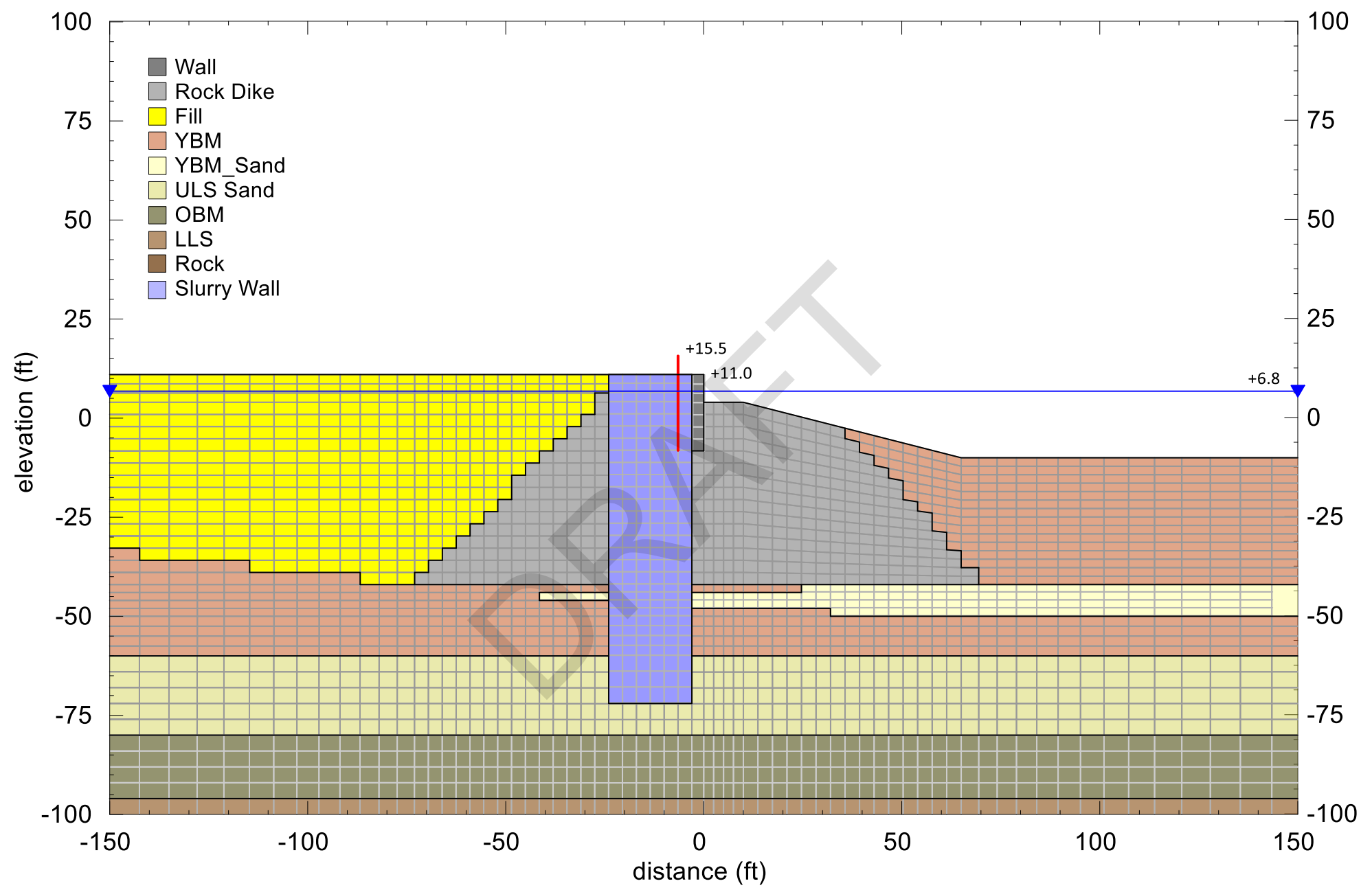


Figure 3-6: Pier 27 with Reinforced Concrete Slurry Wall Ground Improvement

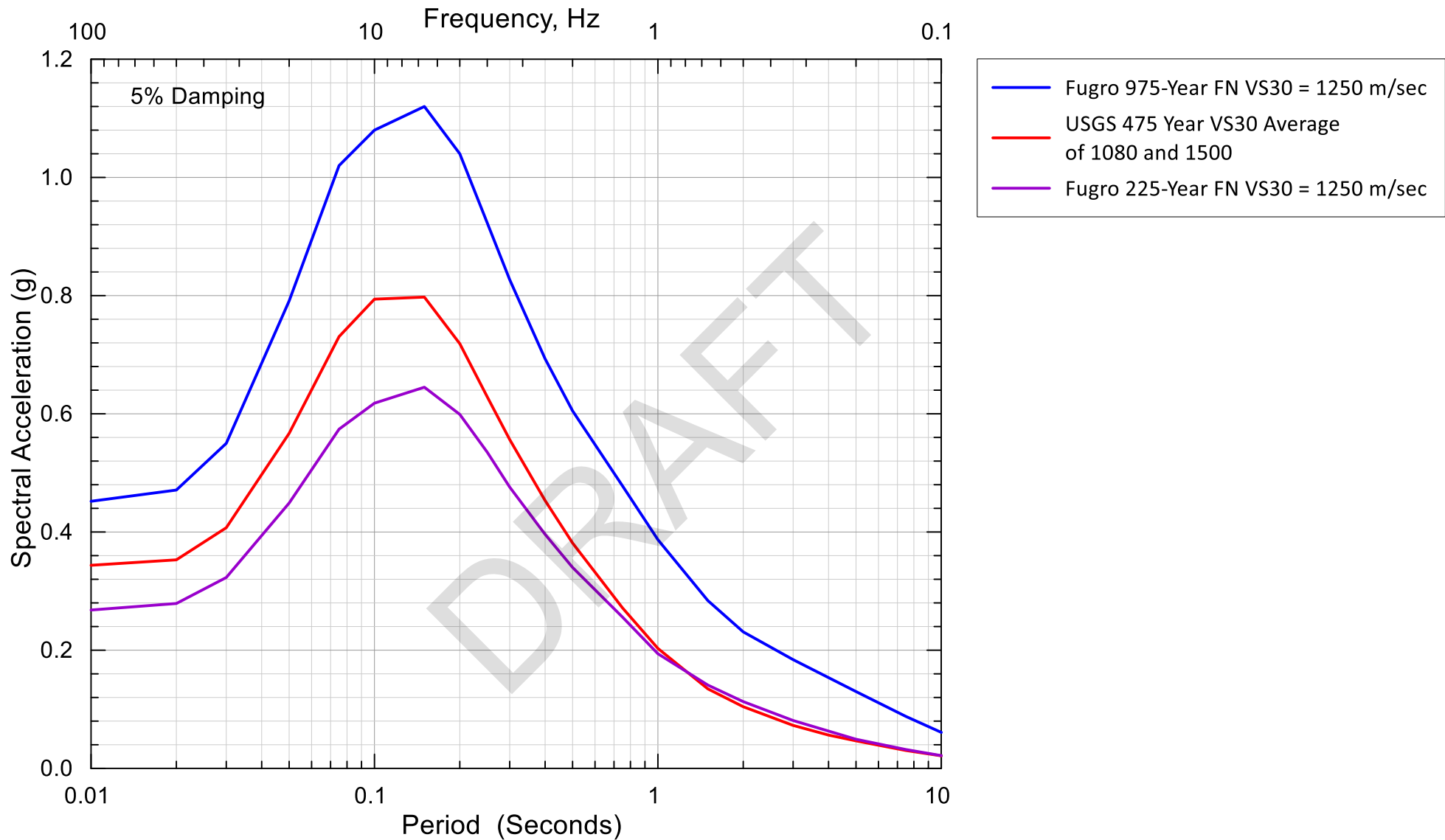


Figure A-1: Uniform Hazard Response Spectra for San Francisco Waterfront ($V_{S30} = 1250$ m/sec)

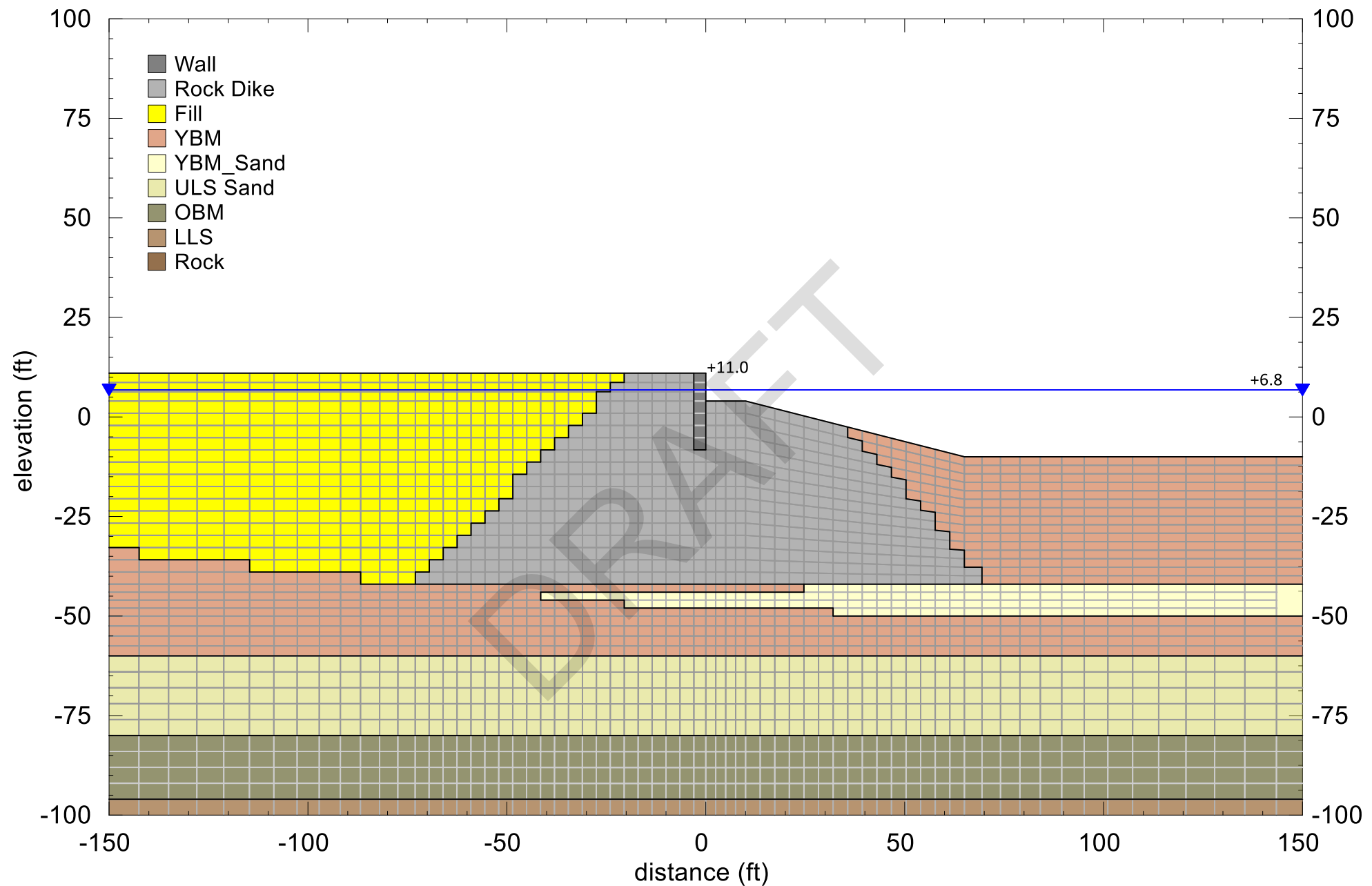


Figure A-2: FLAC Numerical Mesh for Pier 27 Section: Existing Conditions

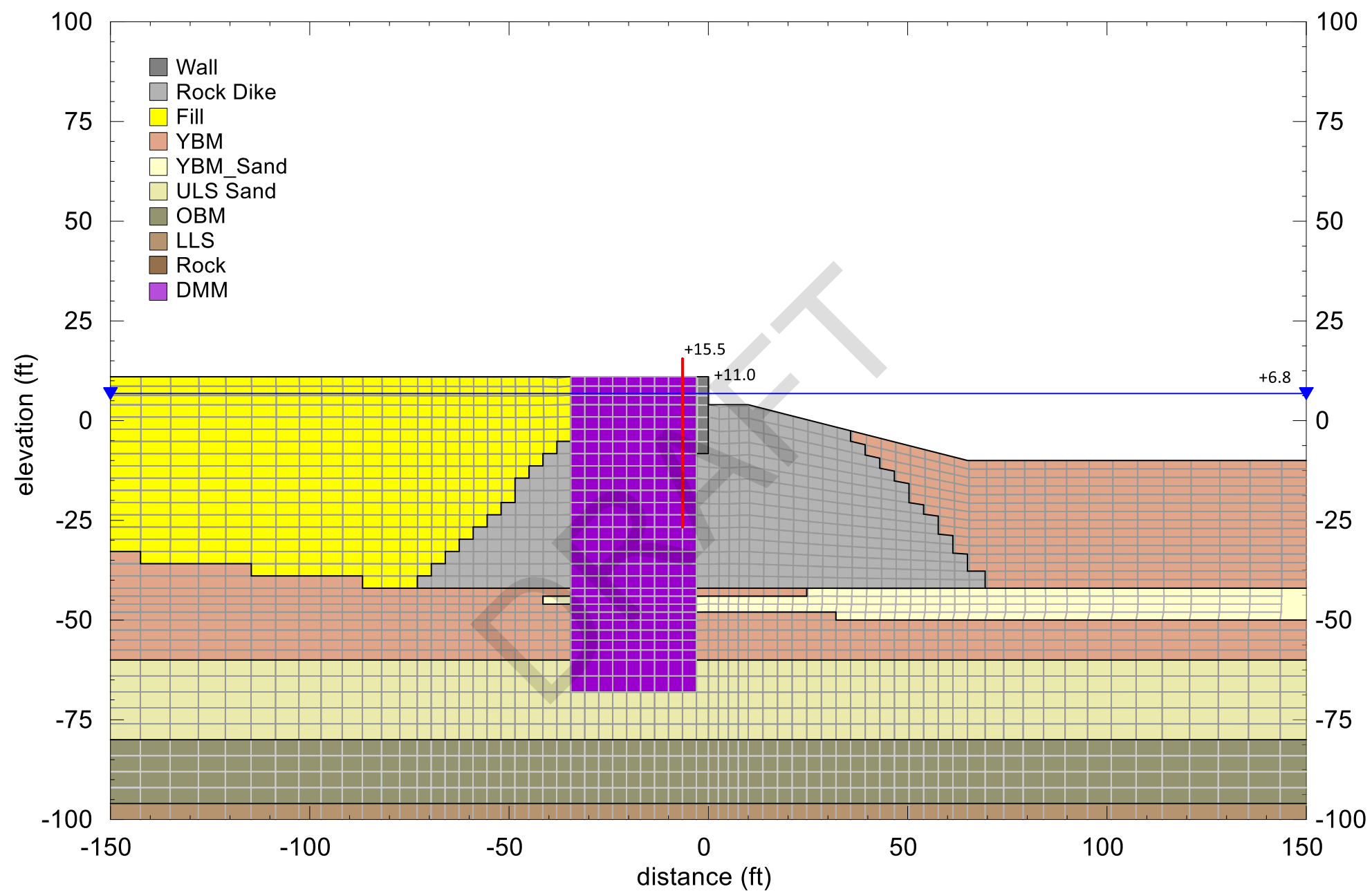


Figure A-3: FLAC Numerical Mesh for Pier 27 Section: DMM Ground Improvement

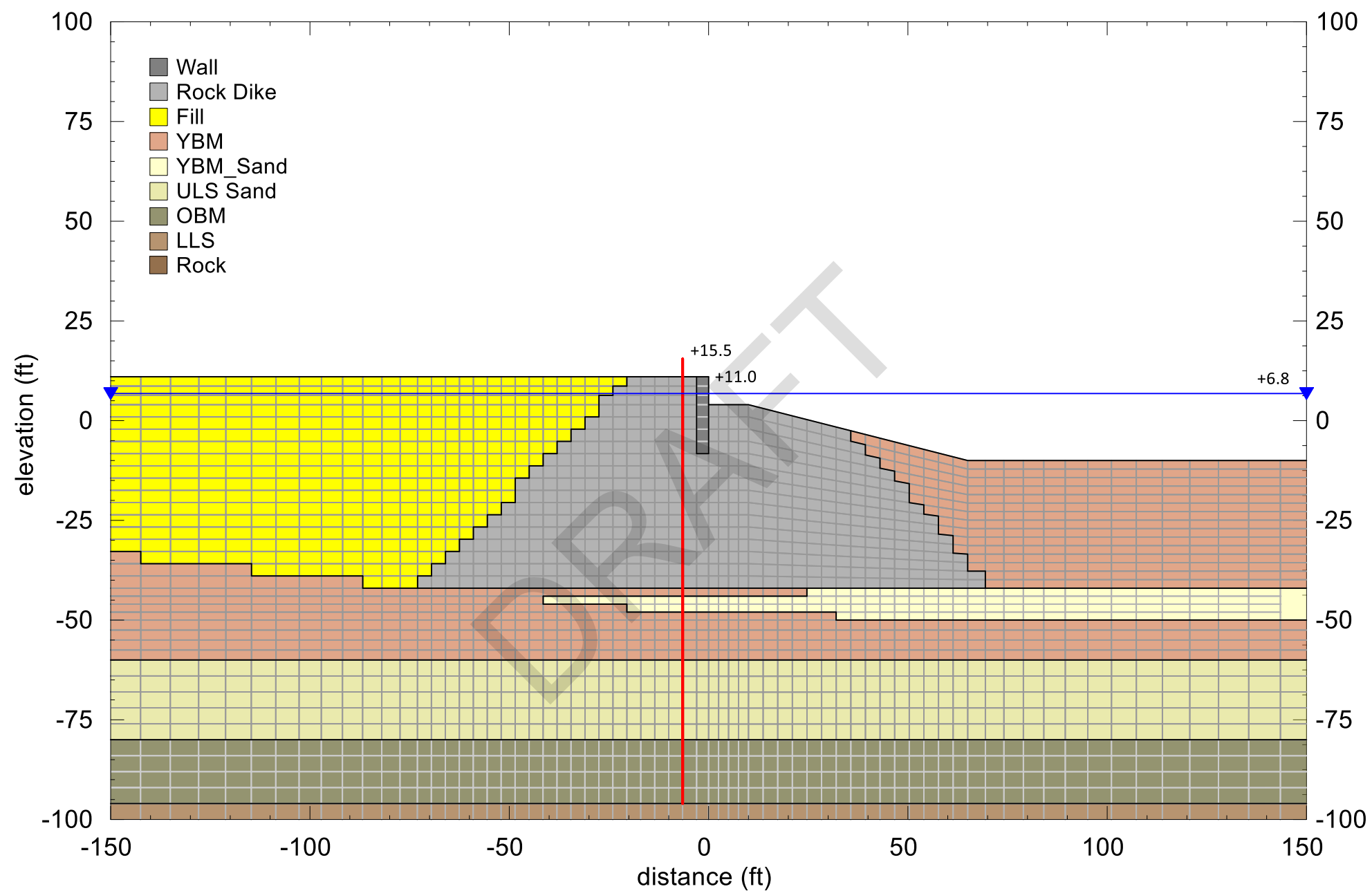


Figure A-4: FLAC Numerical Mesh for Pier 27 Section: Drilled Shaft Secant Wall (10-ft Diameter)

