Recommendations for Hazard Mitigation

for the

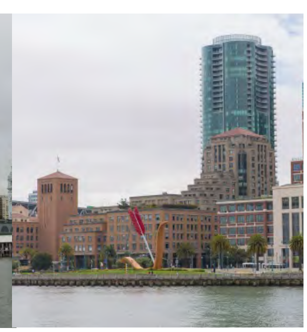
Seawall Earthquake Vulnerability Study

of the

Northern Seawall
San Francisco, California

Phase 3 Report

July 2016



Prepared for:
Port of San Francisco

Prepared by:
GHD-GTC Joint Venture

Recommendations for Hazard Mitigation for the Seawall Earthquake Vulnerability Study

PHASE 3 DRAFT REPORT

Northern Seawall,
Recommendations for Mitigation of Earthquake Hazards

July 2016

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List of Preparers

A consultant team headed by GHD-GTC Joint Venture prepared this report under the guidance of the Port of San Francisco, Engineering Division. A list of the consultant team personnel that worked on the Earthquake Vulnerability Study of the Northern Waterfront Seawall is provided below.

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1. Executive Summary

1.1. Project Description and Scope of Work

The Port of San Francisco (“Port”) is a self-supporting, municipal enterprise agency overseeing 7-1/2 miles of waterfront property along the San Francisco Bay. The Port has initiated a program to identify and upgrade portions of the waterfront vulnerable to earthquakes, and flooding associated with tsunami inundation and sea-level rise.

As such, the Port has commissioned this earthquake vulnerability study of the Northern Waterfront Seawall, which extends approximately 3 miles from Fisherman’s Wharf to Pier 46. Components of the study included: assessment of available information and condition, engineering analysis to determine likely damage to the seawall and infrastructure within the zone of influence, economic impacts resulting from multiple earthquake scenarios, development of conceptual level retrofits/costs, and recommendations for implementation of improvements and/or further study.

The overall study consists of three phases: 1) research, data collection and synthesis, 2) earthquake vulnerability study, and 3) recommendations for mitigation of earthquake hazards. Our Phase 1 report presented our findings, conclusions and recommendations regarding the research, data collection and synthesis phase of this study. Our Phase 2 report presented the results of geotechnical and structural assessments of the performance of the seawall, bulkhead wall/wharf, and other infrastructure within the estimated zone of influence of the seawall section.

For the Phase 3 work, the GHD/GTC Joint Venture (JV) developed a range of conceptual mitigation alternatives to address the seismic vulnerability of the seawall, bulkhead wall/wharf, and other infrastructure within the estimated zone of influence of the seawall sections as well as the flooding hazards associated with sea level rise. The JV evaluated the rough order of magnitude costs for design and implementation. The team also evaluated the costs, benefits, risks and values of mitigation alternatives including construction impacts to Port tenants, Embarcadero Promenade, Embarcadero roadway, utilities, and neighbors; construction risks due to unforeseen conditions, difficult or unique methods, and constructability; environmental and regulatory permitting impacts; historic impacts; resilience and adaptability to sea level rise and other climate change hazards.

1.1. Seawall Vulnerability Study Findings

Seismic Vulnerability

The study identified several major vulnerabilities for the Northern Seawall waterfront areas. The primary seawall vulnerabilities include the following:

- Movement of the rock dike toward the Bay and vertical settlement
- Damage and failure of the bulkhead wall from ground shaking
- Damage and collapse of the bulkhead wall/wharf structures from both ground shaking and movement of the rock dike

Other damage associated with seismic events along the waterfront is expected to include:

- Lateral spreading of the land within the seawall’s zone of influence
- Increased vertical settlement of the land within the zone of influence
- Breaks to utility lines
- Cracking of pavement

- Distortion of rails for Muni Metro system
- Increased damage to finger piers where connected to bulkhead wharves
- Inaccessible finger piers
- Loss of utilities on finger piers
- Erosion of land from bulkhead wall damage
- Increased flooding hazard from subsidence

Disruption associated with seismic events may include:

- Loss of finger piers until restoration of utilities and access
- Pedestrian use of Embarcadero Promenade
- Embarcadero Roadway
- Muni Metro light rail F, N & T Lines
- Ferry Service
- Bar Pilots

Development of the San Francisco waterfront on filled land over the past 100 plus years has produced a risk of large deformations and/or damage to these components during and after a significant seismic event. Young Bay Deposits underlying the seawall are comprised primarily of weak clay (commonly known as Young Bay Mud) and also contain layers of potentially liquefiable loose to medium dense sand deposits. The Young Bay Mud is a low strength material and is susceptible to lateral deformation during seismic events.

This study concluded that, due to the presence of this weak clay stratum and potentially liquefiable sand deposits, the rock dike may move toward the Bay, producing damage to the seawall, bulkhead wharf and supporting piles. The bulkhead wharf and seawall piles are relatively brittle (non-ductile) and will fail in shear, usually at their top connections to supported structure. Liquefaction of the placed fill materials behind the seawall, varying from 10 to 30 feet thick, may cause additional vertical settlement due to permanent ground deformation following a seismic event.

Finally, significant soil movement will also cause cracking and settlement of the upland fill areas supporting the promenade, Embarcadero roadway and MUNI light rail. The seawall and adjacent wharf and building structures, along with critical utilities and related infrastructure, are also located in the seawall zone of influence.

Likely areas of vulnerability are summarized as follows:

- Weak Clay Layer (Young Bay Mud):
  - Subject to degradation of shear strength during earthquake shaking and resulting horizontal strain, with associated significant lateral displacements. Mobilization of cyclic shear strains in the Young Bay Mud deposits underlying the rock dike and seawall may result in lateral displacements in the range of roughly 8 to 120 inches along portions of the Embarcadero waterfront. The large lateral displacements will have significant detrimental impacts on structures located above such lateral movements.
- Rock Dike:
  - Subject to lateral sliding or settlement due to earthquake shaking and associated lateral pressures from retained soils with potentially detrimental impacts on structures supported by or passing through the rock dike material.