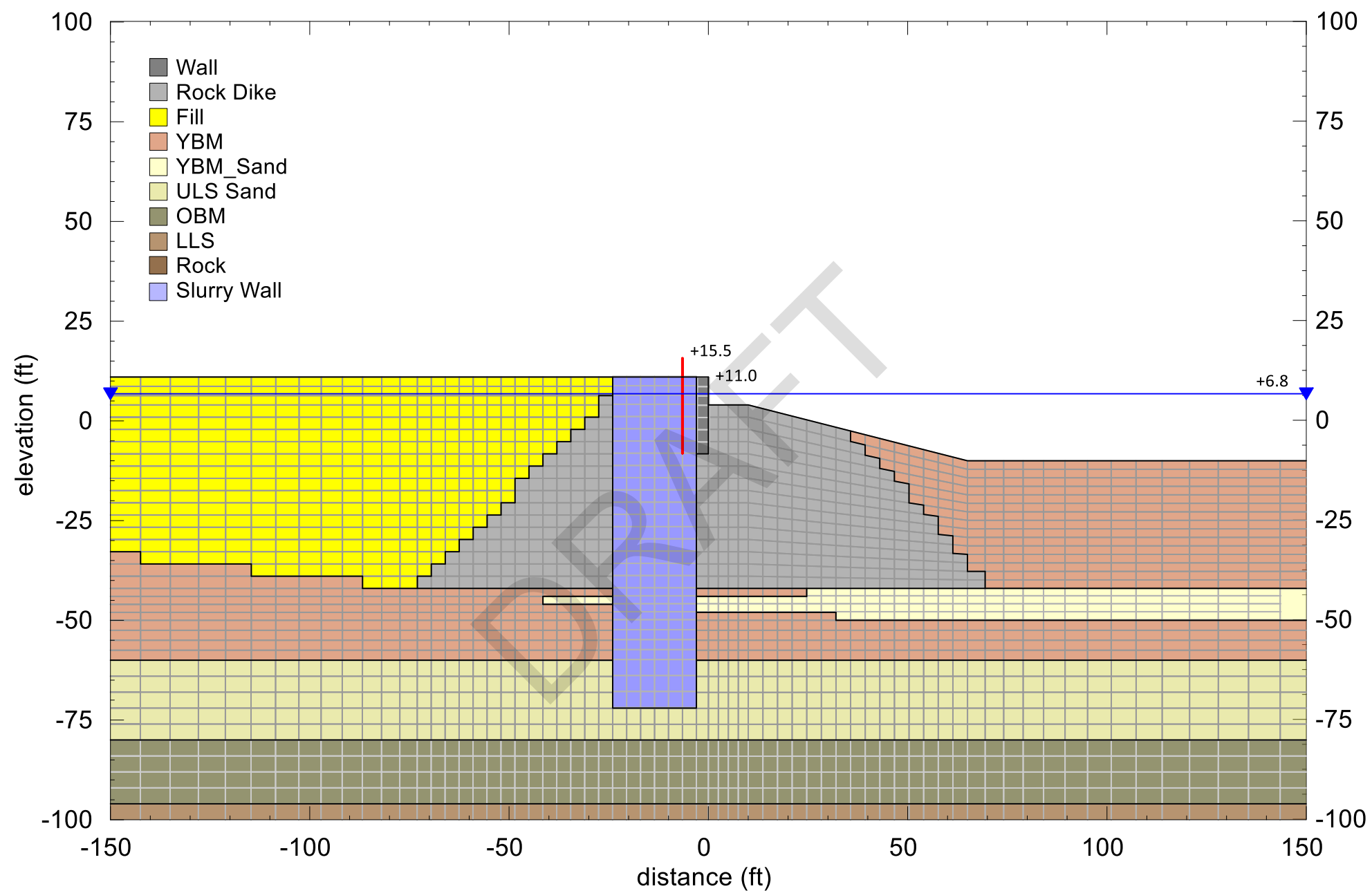


Figure A-5: FLAC Numerical Mesh for Pier 27 Section: Slurry Wall Panels

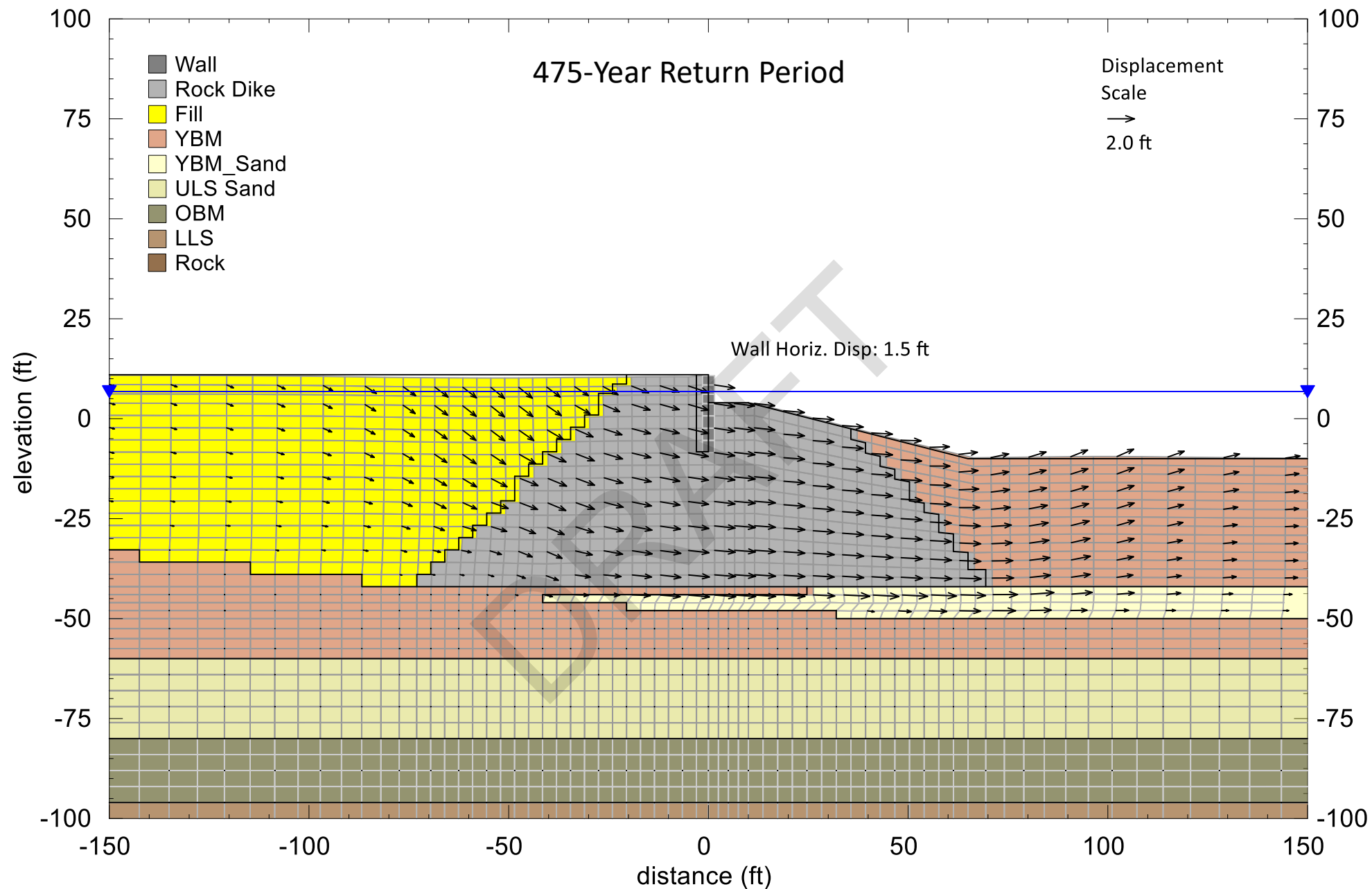


Figure A-6: Displacement Vectors after Shaking, Pier 27: Existing Conditions

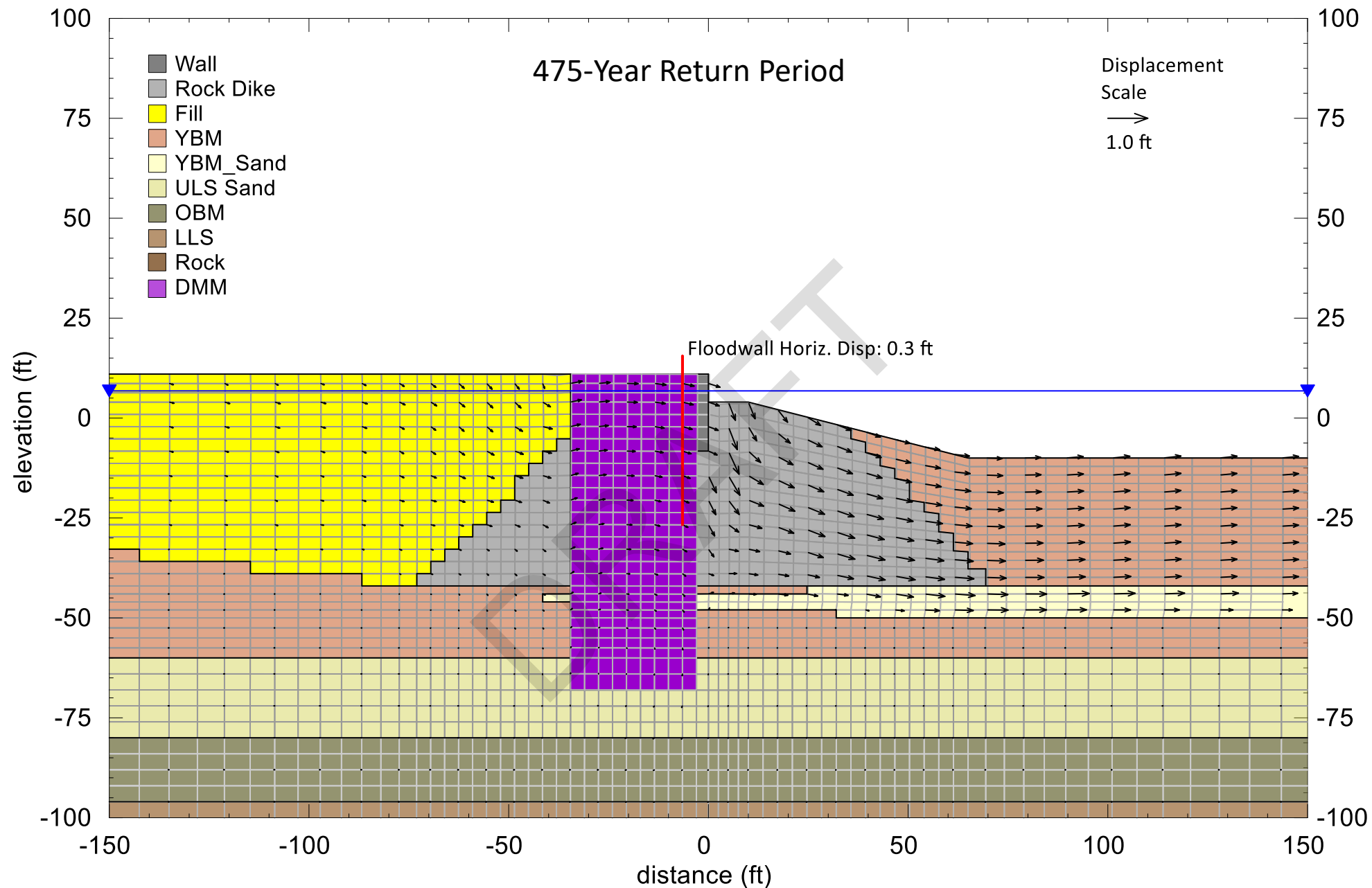


Figure A-7: Displacement Vectors after Shaking, Pier 27: With DMM Ground Improvement

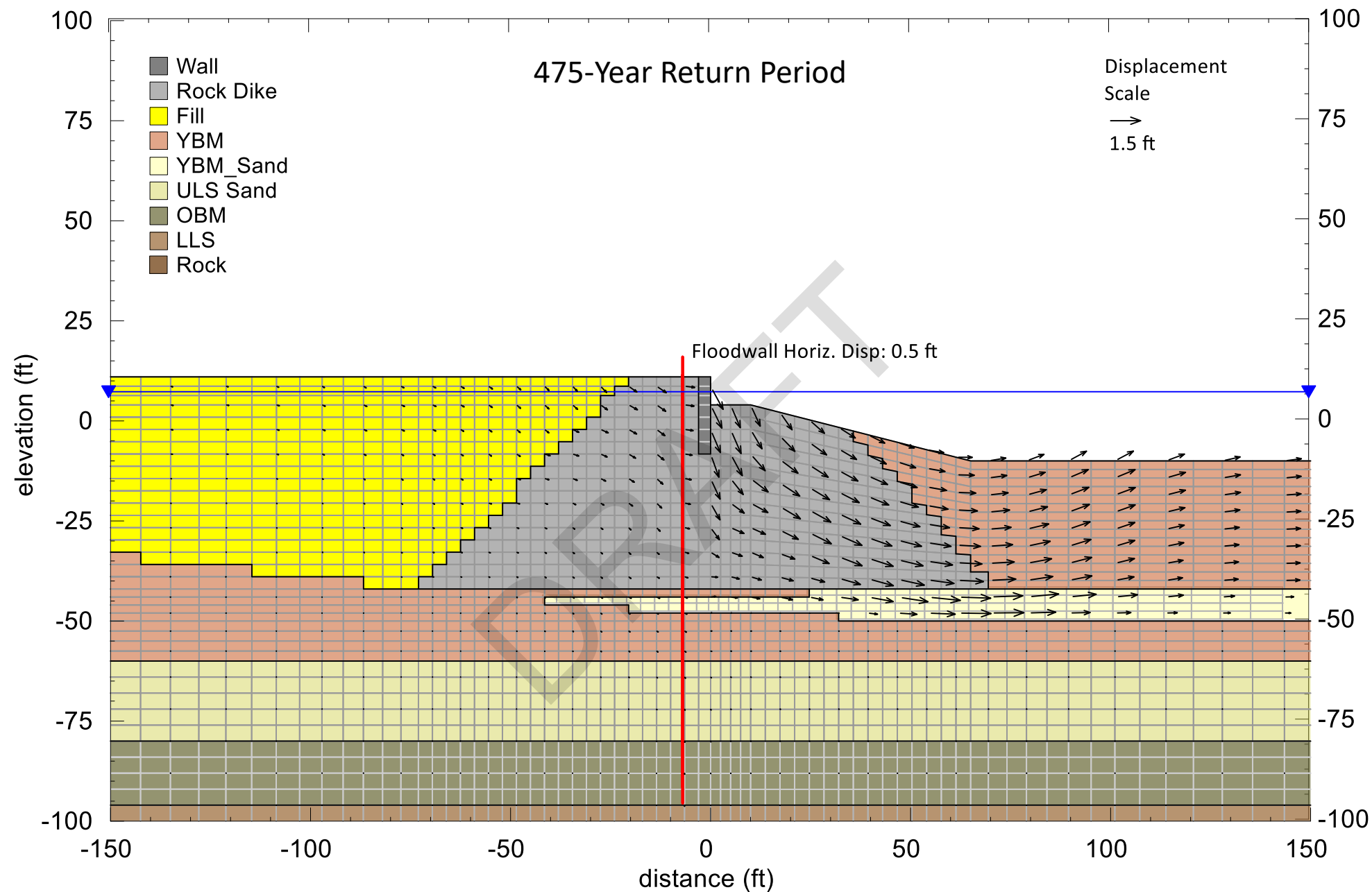


Figure A-8: Displacement Vectors after Shaking, Pier 27: Drilled Shaft Secant Wall (10-ft Diameter)

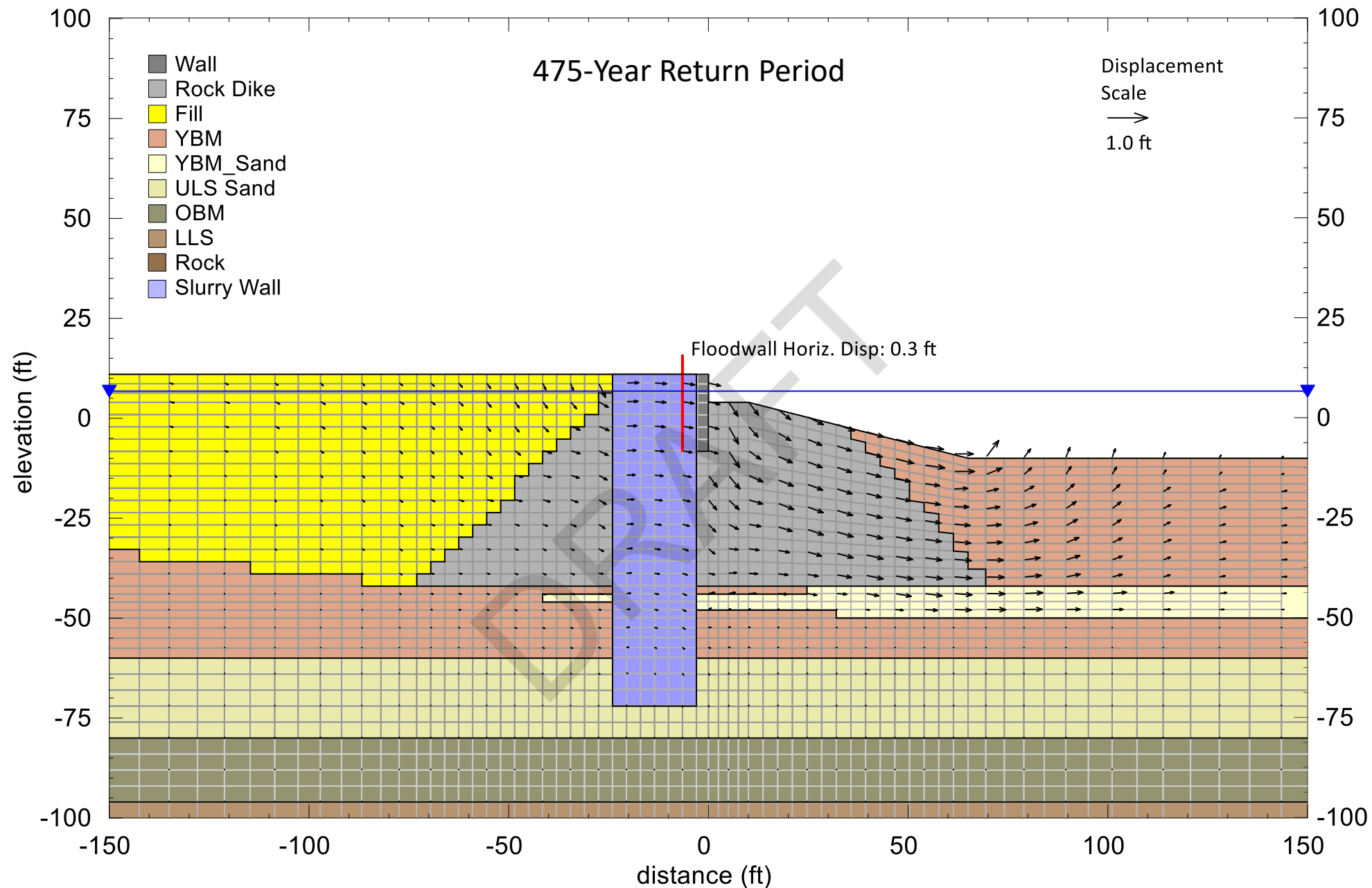


Figure A-9: Displacement Vectors after Shaking, Pier 27: Slurry Wall Panels

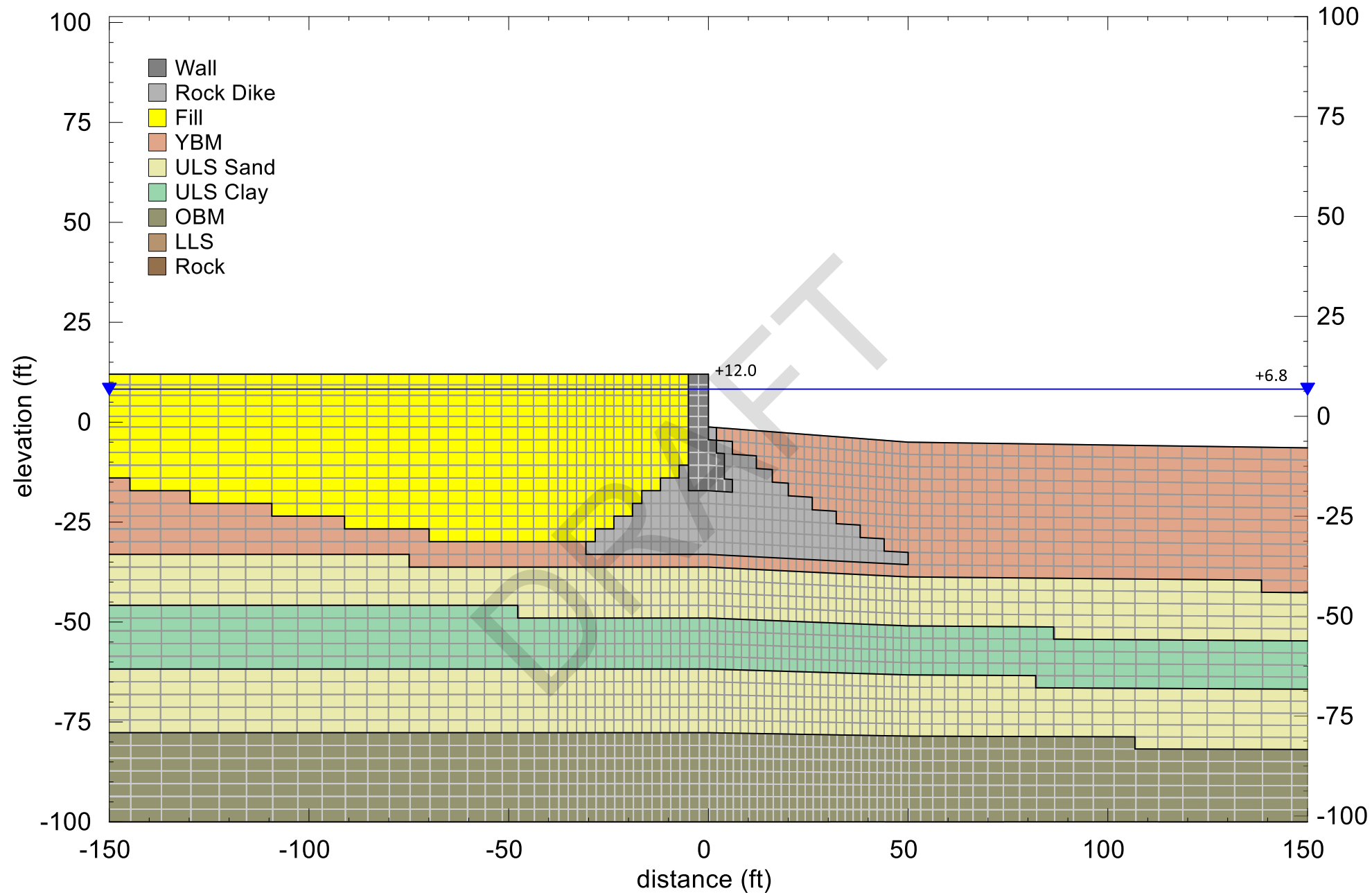


Figure A-10: FLAC Numerical Mesh for Piers 30-32 Section: Existing Conditions

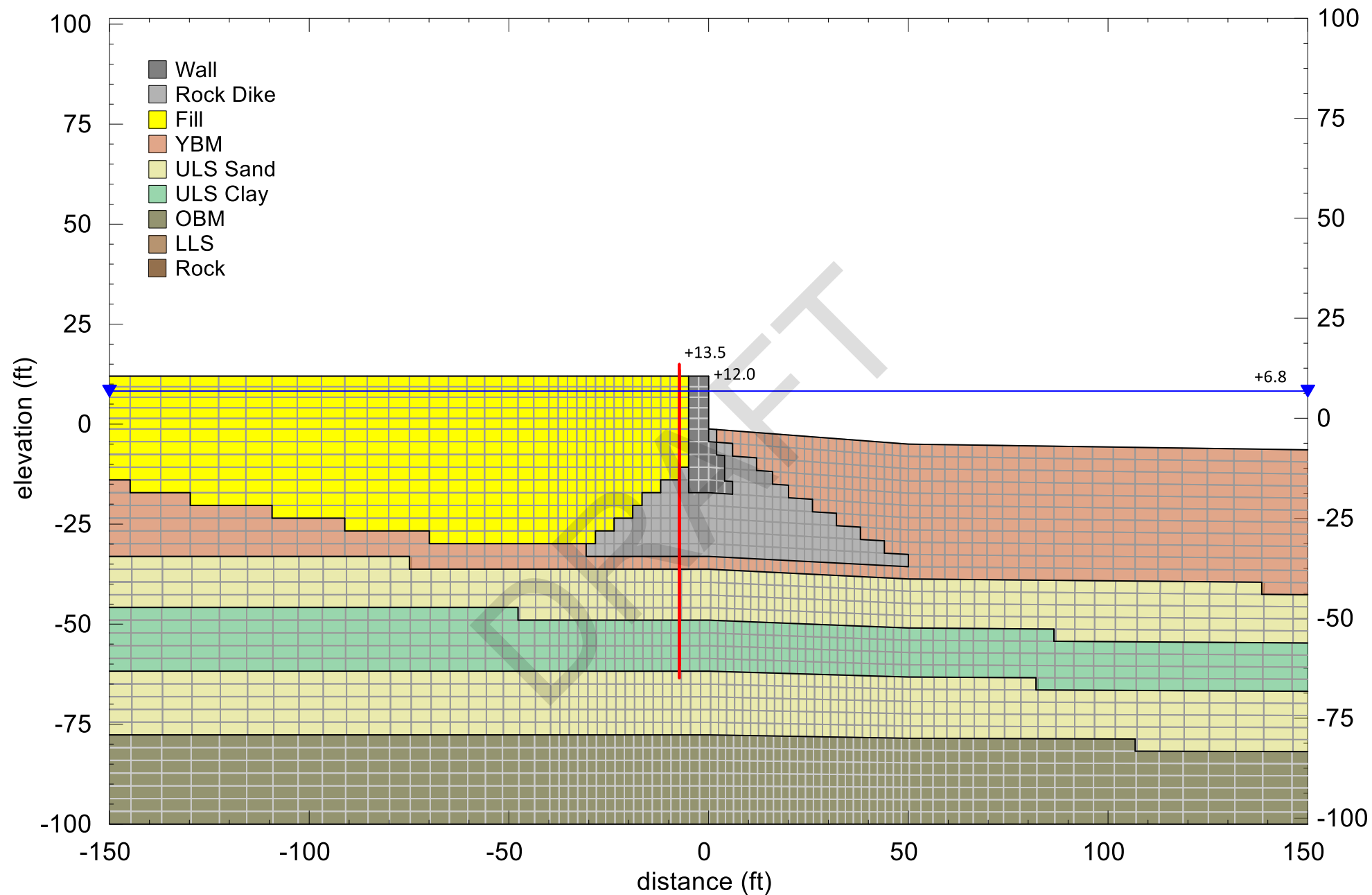


Figure A-11: FLAC Numerical Mesh for Piers 30-32 Drilled Shaft Secant Wall (6-ft Diameter)

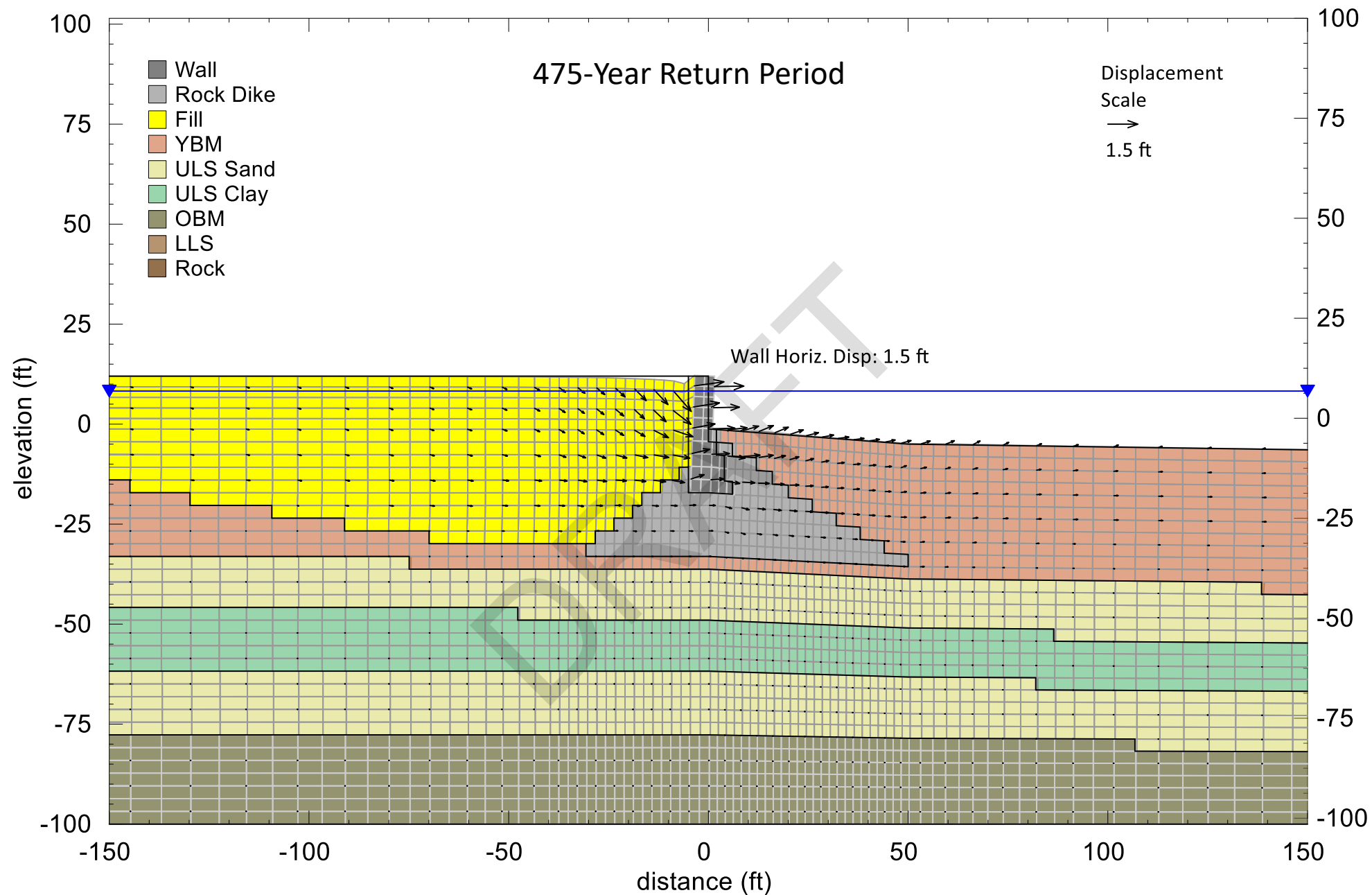


Figure A-12: Displacement Vectors after Shaking, Piers 30-32: Existing Conditions