- Seawall Bulkhead Wall:
  - Subject to lateral sliding or overturning due to earthquake shaking and associated lateral pressures from retained soils. Supporting timber piles may fail at the connections to the bulkhead structure.
  - Subject to failure of rock dike and supporting timber piles under soil lateral sliding of underground weak soil layers. Settlement of supporting rock dike will increase loading on and damage to supporting timber piles.
  - Failure of seawall bulkhead wall may result in partial collapse of adjacent bulkhead wharf structure and significant damage to landside infrastructure, such as roadways, buildings, railways and utilities.
- Bulkhead Wharf
  - Subject to lateral deformations and associated structure component forces due to earthquake shaking. Supporting piles may fail at the connections to the bulkhead wharf deck structure resulting in localized structural failure with associated local deformation of supported building structure. In more severe cases, partial collapse of supported structure may occur. Bulkhead wharf deck beams may fail at connections to the supporting seawall bulkheads resulting in partial collapse of the wharf deck and inaccessibility to the bulkhead wharf and adjoining finger piers.
  - Subject to failure of rock dike and supporting bulkhead wharf piles under soil lateral sliding of underground weak soil layers. Settlement of supporting rock dike will increase loading on and damage to supporting piles, resulting in wharf deck vertical deformations or partial or total collapse.
- Utilities
  - Subject to lateral deformations and associated component forces due to earthquake shaking. Utility structure may fail or deform to an extent that precludes functionality of the utility.
  - Subject to significant lateral deformations associated with soil lateral sliding of a weak underground soil layers. Deformations may be significant and variable along or across the utility, resulting in loss of function.

Two types of earthquake induced loading on the seawall bulkhead wall and bulkhead wharves were considered for the vulnerability study:

- Seismic inertial loading: the structure experiences seismic induced oscillating lateral accelerations. Structure component damage due to transient lateral displacements during the earthquake shaking, typically occurs at the tops of piles of seawall bulkheads, bulkhead wharfs and finger piers, including at pile locations underground. The structure may or may not return to its original configuration, with or without some permanent displacement offset.
- Seismic kinematic loading: seismic shaking induces global lateral displacements of the weak underground soil layers towards the bay, described in this report as “soil lateral sliding” or “lateral spreading”. Structures located above this sliding layer more or less displace with the sliding layer, thereby imposing a displacement demand on portions of the structure and its foundation elements. Structure components that pass into or through this sliding layer, typically piles, are exposed to large displacement induced stresses that are expected to lead to the failure of the pile structure in the vicinity of the soil sliding layer. The failed piles lose the ability to resist any significant lateral or vertical load and result in partial or total collapse of the supported structures above.

1.2. Flooding and Sea Level Rise Assessment

Present-day predictions for the most probable magnitude of sea level rise relative to present day levels are 12 inches by 2050 and 36 inches by 2100. With its present configuration, the existing Northern Seawall structure will not preclude flooding of the adjacent uplands. This flooding may be mitigated by rehabilitating the existing seawall and/or adjacent infrastructure to accommodate the expected sea level rise.

- Weak Clay Layer and Rock Dike:
  - Sea level rise is not expected to directly impact the weak clay layer or rock dike in any significant way. Rising sea levels and any increase in storm wave intensity may have some impact on the existing rock dike structure.
- Seawall Bulkhead Wall:
  - Sea level rise is not expected to impact the seawall bulkhead wall in any significant way with respect to its structural performance. However, the present seawall bulkhead will not preclude bay waters from overtopping the bulkhead wall and flooding adjacent uplands as sea levels rise.
- Bulkhead Wharf:
  - Sea level rise is not expected to impact the seawall bulkhead in any significant way with respect to its structural performance. However, rising waters will accelerate corrosion activity on existing wharf structure. The present bulkhead wharf structure will not preclude bay waters from overtopping the bulkhead wharf deck and flooding supported infrastructure.
- Utilities:
  - Sea level rise will impact utilities if bay waters are not precluded from reaching utility infrastructure. Storm water systems may back-up due to the increased pressure heads at exit points, creating flooding at upland locations. Other utility systems (electrical, communication, potable water, fire water) are subject to damage or loss of functionality should they be inundated by flooding.