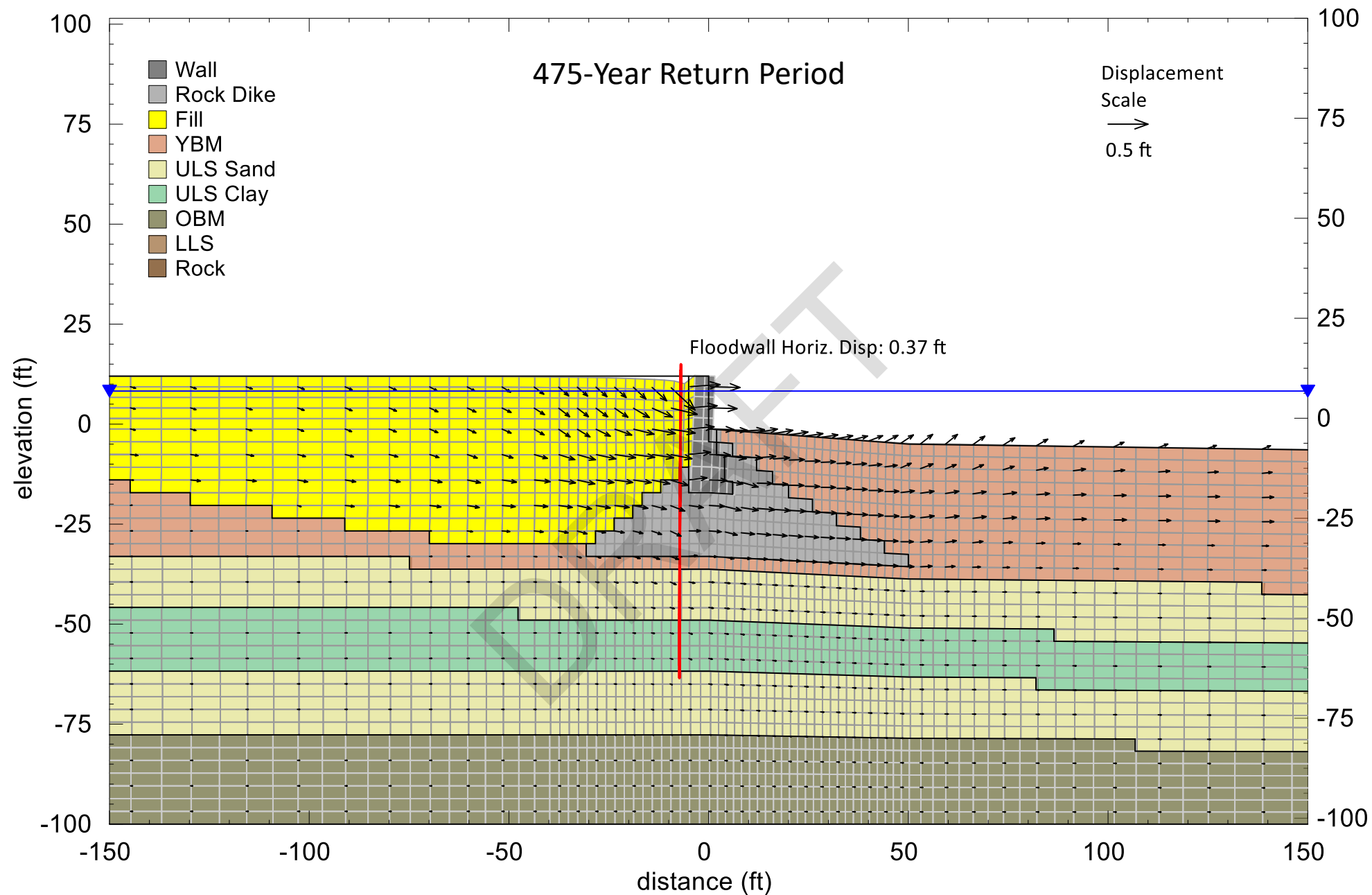


Figure A-13: Displacement Vectors after Shaking, Piers 30-32: Drilled Shaft Secant Wall (6-ft Diameter)

APPENDIX B

SAN FRANCISCO WATERFRONT PROJECT

OBSERVATIONS AND RECOMMENDATIONS FOR SUB-REACHES



U.S. ARMY



US Army Corps
of Engineers®



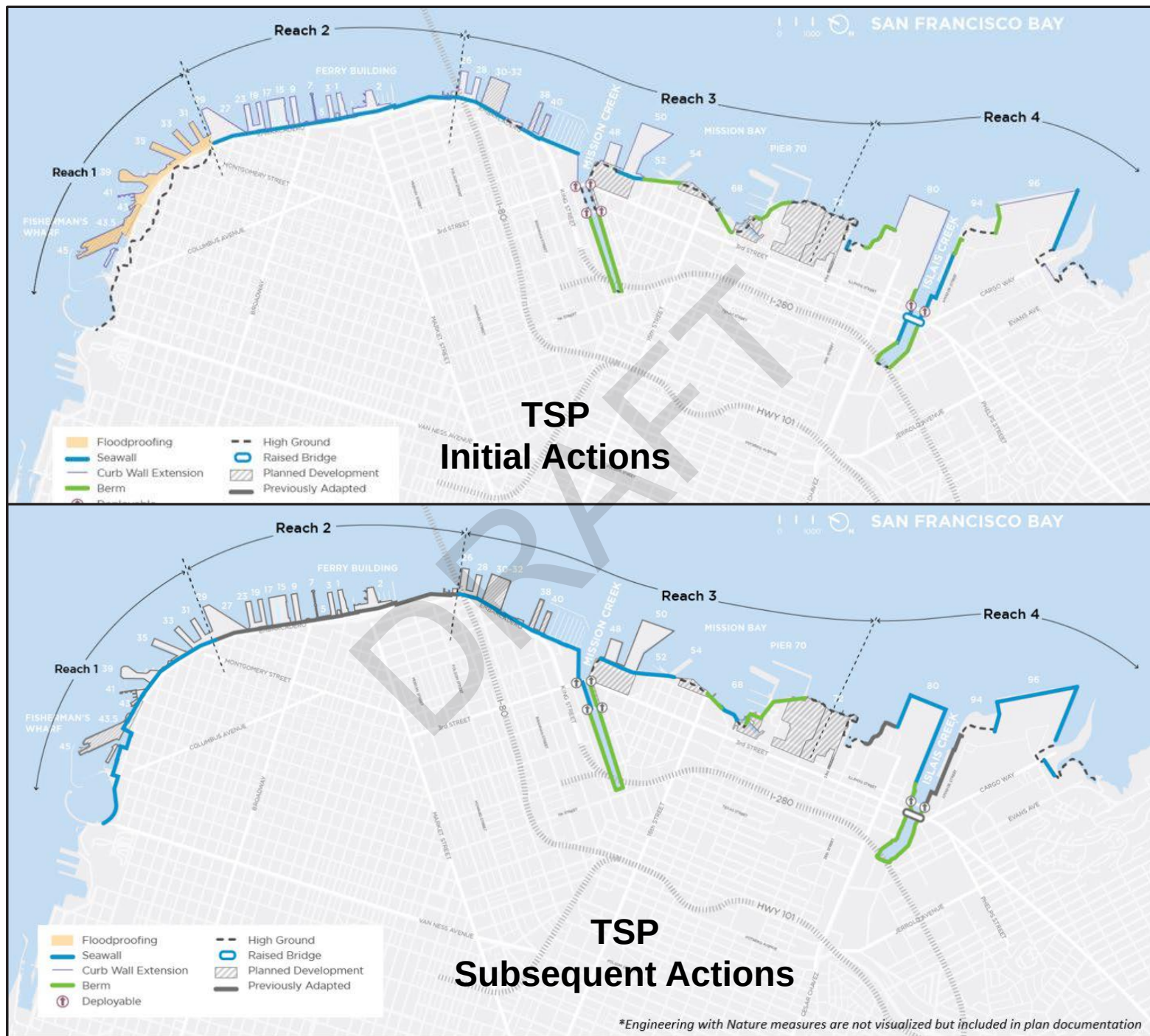
Outline

- Detailed sub-reach-specific observations, comments, preliminary recommendations and proposed alternatives for the Northern Waterfront and the Southern Waterfront
 - ✓ Northern Waterfront: Aquatic Cove to Oracle Park
 - ✓ Southern Waterfront: Oracle Park to Heron's Head Park



TENTATIVELY SELECTED PLAN

(DRFAT EIS,
2024)





Northern Waterfront ~ 3.3 MILES

Major Tasks Under Current Plan:

- 1) Raise/rebuild wharves, piers and bulkhead walls
- 2) Ground improvement on landside of bulkhead wall: 100 ft wide x 100 ft deep or 50 ft wide x 50 ft deep

Constraints:

Ground improvement footprint extends across promenade, roadway, and light rail, requiring major relocation of utilities. May affect nearby buildings and structures. Traffic disruption during construction.

Sub-Reaches (Selected Based on Raise Elevation and Soil/Rock Profile)

- | | |
|----------------------------------|--|
| 1. North Beach: | Raise to EL. +15.5 ft.
5,000 feet (50 ft. x 50 ft. ground improvement) |
| 2. Yerba Buena Cove: | Raise to EL. +15.5 ft
6,500 feet (100 ft. x 100 ft. ground improvement) |
| 3. Ferry Building to Bay Bridge: | Raise to EL. +15.5 ft
2,000 feet (50 ft. x 50 ft. ground improvement) |
| 4. South Beach: | Raise to EL. 13.5 ft.
5,000 feet (50 ft. x 50 ft. ground improvement) |

NORTHERN WATERFRONT SEGMENT SUB-REACHES – POTENTIAL GROUND IMPROVEMENT OR ALTERNATIVE MEASURES



Sub Reach	Land Use	Target Raise Elevation and Current Ground Improvement Plan in Draft EIS (USACE, 2024)	Discussions on Potential Ground Improvement or Other Alternative Measures
Sub-Reach North-1 North Beach 5,000 feet	North - 1A: Aquatic Cove Park area (~1000-1200 feet length), ground elevation rise towards inland (Ghirardelli Square)	Raise to El. 15.5 ft (~5 ft. raise)	Low height curb wall at park area (away from shoreline such as along city streets) and flood gate or other closure structure at both ends may be more appropriate.)
	North - 1B: Wharfs and piers (Pier 39, Fisherman's wharf, etc.)	Ground Improvement 50 ft. x 50 ft.	Smaller Ground Improvement Footprint 30 feet (width) x 65 to 75 feet (depth) ~4000 feet
Sub-Reach North-2 Yerba Buena Cove to Ferry Building 6,500 feet	North – 2A: Pier 29 to Pier 15 (~2500 feet area). Shallower Fill + YBM than Ferry building area.	Raise to El. 15.5 ft (~5 ft. raise)	Smaller Ground Improvement Footprint 30 feet (width) x 65 to 75 feet (depth) ~2500 feet
	North – 2B: Ferry Building Area (Pier 9 to Ferry Building area).	Ground Improvement 100 ft. x 100 ft.	Alignment of floodwall is under considerations. Ground improvement plan should be developed after alignment is selected.
Sub-Reach North-3 South of Ferry Building to Bay Bridge 2,000 feet	Shallower Fill + YBM than Ferry Building area. Park area.	Raise to El. 15.5 ft (~5 ft. raise) Ground Improvement 50 ft. x 50 ft.	Floodwall on Secant Drilled Shaft and No Additional Landward Ground Improvement
Sub-Reach North-4 South Beach 4,000 feet	South of Bay Bridge to Mission Creek (AT&T Park). Wharfs, park, and parking lot area.	Raise to El. 13.5 ft (<2 ft. raise) Ground Improvement 50 ft. x 50 ft.	<u>Alternative 1:</u> Floodwall on Drilled Shaft and NO Additional Landward Ground Improvement. <u>Alternative 2:</u> Shoreline raise integrated with erosion protection and No Additional Landward Ground Improvement (damage expected during earthquake).



Observations and Preliminary Recommendations for the Northern Waterfront (Reach 1)

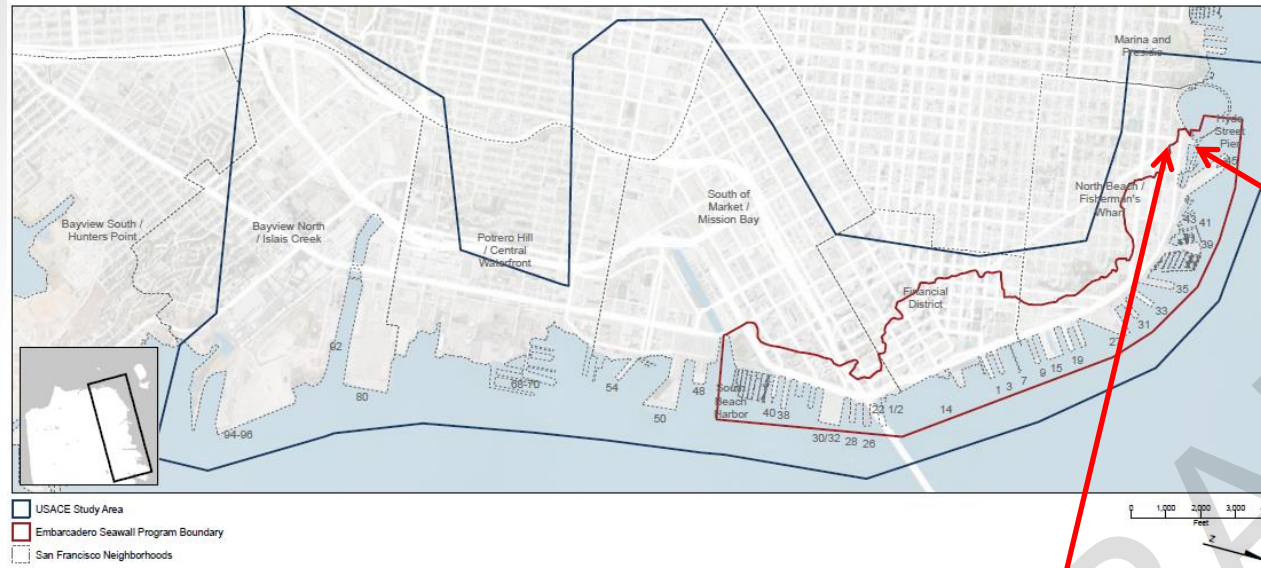
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Sub-Reach North 1A: North Beach – Aquatic Cove Park

Sub Reach	Current Flood Control and Ground Improvement Plan	Comments	Potential Alternative	Recommendations
North 1A: North Beach – Aquatic Cove Park	Raise to El. 15.5 ft (~5 ft. raise) Ground Improvement 50 ft. x 50 ft.	(1). Previous study (San Francisco Seawall Earthquake Safety and Disaster Prevention Program, Phase 1) area starts at Hyde Street Pier and did not include Aquatic Cove Park. (2) Subsurface investigation data (if available) is not documented in Aquatic Cove park area. (3) A beach is located in this sub-reach. A steeper slope towards Ghirardelli Square (open park area). (4) It does not appear that there is any existing seawall and rock dike in this area.	Low height curb wall or naturalized embankment in the Aquatic Cove Park area. Away from shoreline such as along city streets and flood gate or other closure structures at both ends of this sub-reach should be considered.	(1) Subsurface investigation-based longitudinal profile for Aquatic Cove Park Area should be developed. (2) Select alignment of flood protection system utilizing contour map, land-use, and subsurface conditions. A floodwall-sea wall system along the beach would reduce access to beach and would require tall sea wall system. A floodwall system away from the beach area may require low height food control system (such as curb wall, concrete block, naturalized embankment raise, etc.) (3) Develop performance criteria of the flood protection system based on risk-based approach including cost of the mitigation, etc. Rigid structural feature may require extensive design and ground improvement, whereas flexible system like naturalized embankments may be easily repairable (coincident pool during an earthquake is lower). (4) Most likely alignment should be established and length of flood control system should be determined more accurately.



Extent of Fugro Investigations of the Northern Waterfront Segment





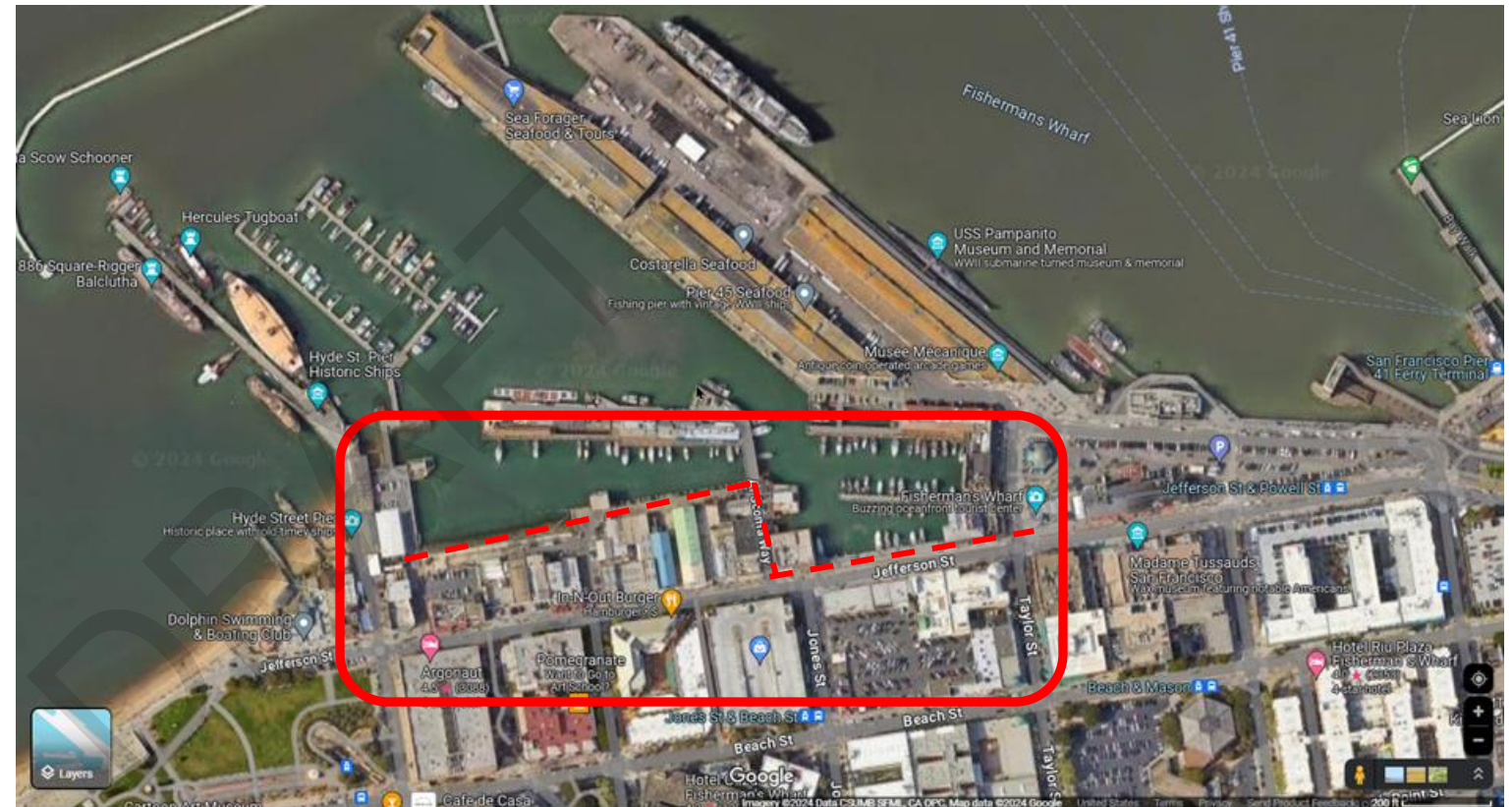
Observations and Preliminary Recommendations for the Northern Waterfront (Reach 1)⁸

Sub-Reach North 1B: North Beach – Hyde Street Pier to Taylor Street

Sub Reach	Current Flood Control and Ground Improvement Plan	Comments	Potential Alternative	Recommendations
North 1B North Beach – Hyde Street Pier to Taylor Street	Raise to El. 15.5 ft (~5 ft. raise) Ground Improvement 50 ft. x 50 ft.	(1). Subsurface profile from Fugro study is available for this sub-reach. (2) This sub-reach has been identified as “FW” sub-reach with alignment of existing wall along the edge of the shoreline. (3) Very limited space for wide area of ground improvement, as existing building are in proximity.	Floodwall on Drilled Shaft and NO or Very Limited Additional Landward Ground Improvement <u>Advantages:</u> ✓ Utilize the existing seawall alignment. ✓ No need for landward ground raise in streets and building area for flood control structure. ✓ No modifications to existing street and building required.	(1) Develop contour maps of existing topography to determine amount of raise. (2) Develop flood control system with limited footprint to avoid utility crossings, traffic control, building relocation, etc. (3) Most likely alignment should be established and length of flood control system should be determined more accurately.



Close Proximity of Commercial Buildings in Seawall Sub-Reach (Port ID: FW)



- Close proximity to buildings and roadway.
- Flood control system utilizing limited footprint should be contemplated.



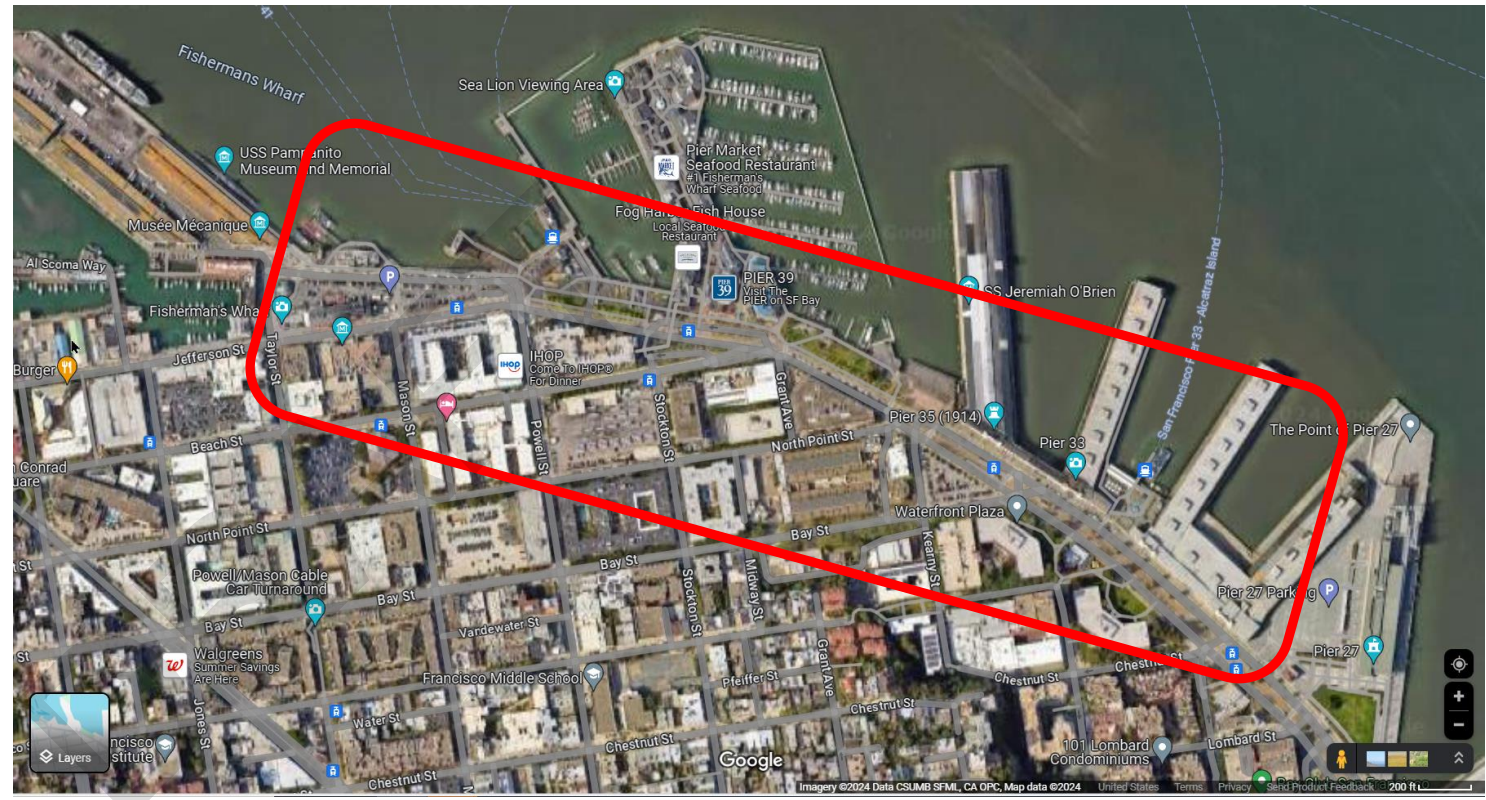
Observations and Preliminary Recommendations for the Northern Waterfront (Reach 1)

Sub-Reach North 1C: Taylor Street to North of Pier 29

Sub Reach	Current Plan	Comments	Potential Alternative	Recommendations
North 1C North Beach – Taylor Street to North of Pier 29	Raise to El. 15.5 ft (~5 ft. raise) Ground Improvement 50 ft. x 50 ft.	(1). Subsurface profile from Fugro study is available for this sub-reach. (2) Landside of this sub-reach has wide promenade, open parking space, park areas along the shore and outward land use are streets and light-rail. (3) Adequate space for ground improvement in promenade and open park space without interruption to streets and light-rail. (4) USACE draft EIS ground improvement recommendations were developed using Port of SF's geomorphology profile with very large scale (for geomorphology mapping). The combined depth of Fill+Young Bay Mud differ from actual conditions, as shown on subsurface profiles and data (based on explorations) shown in Port of SF reports. (5) Major portions of the sub-reach has piers. Presence of these piers (on piles) improve performance of floodwalls. Also, proposed floodwalls are on top of rock dike, which positively impact performance.	Smaller Ground Improvement Footprint ~30 feet (width) x 65 to 75 feet (depth) <u>Advantages:</u> ✓ Smaller footprint of ground improvement can be implemented in Promenade and park area. ✓ Modification may not need to extend to existing street and light-rail and as such major utility relocation, extensive ground improvement, and traffic disruption can be avoided. ✓ No need for landward ground raise in streets and building area for flood control structure.	(1) Develop contour maps of existing topography to determine amount of raise. (2) Document depth of Fill+Young Bay Mud and rationale for ground improvement. (3) Develop flood control system with limited footprint to avoid utility crossings, traffic control, building relocation, etc. (4) Most likely alignment should be established and length of flood control system should be determined more accurately.



Adequate Space for Efficient Ground Improvement Footprint without Impacting Streets and Light-rails in REACH 1: Sub-Reach: Taylor Street to North of Pier 29



- Wide promenade and park area (over rock dike) can be utilized for floodwall and ground improvement
- Flood control system utilizing limited footprint should be contemplated.



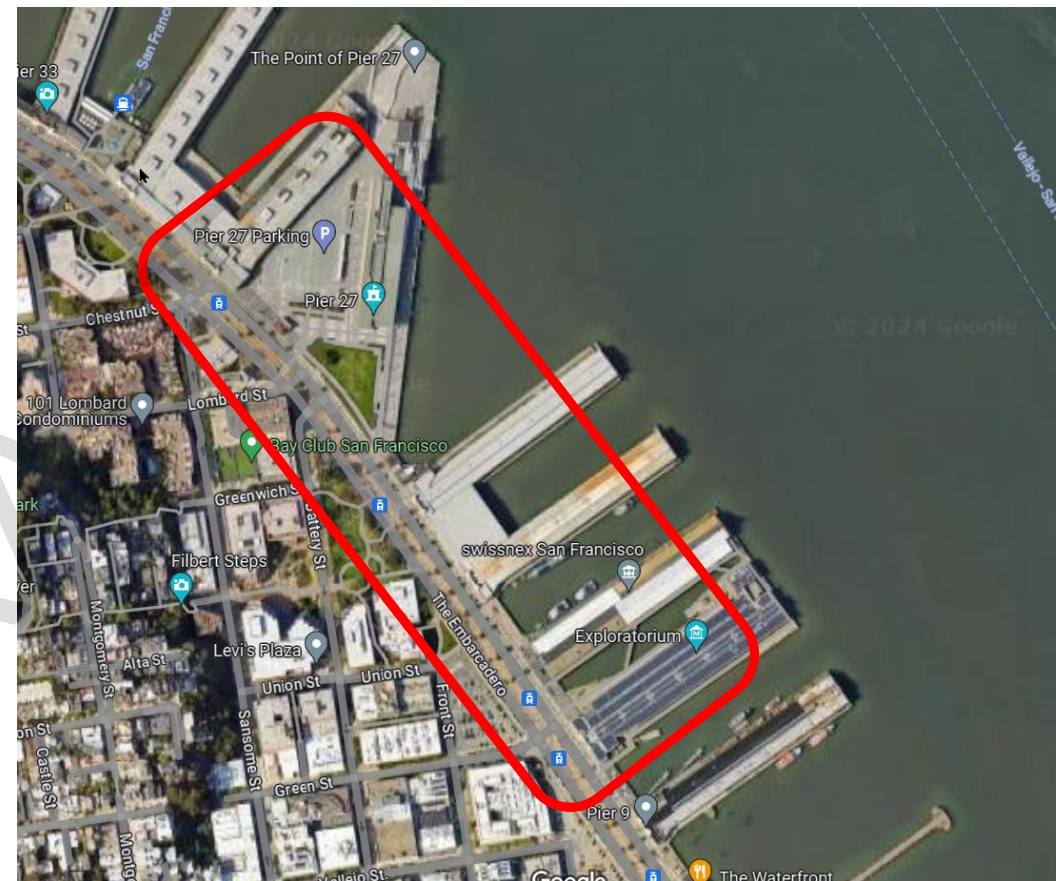
Observations and Preliminary Recommendations for the Northern Waterfront (Reach 2)¹²

Sub-Reach North 2A: Pier 29 to Pier 15

Sub Reach	Current Plan	Comments	Potential Alternative	Recommendations
North 2A: Pier 29 to Pier 15	Raise to El. 15.5 ft (~5 ft. raise) Ground Improvement 100 ft. x 100 ft.	(1). Subsurface profile from Fugro study is available for this sub-reach. (2) Landside of this sub-reach has wide promenade and park areas and outward land use are streets and light-rail. (3) Adequate space for ground improvement in promenade and open park space without interruption to streets and light-rail. (4) USACE draft EIS ground improvement recommendations were developed using Port of SF's geomorphology profile with very large scale (for geomorphology mapping). The combined depth of Fill+Young Bay Mud differ from actual conditions, as shown on subsurface profiles and data (based on explorations) shown in Port of SF reports. Depth is likely be shallower than 100 feet, as estimated in draft EIS. (5) Major portions of the sub-reach has piers. Presence of these piers (on piles) improve performance of floodwalls. Also, proposed floodwalls are on top of rock dike, which positively impact performance.	Smaller Ground Improvement Footprint ~30 feet (width) x 65 to 75 feet (depth) [USACE performed analysis at Pier 27 and it indicates that a a reduced ground improvement footprint should be adequate.] <u>Advantages:</u> ✓ Smaller footprint of ground improvement can be implemented in Promenade and park area. ✓ Modification may not need to extend to existing street and light-rail and as such major utility relocation, extensive ground improvement, and traffic disruption can be avoided. ✓ No need for landward ground raise in streets and building area to support the flood control structure.	(1) Develop contour maps of existing topography to determine amount of raise. (2) Document depth of Fill+Young Bay Mud and rationale for ground improvement. (3) Develop flood control system with limited footprint to avoid utility crossings, traffic control, building relocation, etc. (4) An analysis at Pier 27 (without taking advantage of pile pinning effects from Pier 27) indicate a smaller ground improvement footprint can be adequate.



Adequate Space for Efficient Ground Improvement Footprint without Impacting Streets and Light-rails in REACH 2: Sub-Reach: Pier 29 to Pier 15



- Wide promenade and park area (over rock dike) can be utilized for floodwall and ground improvement
- Flood control system utilizing limited footprint should be contemplated.



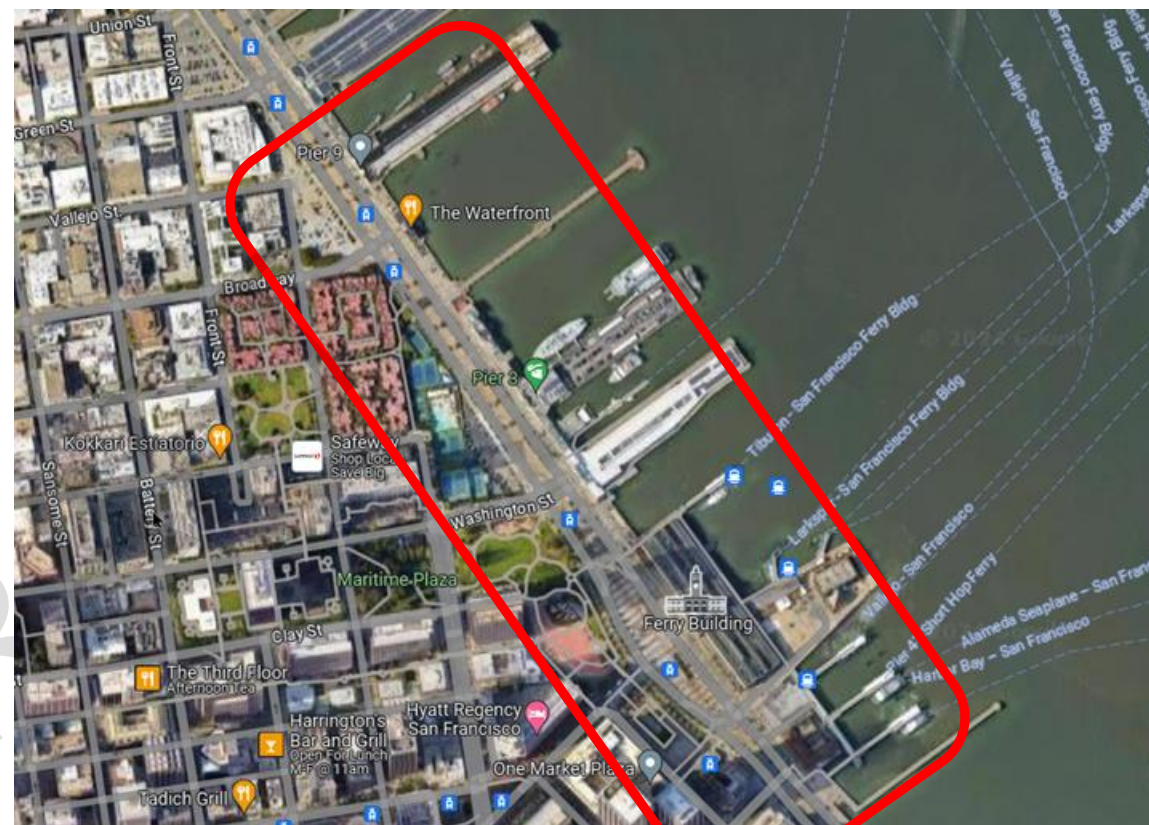
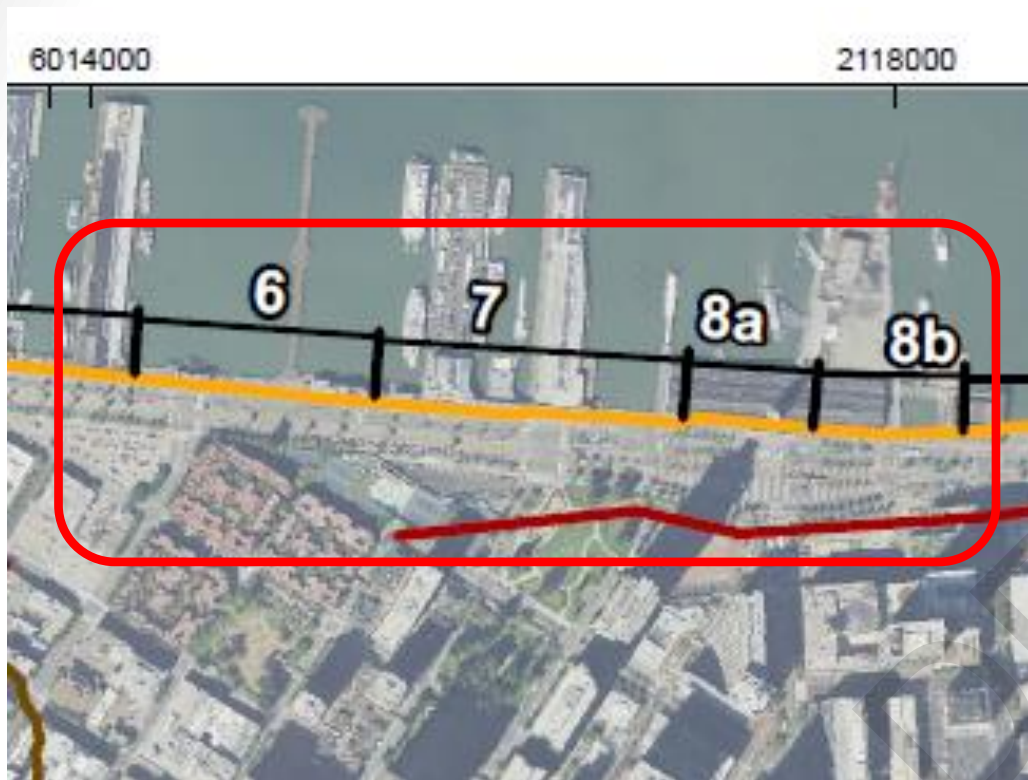
Observations and Preliminary Recommendations for the Northern Waterfront (Reach 2)¹⁴