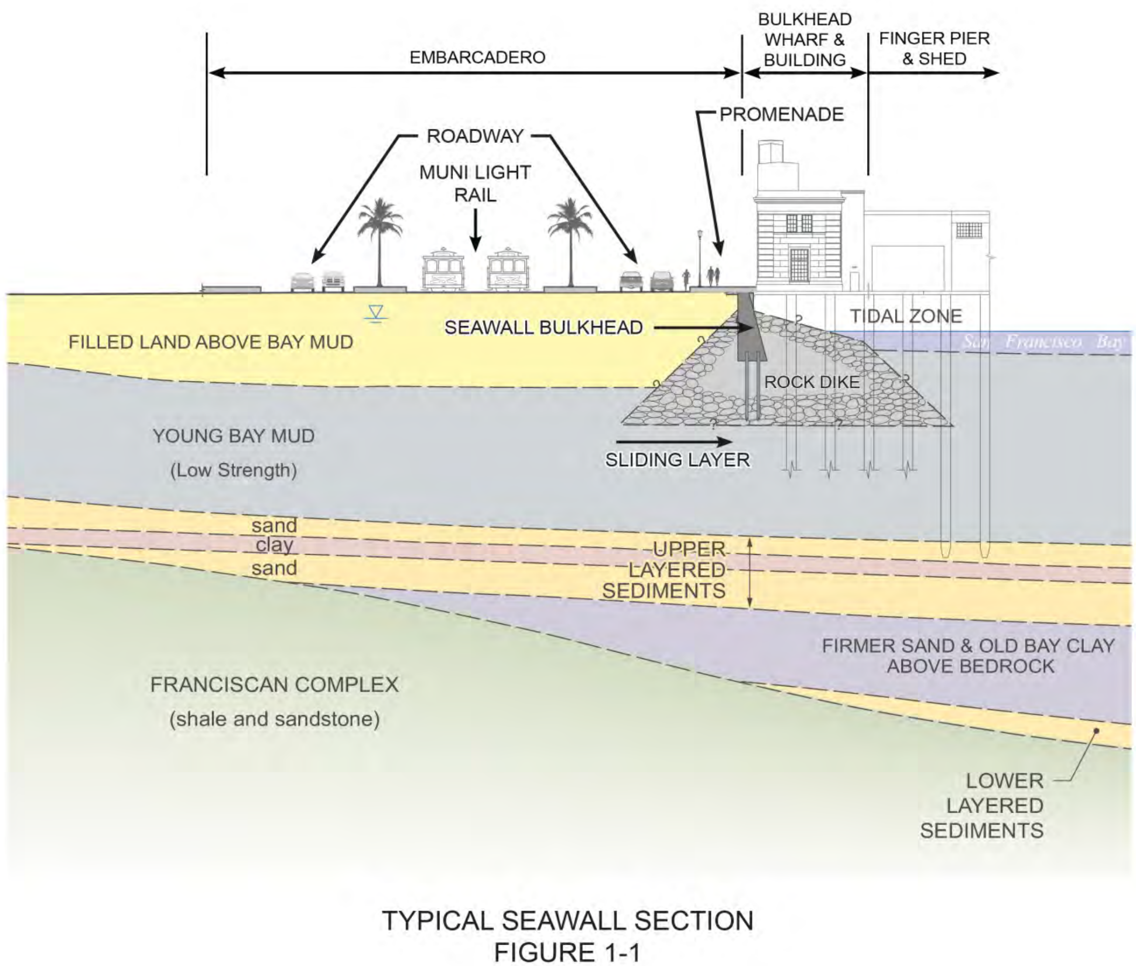


Figure 1-1: Typical Seawall and Bulkhead Wharf Cross Section

1.3. Seawall Vulnerability Mitigation Concepts

Mitigation Alternative Concepts

This study developed a number of mitigation alternatives that address some or all of the existing vulnerabilities presented above. These mitigation alternatives consist of geotechnical or structural mitigation techniques alone or in combination. The study concluded that a combination of techniques may be needed to adequately address all significant impacts identified in this study.

Conceptual mitigation alternatives were developed in this portion of the study and are presented here. The mitigation alternatives fall into four general types as a function of discipline type and area of concern. These are:

- Ground Improvement for Mitigation of Seismic Vulnerability
- Bulkhead Wall and Wharf Structural Retrofits for Mitigation of Seismic Vulnerability
- Bulkhead Wall and Wharf Structural Replacement for Mitigation of Seismic and Sea Level Rise Vulnerability
- Utility Relocation and/or Replacement for Mitigation of Seismic and Sea Level Rise Vulnerability

These mitigation alternatives, conceptual in scope, represent practical waterfront applications. Most, if not all, of the alternatives have been constructed on United States west coast projects. The project team was not charged with analysis of the various mitigation alternatives. At this stage, the ground treatment layout and structure configurations represent judgment-based approximations of appropriate mitigation applications. Aspects of site-specific considerations involving design, construction, permitting, and impacts have not been specifically addressed at this early stage of development. Budget estimates and construction production rates reflect approximate costs for similar projects in the San Francisco Bay Area and west coast.

Geotechnical Solutions

Geotechnical mitigation techniques consist of some form of modification and strengthening of the underlying soil strata. These techniques take the form of jet grouting, deep soil mixing or compaction grouting. The technique may be applied landside or bayside of the existing seawall with varying cost and benefits that are a function of the location, depth and width of the soil treatment. These geotechnical mitigation techniques are summarized as follows:

- Jet grouting
- Deep soil mixing
- Compaction grouting

Geotechnical mitigation techniques address soil strength and soil response to seismic shaking. Geotechnical techniques, by their nature, do not directly address the detrimental impacts of sea level rise. However, if designed for long-term port development, for example by creating a stable foundation on which a new rock dike or seawall can be constructed, ground treatment methods used on the bayside will allow for raising of ground elevation in the future. Thus, such methods can all be used to accommodate sea-level rise, whether or not this is explicitly shown in our mitigation alternatives.

Structural Solutions

Structural mitigation techniques consist of rehabilitation of the existing structure, either by strengthening, supplementing critical structure components and/or replacement of the structure. Component strengthening takes the form of enhancement of pile head and wharf deck beam to seawall connections and increasing the vertical load carrying capacity of wharf deck beams. Supplementing critical structure components involves providing alternative load paths to such critical components. Replacement involves partial or total demolition of the existing structure and construction of new structure.

Structural mitigation techniques address structural component capacity relative to earthquake demand and, by themselves, can be made to mitigate the potentially detrimental effects of seismic shaking. Structural impacts due to soil lateral sliding are a different story since any large displacement occurrence is more than likely to result in structural damage and deformation that is unwanted.

Recommended Short and Long Term Mitigations

The primary factor behind the significant vulnerability of the Northern Seawall to major earthquake events is the poor quality of the supporting soils and the distinct possibility of large lateral deformations of large volumes of soil strata located under the Northern Seawall.

Therefore, the primary objective of any long term mitigation technique is to reduce or eliminate this soil lateral sliding tendency using geotechnical mitigation methods. Where it is not possible to eliminate this effect, either due to cost or constructability given practical considerations, the mitigation technique would include structural mitigation techniques to arrive at a configuration that would provide acceptable short term performance from a life safety and structural collapse perspective. Long term mitigation would also address sea level rise by raising the wharf deck or bulkhead grade elevation.

This study identified and refined several such combined mitigation alternatives for the purposes of providing:

1 Mitigation alternatives that are applicable to and are likely to be used for at least one seawall section.

2 At least one short term and one long term mitigation alternative for each seawall section.

3 A basis for developing rough order of magnitude (ROM) probable cost of construction for mitigation alternatives applicable to a given seawall section.

1.4. Economic Impact Study Results

An economic study was conducted by the JV in order to estimate impacts of large earthquakes on Port property and the San Francisco waterfront. The economic risk was established for each seawall section associated with the following parameters:

Revenue to the Port of San Francisco including leases, business activity and revenue, damage to commercial property, private housing and employment. The Port’s properties generate approximately $2 billion in annual spending, property leases provide approximately $50 million in rent and provide $500 million in employee wages. Property lease revenue, business revenue and employee income costs are considered variable cost items that grow with time.

Estimated property damage and losses using bulkhead wharf structural damage plots for two earthquake scenarios, M8.0 San Andreas – median estimate (approximately 225 year return period) and a larger earthquake with a 975 year return period.

- Disruption to tourism spending in San Francisco. The City of San Francisco receives annually approximately 18 million visitors, $11 billion spending and has a $3 billion payroll.
- Replacement cost of existing Port infrastructure. Replacement costs are considered capital cost items.
- Transportation: Golden Gate Bridge District and WETA Ferry, Muni, Cars, Bikes, Pedestrian.
- Maritime including the cruise ship industry and the Bar Pilots.

- Emergency response include the fire department and Ferry system and other waterside transit.
- Loss of major utility services to the waterfront and City

Economic Impacts Study Results

Total economic value is tabulated for each seawall section on Table 5-3 assuming time increments of zero, six months and one year for assessing maximum possible economic risk over time. The total economic risk for the entire Northern Seawall is $1.607 billion capital cost plus $2.131 billion per year in variable costs.

1.5. Seawall Section Mitigation Prioritization

Seawall sections were assessed for their relative economic risks, cost of mitigation, and resulting relative importance and performance for mitigation based on value engineering techniques. This was done by determining the economic risk of each seawall section, the least costs for short and long term geotechnical and structural mitigation, and assuming relative importance of the economic risk, costs of mitigation, and other non-economic factors that may be important to the Port and stakeholders. Once these items are defined, each item was assigned a rating relative to all seawall sections; most ratings are formulated based on the economic data determined for each seawall section. Ratings for non-economic factors are left to the discretion of the Port but ratings for non-economic factors are assumed here for illustrative purposes.

The result of this exercise was a prioritization of seawall section mitigations and associated minimum short and long term mitigation costs. The short term and long term prioritization is not necessarily the same.

Seawall Section Economic Risk

The economic risk for each seawall section is based on the present value of assets for each seawall section. Replacement costs for such assets have been determined from data provided by the Port and are divided by superstructure or substructure, and landside, bulkhead wharf and finger pier assets.

Seawall Section Mitigation Costs

Estimated rough order of magnitude construction costs were developed for various geotechnical and structural mitigation alternatives. The applicability of these alternatives to each seawall section, either as short or long term mitigation, was determined and, where applicable, the resultant rough order of magnitude (ROM) costs applied for each section. The minimum mitigation cost for each seawall section for both short term and long term mitigation scenarios was assumed as the estimated mitigation cost for the purposes of seawall section ranking and prioritization. These minimum costs per foot of seawall ranged from $38,641 per foot to $183,741 per foot for seawall sections 13 and 11a, respectively.

Seawall Section Ranking

The seawall sections are ranked relative to each other using value engineering principles. Basically, value engineering compares alternatives with each other on a quantitative basis by assigning relative parameter ratings and parameter weights on a rational basis for parameters that are important to the various stakeholders involved with a project. This study assumes parameters, weights, ratings and stakeholders for the purposes of demonstration and determining the seawall section ranking. However, any one or more of these items may be adjusted as the Port sees fit.

The assumed parameters for this study are based primarily on economics with an additional open parameter that reflects social and/or political influences deemed important to the ranking process.

The primary economic parameters are economic risk and mitigation costs. The associated mitigation alternatives are:

- Do nothing.
- Perform short term mitigation.
- Perform long term mitigation.

A third parameter, titled “Other Issues” may include any non-economic parameter deemed important to the ranking process. This study assumes that specific seawall sections will have additional considerations, economic or otherwise, that are deemed worthy of additional consideration. This study assumes that Fisherman’s Wharf, Pier 39, the cruise terminal at Pier 27, the Exploratorium at Piers 15-17, and the other publicly or privately occupied space at Piers 9, 1 to 3, 26-28 and 38 are relatively more important due to tourism, commerce and life safety issues. The new Pier 43.5 and Brannan Street Wharf are deemed to represent lower risk because they are of newer construction as public open space and designed to present day design codes. Section P46 and China Basin are also deemed less important because there is little significant Port infrastructure located at these seawall sections.

Seawall Section Prioritization

A base case prioritization scenario was assessed as a best-estimate for a mix of economic risk, mitigation cost and other issues parameters. In our opinion, this mix best accommodates all of the stakeholder significant items that are important to and are affected by mitigation of the Northern Seawall. Under this scenario, the recommended first and last priorities for short term mitigation are seawall sections 9 (Pier 26-28) and section 9a (Pier 14), respectively. The recommended first and last priorities for long term mitigation are seawall sections 8a (Ferry Plaza) and 9a (Pier 14), respectively..

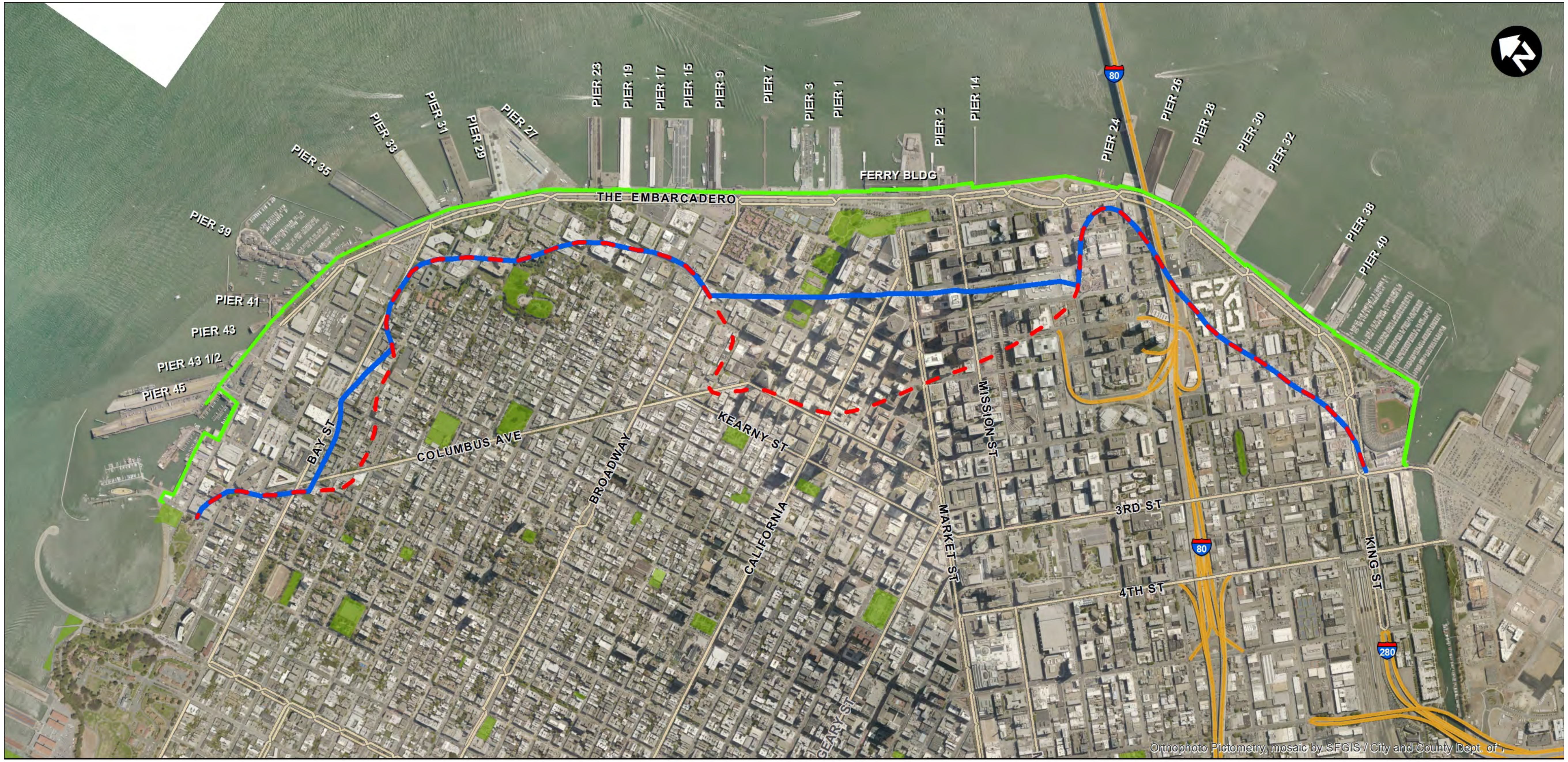
The sensitivity on the prioritization to each parameter was also evaluated by assessing prioritization scenarios for each parameter individually. For example, assuming that only economic risk is important, the recommended first and last priorities for short term mitigation are seawall sections 10 (Pier 30-32) and 9a (Pier 14), respectively. The recommended first and last priorities for long term mitigation are seawall sections 8a (Ferry Plaza) and 9a (Pier 14), respectively.