Sub-Reach North 2B: Pier 9 to Ferry Building

Sub Reach	Current Plan	Comments	Potential Alternative	Recommendations
North 2B Pier 9 to Ferry Building	Raise to El. 15.5 ft (~5 ft. raise) Ground Improvement 100 ft. x 100 ft.	(1). Subsurface profile from Fugro study is available for this sub-reach. (2) Landside of this sub-reach has wide promenade and outward land use are streets and light-rail. (3) Adequate space for ground improvement in promenade without interruption to streets and light-rail. (4) USACE draft EIS ground improvement recommendations were developed using Port of SF's geomorphology profile with very large scale (for geomorphology mapping). The combined depth of Fill+Young Bay Mud differ from actual conditions, as shown on subsurface profiles and data (based on explorations) shown in Port of SF reports. Depth is likely be deeper than 100 feet, as estimated in draft EIS. (5) Major portions of the sub-reach has piers. Presence of these piers (on piles) improve performance of floodwalls. Also, proposed floodwalls are on top of rock dike, which positively impact performance.	Smaller Ground Improvement Footprint (Analysis is needed after finalizing alignment) <u>Advantages:</u> ✓ Smaller footprint of ground improvement can be implemented in Promenade area. ✓ Modification may not need to extend to existing street and light-rail and as such major utility relocation, extensive ground improvement, and traffic disruption can be avoided. ✓ No need for landward ground raise in streets and building area to support the flood control structure.	(1) Alignment needs to be finalized first (landside or waterside of Ferry building). Analysis is needed to estimate ground improvement footprint and depth. As this is a complicated area with deep Fill+YBM, an analysis is needed in planning phase. Two analysis sections in Pier 27 and 30-32 have shown that 1H:1V aspect ratio is not needed to support flood control system considering seismic. However, location of the flood control system and condition of the existing Foundation conditions in Ferry building area should be considered. (2) Develop contour maps of existing topography to determine amount of raise. (3) Document depth of Fill+Young Bay Mud and rationale for ground improvement. (4) Develop flood control system with limited footprint to avoid utility crossings, traffic control, building relocation, etc.



Alignment for Flood Control System Should be Selected in REACH 2: Sub-Reach: Pier 9 to Ferry Building



- Wide promenade and park area (over rock dike) can be utilized for floodwall and ground improvement in area north of Ferry building.
- Alignment of flood control system needs to be finalized for Ferry building area before estimating ground improvement. Depth of ground improvement in this area is expected to be deeper than estimated 100 feet. Also, rock dike is landward in this area.
- Flood control system utilizing limited footprint should be contemplated.



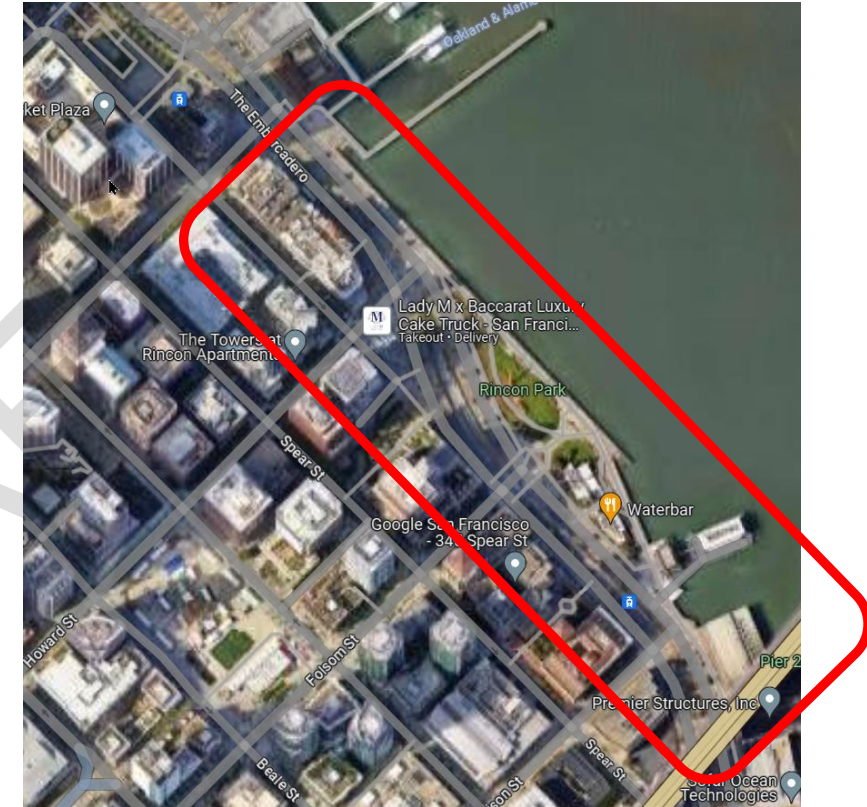
Observations and Preliminary Recommendations for the Northern Waterfront (Reach 2)¹⁶

Sub-Reach North 3: Rincon Park to Bay Bridge

Sub Reach	Current Plan	Comments	Potential Alternative	Recommendations
North 3 South Beach: Rincon Park to Bay Bridge	Raise to El. 15.5 ft (~5 ft. raise) Ground Improvement 50 ft. x 50 ft.	(1). Subsurface profile from Fugro study is available for this sub-reach. (2) Landside of this sub-reach has wide promenade park area and outward land use are streets and light-rail. (3) Adequate space for ground improvement in promenade without interruption to streets and light-rail. (4) USACE draft EIS ground improvement recommendations were developed using Port of SF's geomorphology profile with very large scale (for geomorphology mapping). The combined depth of Fill+Young Bay Mud differ from actual conditions, as shown on subsurface profiles and data (based on explorations) shown in Port of SF reports. Depth of Fill+YBM shallower in this area and close to bottom of rock dike. (5) Portions of this sub-reach has piers. Presence of these piers (on piles) improve performance of floodwalls. Also, proposed floodwalls are on top of rock dike, which positively impact performance.	Floodwall on Drilled Shaft and NO Additional Landward Ground Improvement <u>Advantages:</u> ✓ No need for landward ground raise in streets to support the flood control structure.	(1) Develop contour maps of existing topography to determine amount of raise. (2) Document depth of Fill+Young Bay Mud and rock dike. (3) Develop flood control system with limited footprint to avoid utility crossings, traffic control, building relocation, etc.



Alignment for Flood Control System Should be Selected in REACH 2: Sub-Reach: Rincon Park to Bay Bridge



- Wide bay trail and park area. Due to shallow Fill+YBM and presence of rock dike, a flood wall system in drilled shaft may be adequate in this area.



Observations and Preliminary Recommendations for the Northern Waterfront (Reach 3)¹⁸

Sub-Reach North 4: Bay Bridge to Mouth of Mission Creek

Sub Reach	Current Plan	Comments	Potential Alternative	Recommendations
North 4 South Beach: Bay Bridge to Mouth of Mission Creek	Raise to El. 13.5 ft (~<2 ft. raise) Ground Improvement 50 ft. x 50 ft.	(1). Subsurface profile from Fugro study is available for this sub-reach. (2) Landside of this sub-reach has wide promenade park area and outward land use are streets and light-rail. (3) Adequate space for ground improvement in promenade without interruption to streets and light-rail. (4) USACE draft EIS ground improvement recommendations were developed using Port of SF's geomorphology profile with very large scale (for geomorphology mapping). The combined depth of Fill+Young Bay Mud differ from actual conditions, as shown on subsurface profiles and data (based on explorations) shown in Port of SF reports. Depth of Fill+YBM shallower in this area and close to bottom of rock dike. (5) Portions of this sub-reach has piers. Presence of these piers (on piles) improve performance of floodwalls. Also, proposed floodwalls are on top of rock dike, which positively impact performance.	Floodwall on Drilled Shaft and NO Additional Landward Ground Improvement [USACE performed analysis at Pier 30-32 and it indicates that a floodwall on drilled shaft should be adequate in this area. Port of SF analysis also shows limited deformations for existing conditions.] <u>Advantages:</u> ✓ No need for landward ground raise in streets to support the flood control structure.	(1) Develop contour maps of existing topography to determine amount of raise. (2) Document depth of Fill+Young Bay Mud and rock dike. (3) Develop flood control system with limited footprint to avoid utility crossings, traffic control, building relocation, etc.



Thickness of Rock Dike is Equal or Close to Thickness of Rock Dike + Young Bay Mud in REACH 3: Sub-Reach: Bay Bridge to Mouth of Mission Creek



- Wide bay trail, park, and parking lot area. Due to shallow Fill+YBM and presence of rock dike, a flood wall system in drilled shaft may be adequate in this area.



Southern Waterfront ~ 5 MILES

Major Tasks Under Current Plan:

- (1) Naturalized or embankment shorelines, floodwalls, and curb extensions
(mostly <2 feet raise)
- (2) Ground improvement by 50 ft X 50 ft in all areas, except two wharf areas
(Pier 80 and Piers 90-92-94-96 with 100 ft x 100 ft)

Existing Park and Trails

(1) Mission Creek Park, (2) Huffaker Park, (3) Mission Creek, Stormwater Park, (4) China Basin Park (highland – no mitigation), (5) Bay Front Park, (6) Aqua Vista Park, (7) Mariposa Bay Front Park, (8) Crane Cove Park, (9) Warm Water Cove Park, (10) Islais Creek Parks (Muni Park, Promenade, Skate Park, etc.), (11) Heron's Head Park, (12) San Francisco Bay trail along Oracle Park, etc.

Existing Sub-Reaches

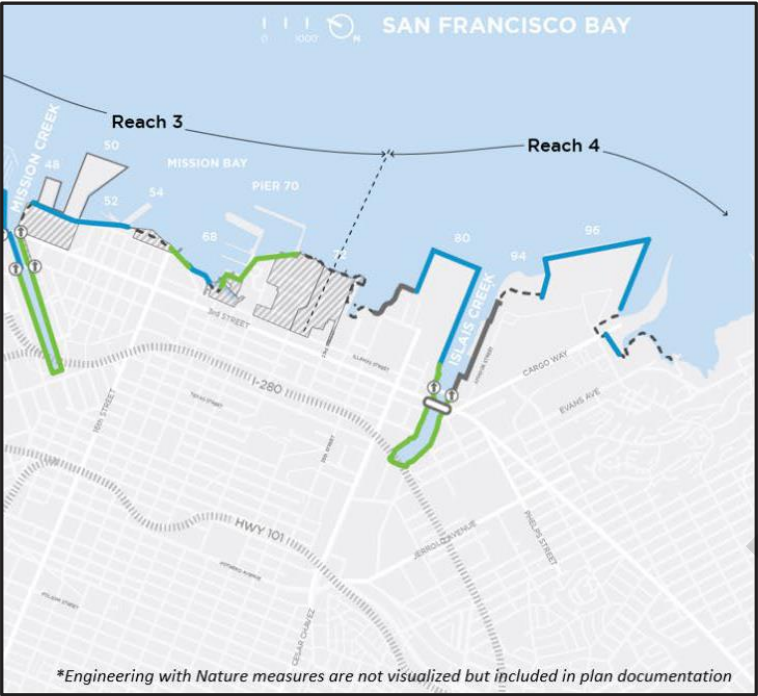
1. Mission Creek: 7,000 feet (50 ft. x 50 ft. ground improvement)
2. Mission Creek to Islais Creek: 7,700 feet (50 ft. x 50 ft. ground improvement)
3. Piers: 14,800 feet (100 ft. x 100 ft. ground improvement)

MAJOR LIMITATION IN SOUTHERN WATERFRONT

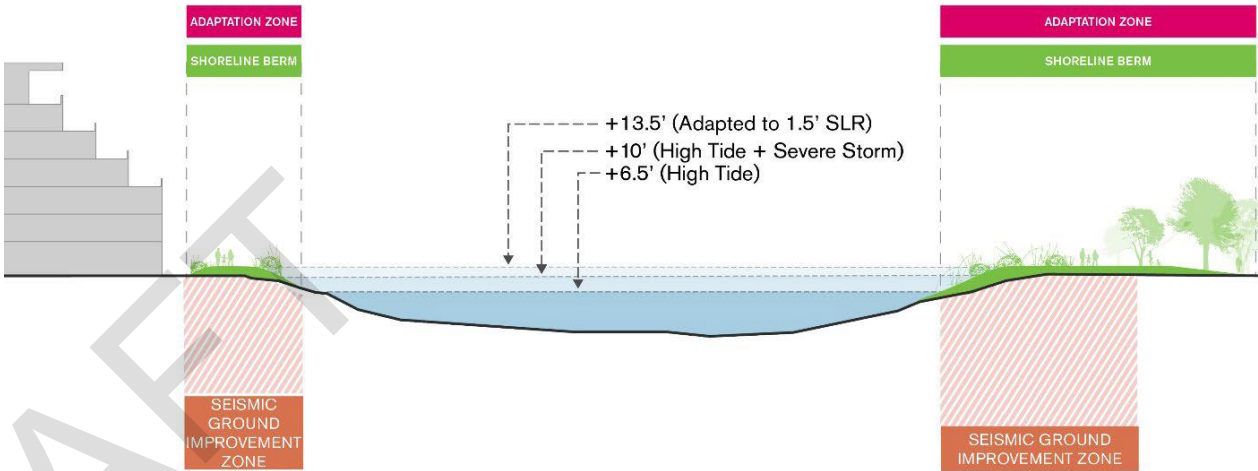
*Subsurface data along the proposed alignment is either unavailable
or inadequate for engineering evaluations*



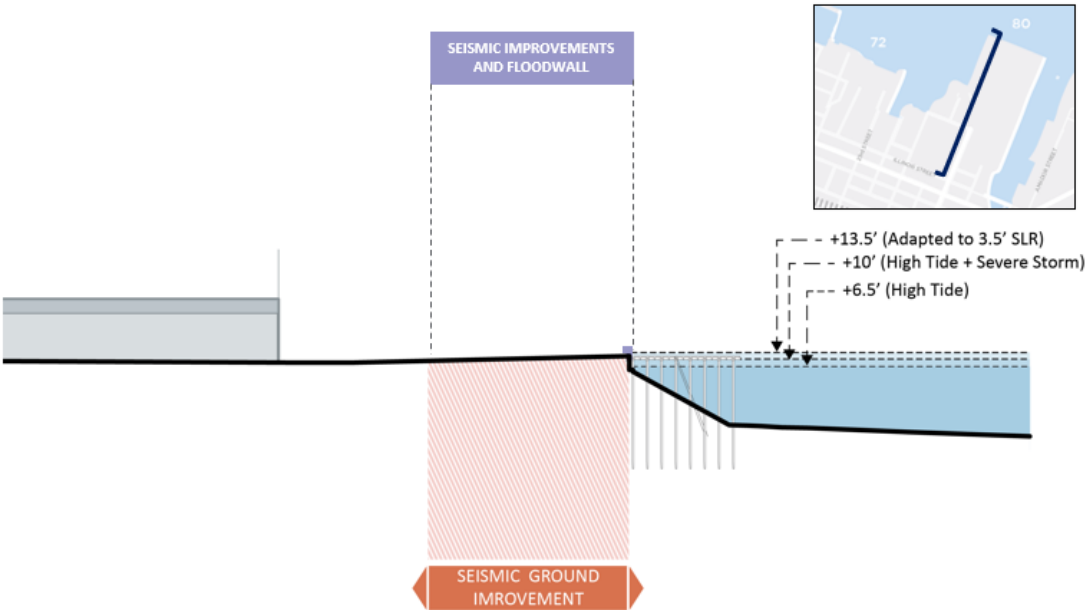
Southern Waterfront ~ 5 MILES



Shoreline Berm (14,700 feet)