By comparison, assuming only mitigation cost is important, the recommended first and last priorities for short term mitigation are seawall sections 13 (former Piers 42 and 44) and 8 (Pier 2 and Agricultural Building). The recommended first and last priorities for long term mitigation are seawall sections P46 (Pier 46) and 11a (Brannan Street Wharf).

Finally, assuming only other issues are important and that emergency services and port operations are the highest ranked priority, the recommended first priority for both short and long term mitigation is seawall section 4 (Pier 27 and Cruise Terminal) This scenario eliminates the economic factors in the decision making which may or may not be appropriate.

1.6. Moving Forward: Considerations for Refining and Implementing Mitigation Strategies

The recommended seawall section priorities for mitigation, as determined by this study, should be used as a basis for further investigation and engineering studies. Short term mitigation work should take precedence over long term mitigation work unless funding is somehow obtained for the latter. Site specific investigation and detailed engineering design of mitigation alternatives applicable and specific to the high priority seawall sections should be performed in order to better define the vulnerability risks and costs of construction. The resulting data may be used in conjunction with this study to revise and enhance the results to refine mitigation costs and section mitigation priorities.



LEGEND

Seawall Bulkhead

Lateral Spread Hazard Boundary (HLA et al., 1992)

Project Study Area, within 1200 feet of the Seawall Bulkhead and within the Lateral Spread Hazard Zone

0 500 1,000 2,000 Feet

Lateral Spread Boundary Source: Harding Lawson Associates (HLA), Dames & Moore, Kennedy/Jenks/Chilton, EQE Engineering, 1992. Final Report, Liquefaction Study, North Beach, Embarcadero Waterfront, South Beach, and Upper Mission Creeek Area, San Francisco, California.

Figure 1-2: Seawall Project Study Area Map

2. Seawall Hazards and Vulnerability Summary

2.1. Introduction

The study identified several major vulnerabilities for the Northern Seawall waterfront areas. The primary seawall vulnerabilities include the following:

- Movement of the rock dike toward the Bay and vertical settlement
- Damage and failure of the bulkhead wall from ground shaking
- Damage and collapse of the bulkhead wall/wharf structures from both ground shaking and movement of the rock dike

Other damage associated with seismic events along the waterfront is expected to include:

- Lateral spreading of the land within the seawall's zone of influence
- Increased vertical settlement of the land within the zone of influence
- Breaks to utility lines
- Cracking of pavement
- Distortion of rails for Muni Metro system
- Increased damage to finger piers where connected to bulkhead wharves
- Inaccessible finger piers
- Loss of utilities on finger piers
- Erosion of land from bulkhead wall damage
- Increased flooding hazard from subsidence

Disruption associated with seismic events may include:

- Loss of finger piers until restoration of utilities and access
- Pedestrian use of Embarcadero Promenade
- Embarcadero Roadway
- Muni Metro light rail F, N & T Lines
- Ferry Service
- Bar Pilots

Development of the San Francisco waterfront on filled land over past 100 plus years has produced a risk of large deformations and/or damage to these components during and after a significant seismic event. Liquefaction of the placed fill materials behind the seawall, varying from 10 to 30 feet thick, may cause additional vertical settlement due to permanent ground deformation following a seismic event. In addition, the weak clay layer (commonly known as Young Bay Mud), is a low strength material and is susceptible to lateral spreading during and after seismic events.

This study concluded that, due to the presence of this weak clay layer, the rock dike may move toward the Bay, producing damage to the seawall, bulkhead wharf and supporting piles. The bulkhead wharf and seawall piles are relatively brittle (non-ductile) and will fail in shear, usually at their top connections to supported structure.

Finally, significant soil movement will also cause cracking and settlement of the upland fill areas supporting the promenade, Embarcadero roadway and MUNI light rail. The seawall and adjacent wharf and building structures, along with critical utilities and related infrastructure, are also located in the seawall zone of influence.

Likely areas of vulnerability are summarized as follows:

- Weak Clay Layer (Young Bay Mud):
  - Subject to liquefaction under earthquake shaking, with associated significant lateral displacements of a soil layer. The zone of sliding may be on the order of 4 to 15 feet thick (unless constrained by stiffer and stronger soil layers) and may displace from 8 to 120 inches, depending on the total layer thickness and the existing properties of the soil material. The large lateral displacements will have significant detrimental impacts on structures located above such lateral movements.
- Rock Dike:
  - Subject to lateral sliding on weak underlying soils or settlement due to earthquake shaking and associated lateral pressures from retained soils with potentially detrimental impacts on structure supported by or passing through the rock dike material.

- Seawall Bulkhead Wall:
  - Subject to lateral sliding or overturning due to earthquake shaking and associated lateral pressures from retained soils. Supporting timber piles may fail at the connections to the bulkhead structure.
  - Subject to failure of rock dike and supporting timber piles under soil lateral sliding of underground weak soil layer. Settlement of supporting rock dike will increase loading on and damage to supporting timber piles.
  - Failure of seawall bulkhead wall may result in partial collapse of adjacent bulkhead wharf structure and significant damage to landside infrastructure, such as roadways, buildings, railways and utilities.
- Bulkhead Wharf
  - Subject to lateral deformations and associated structure component forces due to earthquake shaking. Supporting piles may fail at the connections to the bulkhead wharf deck structure resulting in localized structural failure with associated local deformation of supported building structure. In more severe cases, partial collapse of supported structure may occur. Bulkhead wharf deck beams may fail at connections to the supporting seawall bulkheads resulting in partial collapse of the wharf deck and inaccessibility to the bulkhead wharf and adjoining finger piers.
  - Subject to failure of rock dike and supporting bulkhead wharf piles under soil lateral sliding of underground weak soil layer. Settlement of supporting rock dike will increase loading on and damage to supporting piles, resulting in wharf deck vertical deformations or partial or total collapse.
- Utilities
  - Subject to lateral deformations and associated component forces due to earthquake shaking. Utility structure may fail or deform to an extent that precludes functionality of the utility.
  - Subject to significant lateral deformations associated with soil lateral sliding of a weak underground soil layer. Deformations are significant and variable along or across the utility, resulting in loss of function.

Two types of earthquake induced loading on the seawall bulkhead wall and bulkhead wharves were considered for the vulnerability study:

- Seismic inertial loading: the structure experiences seismic induced oscillating lateral accelerations. Structure component damage due to lateral displacements during the earthquake shaking, typically occurs at the tops of piles of seawall bulkheads, bulkhead wharfs and finger piers, including at pile locations underground. .The structure may or may not return to its original configuration, with or without some permanent displacement offset.
- Seismic kinematic loading: the weak underground soil layer liquefies and induces global soil layer displacements, most likely towards the bay, described in this report as “soil lateral sliding”. Structure located above this sliding layer more or less displaces with the sliding layer. Structure components that pass into or through this sliding layer, typically piles, are exposed to large displacement induced stresses that are expected to lead to the failure of the pile structure in the vicinity of the soil sliding layer. The failed piles lose the ability to resist any significant lateral or vertical load and result in partial or total collapse of the supported structures above.

Additional Susceptibility

Another area where seismic damage is expected to occur is at the transition between the finger pier and bulkhead wharf. This damage is caused by having a relatively stiff structure (bulkhead wharf) behaving very different than a more flexible structure (finger pier). A seismic joint can be installed at the interface between these two structures to mitigate damage.

Finger piers will need to be reviewed after removing the stiffer, shorter piles near the rock dike and bulkhead wharf. Impact may be significant change to the structural response, increasing the structural period and lateral displacements (displacement demand.) In addition, liquefaction of cohesionless material may also increase effective length of piles and produce down drag loading on the pier piles.

Demand may also be reduced as a result of the longer piles and corresponding decrease in base shear from response spectra. Demand/Capacity ratios (DCRs) will need to be reviewed.

2.2. Immediate Life Safety Items

The following life safety items are listed in their order of concern:

Soil lateral sliding – this is lateral straining of underground soil layers due to seismic shaking with accompanying significant permanent lateral displacements towards the bay. The lateral displacements associated with moderate earthquakes are deemed to be detrimental to the piled structures along the Northern Seawall and the magnitude of lateral displacement will increase with shaking intensity. These lateral displacements are expected to also cause settlements along the seawall, the combined displacement resulting in displacement induced structural damage to the supporting piles and parts or all of the seawall, bulkhead wharfs, finger piers and structures located landside of the seawall with associated risk of life safety damage.

Seawall to bulkhead wharf connections – these typically consist of concrete or concrete encased steel wide flange beams seated into the seawall bulkhead structure. Details of these connections at each seawall section are typically unknown and the actual pull-out strength is not known. In a recent example, based on demolition activities of the bulkhead wharf at Brannan Street Wharf in 2012, these connections demonstrated little or no load capacity. If this is the actual case, the failure of these connections with associated failure of the bulkhead wharf deck along the seawall is very likely during significant seismic shaking and perhaps during less significant earthquake events as well, with potential risk of life safety damage and the immediate inability to access the bulkhead wharf and finger pier structures and inhabitants beyond.

Wharf pile head to deck connections - these connections typically are the first to exhibit structural damage during a significant earthquake. While controlled, ductile, and repairable damage is by design in present-day design codes, these existing pile head to deck connections on the bulkhead wharf structures are particularly susceptible as the provided displacement capacity is determined to be low by present-day design standards. The difference between life safety and collapse displacement capacities for these connections also appears to be relatively small with little capacity difference between the two associated seismic events. However, there is a variation between seawall sections in the ability of bulkhead wharf structures to resist the imposed displacement demands. Some bulkhead wharf sections are expected to survive a life safety seismic event while some others are expected to suffer significant damage.

2.3. Summary of Hazards

Summary of Hazards

Below grade utility lines (electrical, water, sewer, storm drain and telecommunications) running along the Embarcadero, with laterals crossing or penetrating the seawall and out to finger piers may be damaged during a seismic event. Many utility lines have rigid joints and connections that do not accommodate out-of-plane movement or expansion/compression. Vertical support may also be lost if the Embarcadero and promenade suffer ground displacement of underlying fill or the bulkhead wharves and finger piers are damaged.

Liquefaction of sandy fill materials may cause vertical displacement and cracking in Embarcadero roadway. Lateral spread may also cause cracks. Fill is thickest behind the seawall bulkhead so greater displacement can be expected in this area. Reviewing permanent ground deformation (PGD) plots for varying ground motion levels, we can anticipate moderate to significant damage to roadway following large seismic event. Post-earthquake repairs to the pavement will be needed to allow traffic to safely use the roadway.

Similar to the Embarcadero, damage can be expected to the rails for the Muni light rail and F-line along the Embarcadero. Settlement and possible distortion of the rails should be expected. Post-earthquake work will be required to filled in depressed areas and straighten, shim and level rails prior to reuse.

Access and entry to Pier 1, Pier 9 and entry to the Ferry Building and terminals also could be cutoff by seawall failure and other damage due to permanent ground displacement. This may impact ferry service and potential evacuation needs, as well as the functioning of the emergency water transport. Additionally, public and private assets along the waterfront are at risk of direct building damage or indirect losses due to potential ground failure and seawall damage, utility outages and prolonged closures.