Piers (14,800 feet)





SOUTHERN WATERFRONT SEGMENT SUB-REACHES –POTENTIAL GROUND IMPROVEMENT OR ALTERNATIVE MEASURES

Sub Reach	Land Use	Target Raise Elevation and Current Ground Improvement Plan in Draft EIS (USACE, 2024)	Discussions on Potential Ground Improvement or Other Alternative Measures
South-1 Mission Creek ~7,000 feet	South1A; Oracle Park (~1000 feet)	Raise to El. 13.5 ft Naturalized shoreline (<2 ft. raise) Ground Improvement 50 ft. x 50 ft.	Limited shoreline work may be needed, if recent bulkhead wall retrofit and foundation work for AT&T park meet project objectives for SFWP.
	South1B: North Mission Creek Bank (~3000 feet)		Naturalized shoreline berm for 1.5 ft SLR Alternative 1: No ground improvement may be needed, if project allows post-seismic repair based on risk-assessment, as cost of naturalized shoreline berm of 1.5 ft repair may not be significant. Seismic analysis will be required to assess damage potential.
	South 1C: South Mission Creek Bank (wider park area) (~3000 feet)		Alternative 2: Limited ground improvement based on location, type, and consequence of flood control measure.
South-2 Mission Creek to Islais Creek ~7,700 feet	South-2 Pier 48 to Potrero Point (~3000 feet) Islais Creek (~4,700 feet)	Raise to El. 13.5 ft Naturalized shoreline (<2 ft. raise) Ground Improvement 50 ft. x 50 ft.	Naturalized shoreline raise for 1.5 ft SLR. Alternative 1: No ground improvement may be needed, if project allows post-seismic repair based on risk-assessment, as cost of naturalized shoreline berm of 1.5 ft repair may not be significant. Seismic analysis will be required to assess damage potential. Alternative 2: Limited ground improvement based on location, type, and consequence of flood control measure.
South-3 Pier 80 to Pier 96 ~14,800 feet	South-2 Pier 80 (~6,300 feet) Pier 92-94-96 (~8,500 feet)	Raise to El. 13.5 ft Curb Wall (<2 ft. raise) Ground Improvement 100 ft. x 100 ft.	Curb wall at a distance from edge to reduce need for extensive ground improvement. Different types of ground improvement measures should be evaluated.



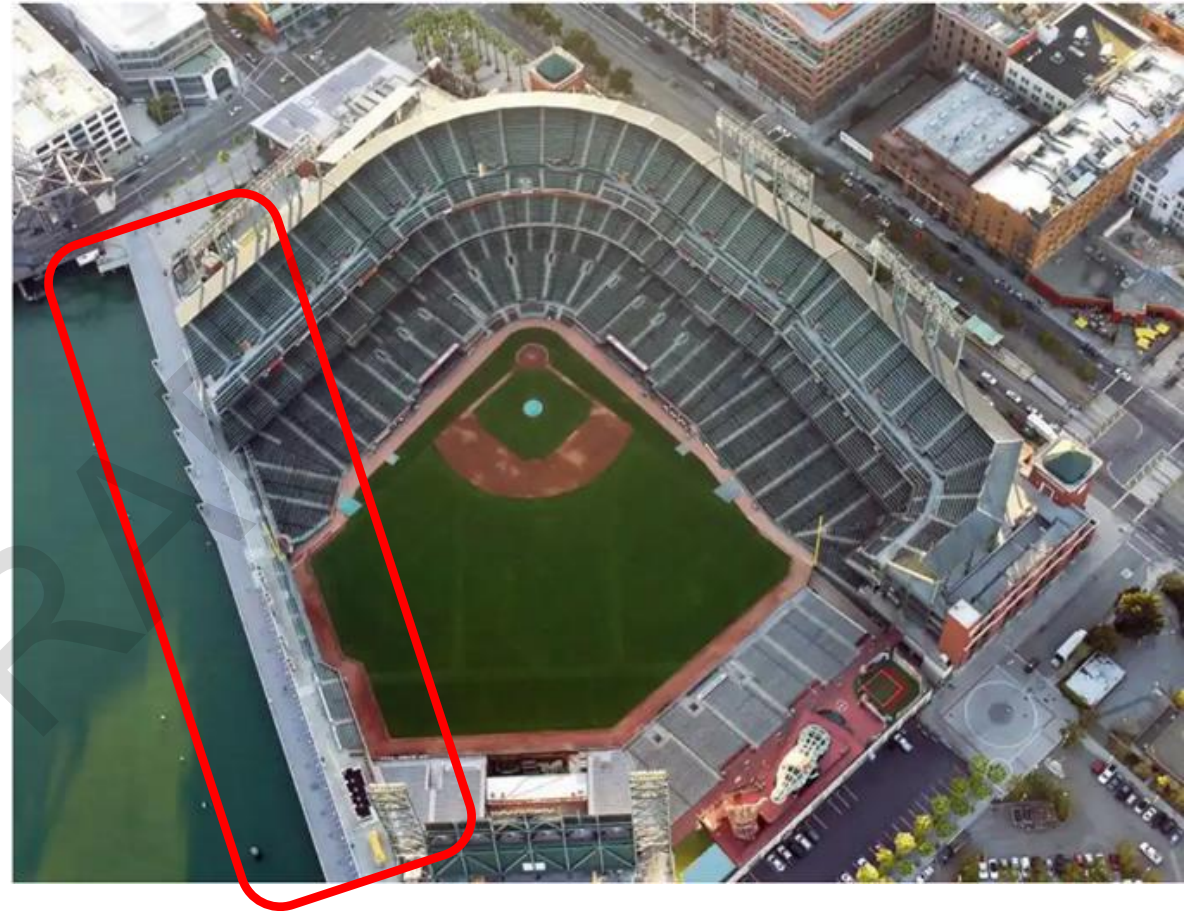
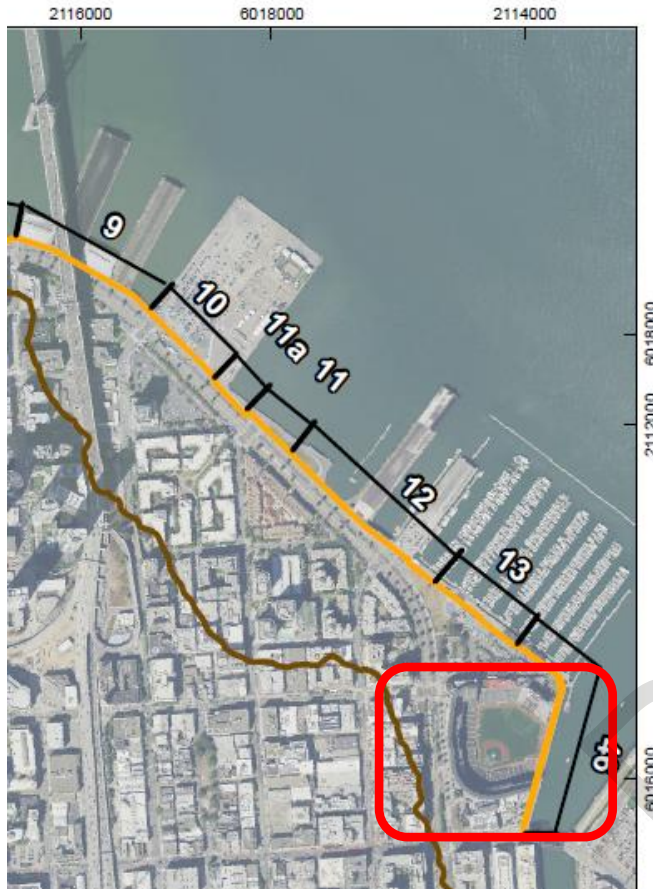
Observations and Preliminary Recommendations for the Southern Waterfront (Reach 3)²³

Sub-Reach South 1A: Oracle Park

Sub Reach	Current Plan	Comments	Potential Alternative	Recommendations
South 1A: Oracle Park	Raise to El. 13.5 ft (~<2 ft. raise) Ground Improvement 50 ft. x 50 ft.	(1). Subsurface profile from Fugro study is available for this sub-reach. (2) Landside of this sub-reach is Oracle Park (San Francisco Giants baseball stadium). (3) Information based on web-search indicates that Oracle Park has gone through seismic retrofit including foundation work and bulkhead wall seismic retrofit. Information from such project should be evaluated in this project. (4) Presence of oracle Park with foundation work may reduce need for extensive ground improvement.	If existing bulkhead wall is adequate and Oracle Park foundation has been improved, this sub-reach may not need additional ground improvement and floodwall work or the effort under this project could be limited.	(1) Develop contour maps of existing topography to determine amount of raise. (2) Document depth of Fill+Young Bay Mud. (3) Develop flood control system with limited footprint to avoid interference with Oracle park. (4) Collect information on recent seismic retrofit for Oracle park and evaluate the performance of the existing conditions and future conditions based on data from Oracle park's recent retrofit project.



REACH 3: Sub-Reach: Oracle Park



- Adjacent to Oracle Park. Based on information available in web, foundation and bulkhead retrofit have been performed for seismic.



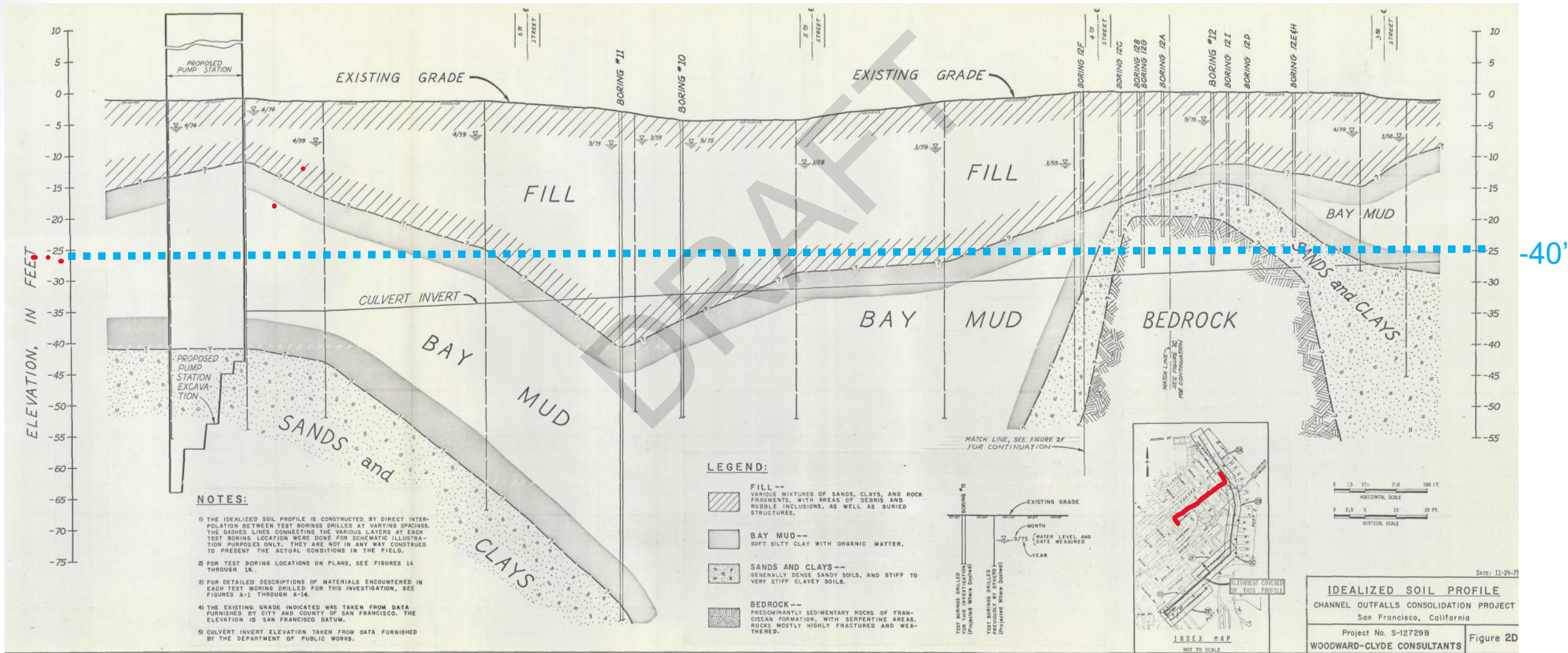
Observations and Preliminary Recommendations for the Southern Waterfront (Reach 3)²⁵

Sub-Reach 1B and 1C: Mission Creek

Sub Reach	Current Plan	Comments	Potential Alternative	Recommendations
South 1B and 1C Mission Creek	Raise to El. 13.5 ft (~<2 ft. raise) Ground Improvement 50 ft. x 50 ft.	(1). Subsurface data from previous studies is not documented/organized for this project or it is not clear any subsurface data, beside 1975 geologic profile for outfall structure is available. The combined thickness of Fill and Young Bay Mud (as used for ground improvement depth estimation) is much deeper than 50 feet (estimated depth of ground improvement for Mission Creek). (2) Residential buildings, park area, and a pump station are located on the landside of this sub-reach.	Naturalized shoreline berm for 1.5 ft SLR Alternative 1: No ground improvement may be needed. Alternative 2: Ground improvement with limited footprint	(1) Develop contour maps of existing topography to determine amount of raise. (2) Document depth of Fill+Young Bay Mud. (3) Develop flood control system with limited footprint to avoid interference with Oracle park. (4) Seismic analysis in this sub-reach is needed to evaluate (1) the performance of a flood control system in presence of nearby buildings and pump house, (2) thick Fill and YBM, and (3) invert elevation of Mission Creek.

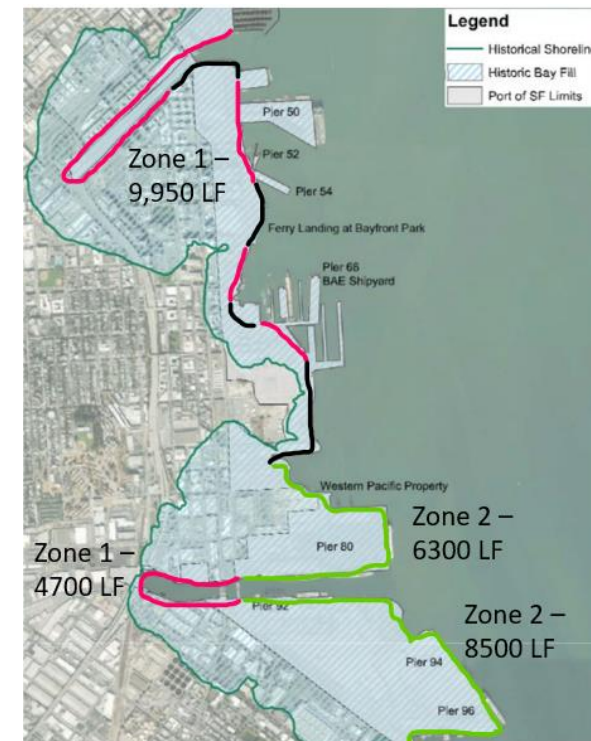
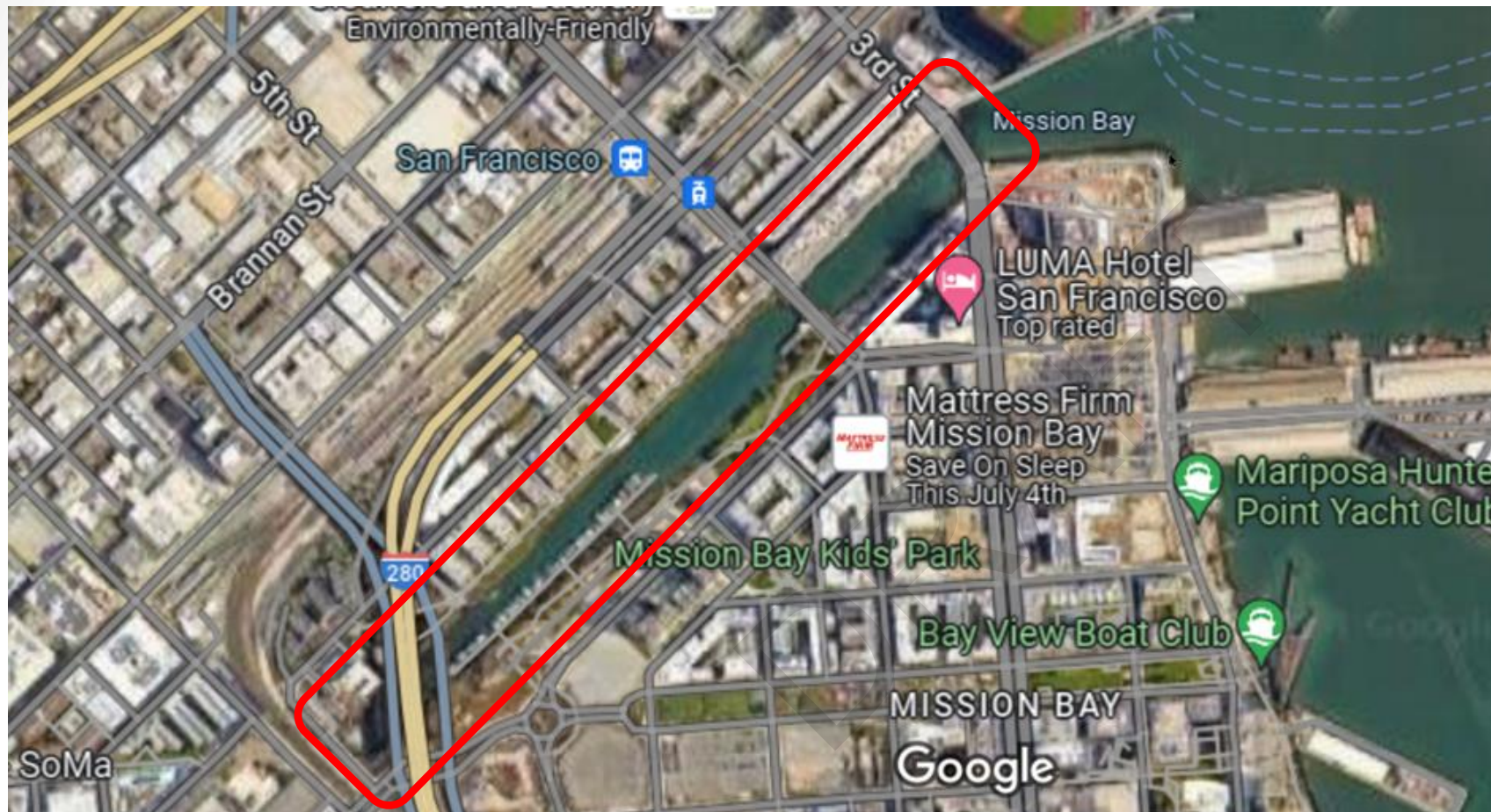