Water transportation, which includes the ferry system, barges, and the harbor pilots located at Pier 9. There may be increased needs for ferry and barge-related operations post-earthquake. It is also crucial to keep the harbor (bar) pilots in operation as they will provide commercial maritime navigation services for San Francisco Bay. The ferries must remain operational to allow emergency evacuation from San Francisco to other areas within the region.

Recovery and resiliency from earthquakes may include stockpiling of fill material and storage of movable transfer span that can be implemented following an event where significant damaged is sustained. The Port and other public agencies may maintain an inventory list and continuously update emergency resources of temporary bypass piping, pipe, fittings, repair clamps, equipment and construction industry specialized trained personnel.

2.4. Operational Concerns

Soil Lateral Sliding – see discussion above.

Sea level rise and associated flooding – it is generally accepted that sea level rise has occurred and is continuing to occur at an accelerating rate. The rate of sea level rise has been about 3 mm per year over the last 50 years with that rate continuously increasing. By 2050, it is generally accepted that mid-range sea levels will be about 12 inches higher than they are today. By 2100, that mid-range increase is estimated to be 36 inches higher than today. The actual increases in sea level may be much greater.

There is already evidence that the height of the Northern Seawall and associated bulkhead wharfs is deficient with respect to the present sea level. The highest tides during June/July and December/January combined with wave action on the bay, produce localized flooding at a number of locations along the seawall. This is at best an annoyance now. By the year 2100, the added sea level height without mitigation measures in place, will result in significant disruption in along the entire water front, especially into the downtown area, and into other areas as well.

2.5. Future Study

Access to Ferry Plaza through and adjacent to the Ferry Building and the ferry terminals following an earthquake is a concern; further study is needed for this section as record information for the Ferry Building substructure is not available.

The recommended mitigation priorities presented in this report should be used as a basis for further investigation and engineering studies. Site specific investigation and detailed engineering design of mitigation alternatives applicable and specific to the high priority seawall sections should be performed in order to better define the vulnerability risks and costs of construction.

3. Mitigation Alternatives

3.1. Introduction

Conceptual mitigation alternatives considered in the vulnerability study are presented here. These mitigation alternatives fall into four general types as a function of discipline type and area of concern. These are:

- Ground Improvement for Mitigation of Seismic Vulnerability
- Bulkhead Wall and Wharf Structural Retrofits for Mitigation of Seismic Vulnerability
- Bulkhead Wall and Wharf Structural Replacement for Mitigation of Seismic and Sea Level Rise Vulnerability
- Utility Relocation and/or Replacement for Mitigation of Seismic and Sea Level Rise Vulnerability

These mitigation alternatives, conceptual in scope, represent practical waterfront applications. Most, if not all, of the alternatives have been constructed on west coast projects. The ground treatment layout and structure configurations represent judgment-based approximations of appropriate mitigation applications, and a thorough design-level analysis of the mitigation alternatives was not performed at this stage. Aspects of site-specific considerations involving construction, permitting, and impacts have not been specifically addressed at this early stage of development. Budget estimates and construction production rates reflect approximate costs for similar projects in the San Francisco Bay Area and west coast.

3.2. Ground Improvement Mitigation Alternatives

General

As detailed in the Phase 2 Report of this earthquake vulnerability study of the Northern Waterfront Seawall, the entire approximately 3 miles of seawall is subject to seismically-induced horizontal ground deformations. The movement of the seawall toward the San Francisco Bay will result in horizontal ground deformation and ground surface settlement of the land behind the seawall. Maps showing the zone of influence and amount of permanent horizontal ground deformation and settlement as a result of seawall movement for four seismic hazard levels are provided in the Phase 2 report. Independent of seawall movement, ground surface settlement may also result from liquefaction of the loose sandy fill soils placed to reclaim land within the historic limits of San Francisco Bay. The total vertical settlement caused by a combination of deviatoric strains (deviatoric strain is related to deformation at constant volume) caused by seawall movement and volumetric strains from post-liquefaction, re-consolidation of sandy fill is presented on maps in the Phase 2 report.

The effects of lateral spread and liquefaction can be very damaging to existing structures and infrastructure. This will likely include:

- Severe damage to existing pile foundations of structures that pass through the zone of potential sliding;
- Breaks of water mains, firefighting systems, sewer systems, telecommunication systems, and gas and power lines that are within liquefiable zones and/or the zone of influence of the seawall movement;
- Disruption to transportation systems such as the Muni F line and T-Third Street and other transportation facilities within the zone of influence;

- Accessibility issues to existing buildings and to the Embarcadero roadway due to large differential movements both laterally and vertically; and
- Increased flooding hazard due to damage to the bulkhead wall and settlement of the land behind the seawall.

To mitigate the potential for lateral spread and liquefaction, several mitigation strategies were explored. These strategies can be divided into two general classifications: 1) liquefaction mitigation of the loose, sandy fill soils placed to reclaim land behind the seawall, and 2) soil strengthening to increase the shearing resistance of the foundation soils below and/or adjacent to the seawall to mitigate the lateral spread hazard. The soil strengthening mitigation strategies can be performed while maintaining the current grades and waterfront line, or can be included within a strategy to raise the existing grades to prepare for sea level rise. The mitigation strategies are further described in the following sections.

Liquefaction Mitigation

The JV team explored and discussed the several strategies for improving the artificial fill soils within the land behind the seawall. The depth of the improvement is generally 20 to 30 feet from the existing ground surface though isolated sections may need to be improved to greater depths. Liquefaction mitigation might include deep dynamic compaction, Rapid Impact Compaction, vibratory compaction methods, vibro-replacement stone columns, and various grouting techniques including compaction grouting, particulate or chemical grouting, jet grouting and deep soil mixing. Each of the mitigation options are beset by the difficulties of improving soil within a dense, urban environment. These difficulties include temporarily relocating or protecting and working around subsurface utilities and structures, the phasing of construction to maintain vehicle traffic, transit and pedestrian access along City streets and to places of business, and construction-induced impacts that may include vibration, noise, and disposal of “spoils” (i.e., displaced soils during ground treatment). Because of these limitations, some mitigation options are less viable than others although all options would be expected to cause major disruptions along the Northern Waterfront. The strategies that appear to be the most effective at a reasonable cost are vibro-replacement stone columns and compaction grouting. Rapid Impact Compaction may also be a potential mitigation strategy, especially for shallower fill sites.