Thickness of Fill + Young Bay Mud Greater than 50 feet assumed for Mission Creek





REACH 3: Sub-Reach: Mission Creek



- Adjacent to Oracle Park. Based on information available in web, foundation and bulkhead retrofit have been performed for seismic.



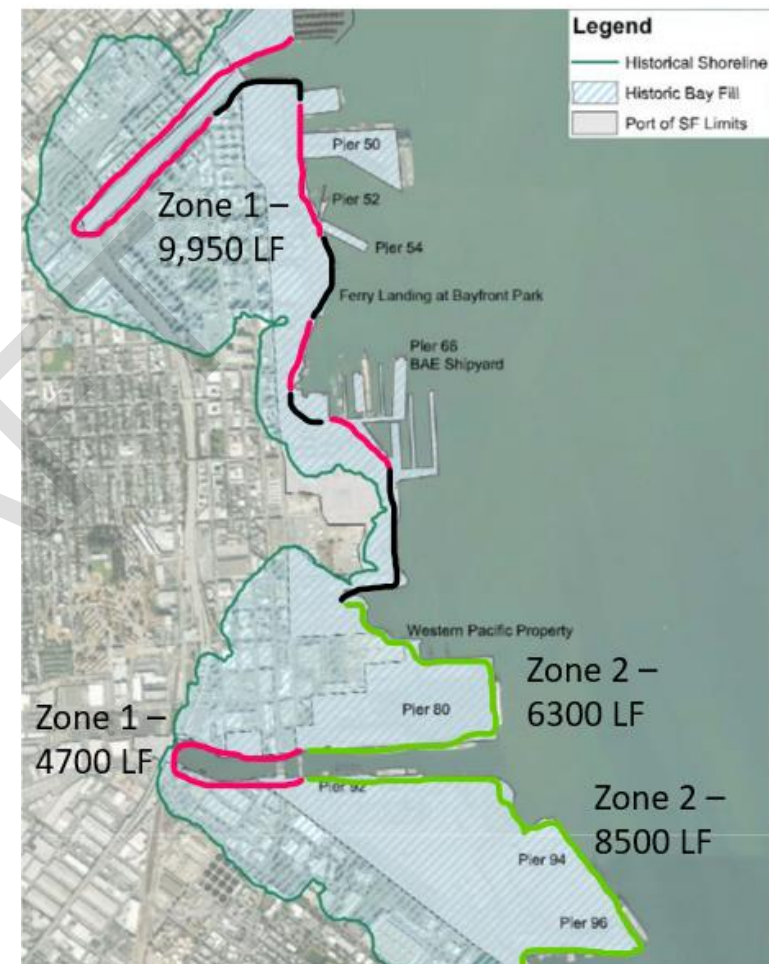
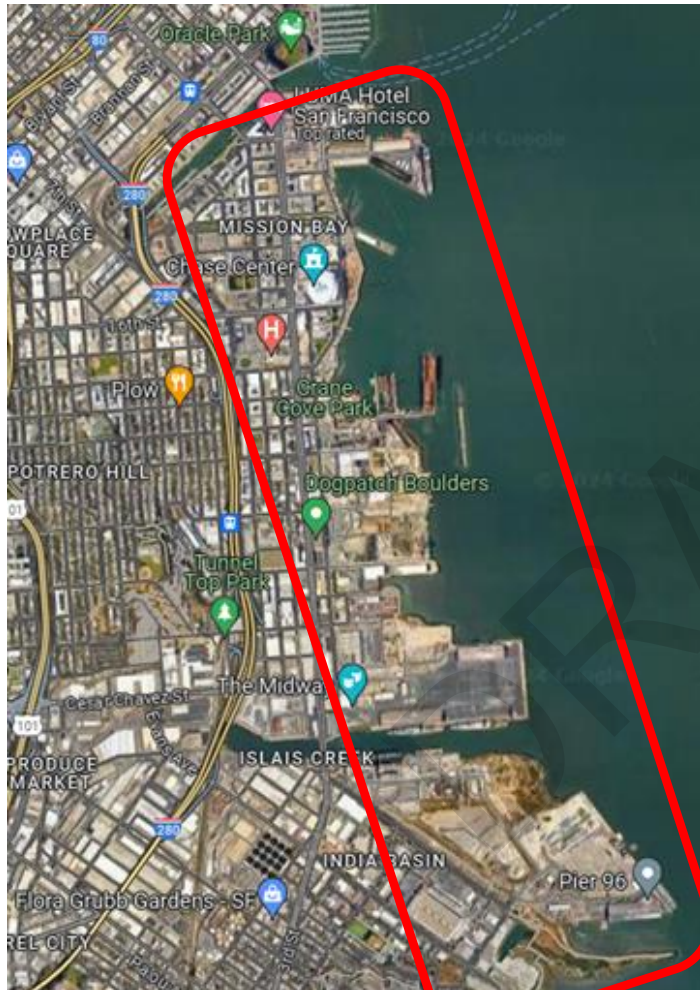
Observations and Preliminary Recommendations for the Southern Waterfront (Reach 4)²⁸

Sub-Reach South 3: Mission Rock to Hearon's Head Park, Except Piers 80 and 92-94-96, and High Lands

Sub Reach	Current Plan	Comments	Potential Alternative	Recommendations
South 3: Mission Rock to Hearon's Head Park, Except Piers 80 and 92-94-96, and high lands	Raise to El. 13.5 ft (~<2 ft. raise) Ground Improvement 50 ft. x 50 ft.	(1). It appears that majority of these segments do not have any subsurface data. (2) Parks and trails, Piers, and industrial facilities are located in this sub-reach. (3) No rock dike is present in this area like Northern waterfront. Hydraulic fill berm (4) It does not appear that there is any existing seawall in these piers.	As raise at these pier locations is only less than 2 feet (coincident pool for earthquake is lower than current ground elevation), different effective schemes than current draft IES plan can be considered: (1) Naturalized berm with an offset from the edges of the piers with limited or NO ground improvement. (2) Considering available space and subsurface conditions, other ground improvement measures can be contemplated (such as dynamic compaction, etc.). (3) Existing erosion protection measures (riprap) can be extended with other simplified approaches to provide <2 feet of raise for flood protection.	(1) Develop contour maps of existing topography to determine amount of raise. (2) Document depth of Fill+Young Bay Mud. (3) Develop subsurface profile of southern waterfront. (4) Considering the low height raise and land-use in the area, select alignment for flood control structure such that it may require less ground improvement, while meeting flood control and seismic requirements. (5) Seismic analysis in this sub-reach is needed to evaluate (1) the performance of a flood control system in different subsurface conditions that northern SFWP, (2) location of flood control system.



REACH 4: Sub-Reach South 3: Mission Rock to Hearon's Head Park, Except Piers 80 and 92-94-96, and High Lands



- Select alignment for flood control system considering land use in the area such as parks, streets, etc.. Also, different ground improvement schemes should be considered to reduce footprint, cost, etc. while ensuring a reliable system.



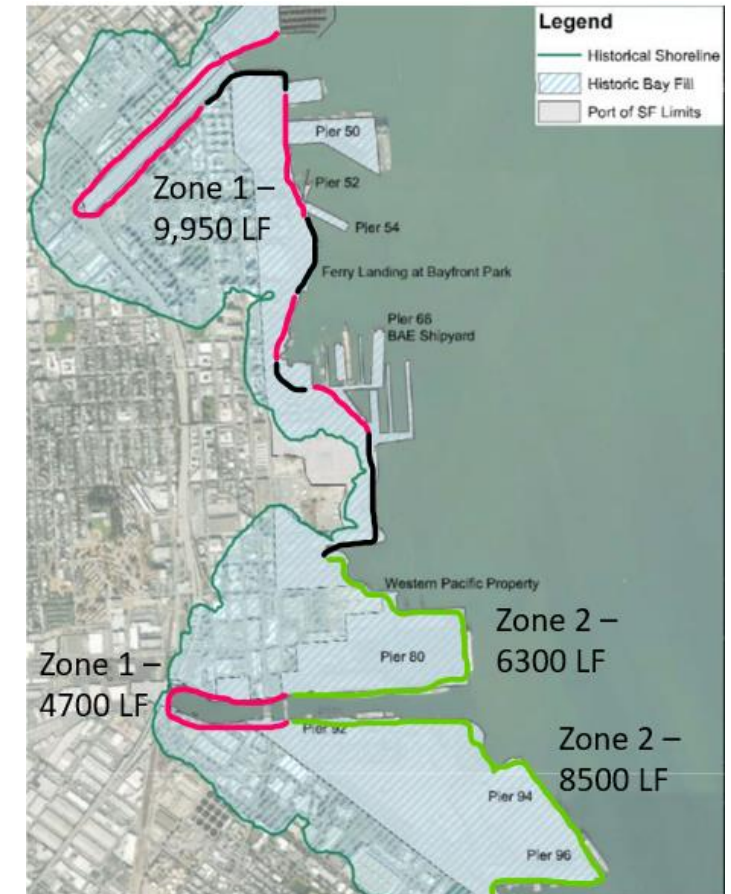
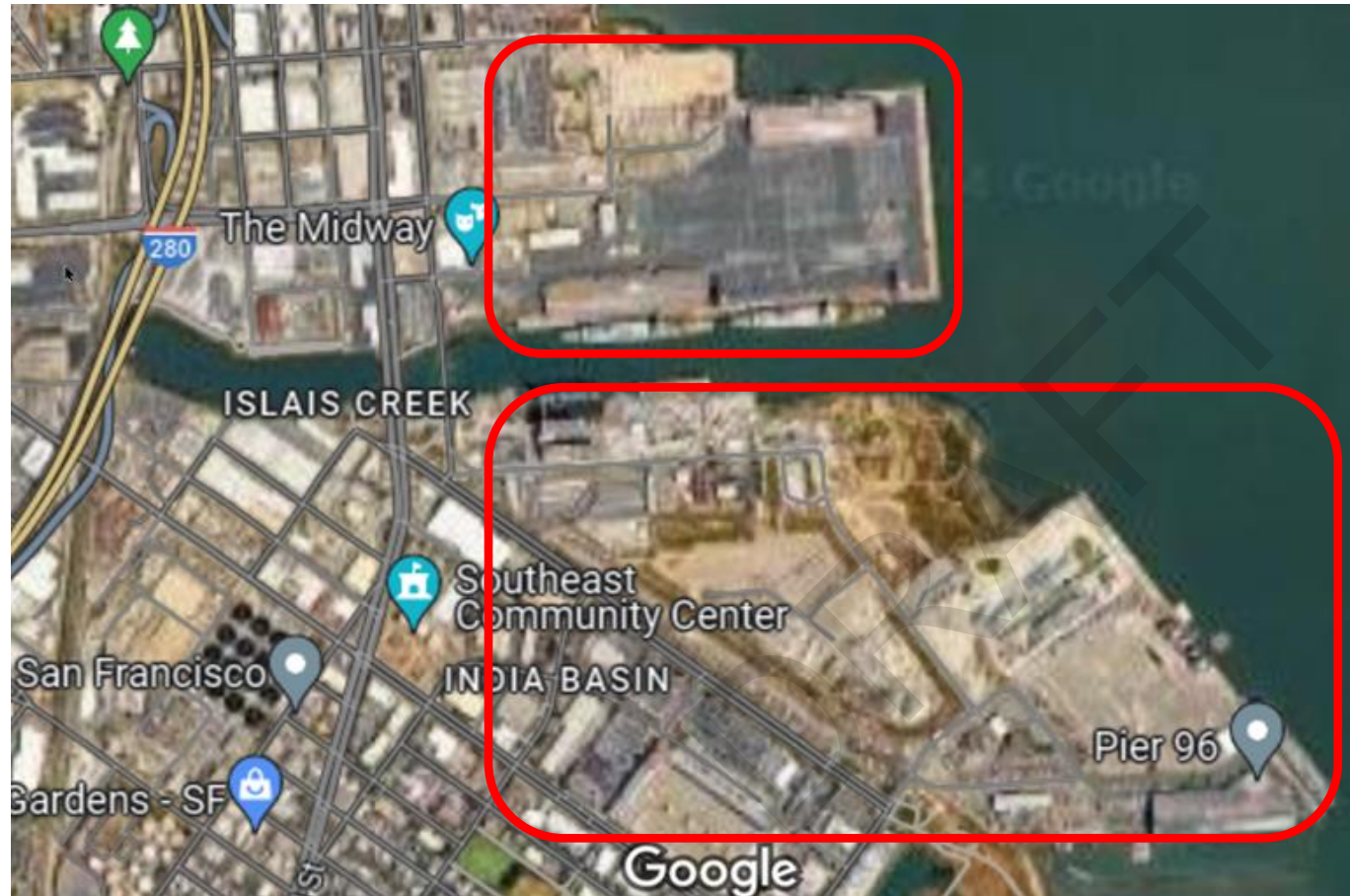
Observations and Preliminary Recommendations for the Southern Waterfront (Reach 4)³⁰

Sub-Reach South 4: Pier 80 and Piers 92-94-96

Sub Reach	Current Plan	Comments	Potential Alternative	Recommendations
South 4: Pier 80 and Piers 92-94-96	Raise to El. 13.5 ft (~<2 ft. raise) Ground Improvement 100 ft. x 100 ft.	(1). Subsurface data from previous studies has not been documented/organized for this project. The combined thickness of Fill and Young Bay Mud (as used for ground improvement depth estimation) at Pier 80 is deeper than 100 feet (estimated depth of ground improvement at Pier 80). (2) Piers and industrial facilities are located in this sub-reach. (3) No rock dike is present in this area like Northern waterfront. Hydraulic fill berm (4) It does not appear that there is any existing seawall in these piers.	As raise at these pier locations is only less than 2 feet (coincident pool for earthquake is lower than current ground elevation), different effective schemes than current draft IES plan can be considered: (1) Naturalized berm with an offset from the edges of the piers with limited or NO ground improvement. (2) Considering available space and subsurface conditions, other ground improvement measures can be contemplated (such as dynamic compaction, etc.). (3) Existing erosion protection measures (riprap) can be extended with other simplified approaches to provide <2 feet of raise for flood protection.	(1) Develop contour maps of existing topography to determine amount of raise. (2) Document depth of Fill+Young Bay Mud. (3) Develop subsurface profile of Pier 80 and Pier 92-94-96 (4) Considering the low height raise and land-use in the area, select alignment for flood control structure such that it may require less ground improvement, while meeting flood control and seismic requirements. (5) Seismic analysis in this sub-reach is needed to evaluate (1) the performance of a flood control system in different subsurface conditions that northern SFWP, (2) location of flood control system.



REACH 4: Sub-Reach South 4: Pier 80 and 92-94-96



- Select alignment for flood control system considering land use in these Piers. Also, different ground improvement schemes should be considered to reduce footprint, cost, etc. while ensuring a reliable system.