Vibro-replacement stone columns consist of penetrating the liquefiable soil layer with a vibrating probe to densify the soils and to create a cavity, and then placing stone backfill through a supply tube to the bottom of the hole. Stone continues to be placed as the vibrator and supply tube are slowly extracted from the hole. The stone columns produce reinforcement of the loose soils while also laterally compacting the loose soils to increase their density. The stone columns have the added benefit over columns of jet grout or deep soil mixing, for example, of providing a vertical drainage element adjacent to the sandy fill for dissipation of excess pore pressures. The stone columns can be arranged in a pattern that essentially eliminates the liquefaction potential of the fill, and mitigates the vertical settlement caused by post-liquefaction, re-consolidation.

Rapid Impact Compaction has seen more use in recent years to improve near-surface, loose granular soils. The method involves repeatedly striking an impact plate with a heavy hydraulic hammer. The hammer strikes the ground at approximately 40 blows per minute and creates densification of soils within the upper approximately 10 to 20 feet. This method would improve the seismic performance of the potentially liquefiable soils but may not be as effective as vibro-replacement stone columns and compaction grouting, especially at greater depths.

Compaction grouting may be more applicable to locations close to existing subsurface structures that cannot be temporarily relocated. Whereas vibro-replacement stone columns, Rapid Impact Compaction and similar vibratory compaction methods are best used and most cost effective within large open areas, compaction grouting programs can be designed to improve soils adjacent to existing structures. A grout tube is inserted into the ground, and a very low slump aggregate grout is pumped in stages to create a series of grout bulbs as the grout tube is extracted from the drill hole. The pressure can be adjusted when working close to structures, utilities and the ground surface as to not heave structures and cause damage. Compaction grouting mitigates liquefaction by densifying the surrounding loose sandy soils and reinforcing the soil mass.

The approximate width of liquefaction remediation is anticipated to be the width of the Embarcadero Promenade and roadway, or approximately 140 feet. An example of the treatment zone is shown as Alternative G-2 on ***Figure 3-1.*** Although the mitigation option shown on ***Figure 3-1*** is stone columns, the actual method will likely vary along the waterfront to address site-specific subsurface soil conditions.

Advantages of liquefaction mitigation by the various methods are:

- Lessens lateral spreading, but does not eliminate permanent lateral ground deformation
- Mitigates vertical settlement of filled uplands
- Small improvement to Bulkhead Wall/Wharf, still need structural retrofits that are more costly
- Disadvantages and constructability issues associated with liquefaction mitigation by the various methods are:
- Existing utilities and substructures complicate construction
- Significant disruption along the Embarcadero Promenade and roadway during construction
- Will not provide foundation for raising waterfront edge

Lateral Spread Mitigation of Existing Seawall

Because of the poor foundation soils below the seawall over a large portion of the waterfront, the lateral spread potential across the majority of the Northern Waterfront Seawall is high for moderate to large seismic events. The predicted horizontal ground deformation is on the order of a couple to several feet. In order to mitigate the lateral spread potential and restrain the large inertial loads of the rock dike during seismic shaking, a fairly wide soil improvement zone will need to be created. This can be accomplished most effectively using jet grouting techniques. Two general concepts were developed to mitigate the lateral spread potential of the existing seawall: a jet grout buttress beneath the rock dike to improve the lateral sliding resistance of the foundation soils (***Figure 3-2***), and where this is not practical, a jet grout buttress landward of the bulkhead wall and bulkhead buildings (***Figure 3-4***). The placement of the jet grout buttress is most efficient beneath the rock dike as it will work in concert with the rock dike to resist soil lateral sliding. The jet grout buttress can be moved on land, however, if more practical. Due to the presence of the rock dike and other subsurface obstructions, deep soil mixing may have some limited applicability at certain seawall sections. Deep soil mixing production rates are considerably higher and therefore are a lower cost alternative where this technique is appropriate. Based on available plans, a special condition exists at Seawall Section 46. The rock dike is founded on a sand fill that is potentially liquefiable. Because the sand fill is assumed to be keyed into competent soils, compaction grouting of the sand fill should adequately mitigate the lateral spread potential at this one seawall section (***Figure 3-5***).

We note that if designed for long-term waterfront development, all of the ground treatment methods used on the bayside will allow for raising the grade elevation in the future. Thus, they can all be used to accommodate sea-level rise.

Jet Grout Buttress

The purpose of the jet grout buttress is to improve the soil below the rock dike to greatly limit lateral spreading of the seawall and resulting damage to piles, subsurface utilities, etc. that would otherwise be subjected to large lateral displacements. The jet grouting would likely include a combination of overwater work and work along the Embarcadero Promenade and roadway and from the wharf deck. If access to the wharf deck or overwater is not feasible due to existing structures, the jet grouting can be accomplished using inclined drilling from the Embarcadero Promenade and roadway. Because this would necessitate a much smaller work zone, the production rates for inclined drilling are estimated to be about one half of what can be accomplished with good access and vertical drilling. Also, inclined drilling is less efficient in covering the treatment zone, and therefore more drill holes and longer drilling lengths will be required compared to the vertical drilling operation. The general construction procedure for both vertical and inclined drilling and grouting options includes drilling through the rock dike section with a 10- to 12-inch downhole hammer, jet grouting the bay mud layer and keying into the underlying sediments.

Construction methods include use of both land-based and barge mounted jet grout drill rigs. Jet grouting is possible offshore as the drill stem is fully encased. Control of spoils consisting of a mixture of soil, cement and water will be an environmental concern. It may be possible to contain and remove spoils by dredging at the end of the project.

For conceptual and cost estimating purposes, the jet grout width was estimated considering that the width of the treated block should be similar to the depth of treatment. For shallow bay mud profiles, at least ½ of the rock dike width would be treated. An area replacement ratio of 35% was assumed. A conservative estimate of 3-foot diameter jet grout columns was assumed with columns on 4.5-foot centers. These estimates would need to be further evaluated during subsequent design efforts at specific seawall sections with additional supporting site investigations and engineering analyses.

Advantages of the jet grout buttress are:

- Greatly limits lateral spreading.
- No need to change existing ground elevation.
- Can allow raising of ground elevation in future.

Disadvantages of the jet grout buttress are:

- Landside disruption during construction.
- Costly ground improvement technique.
- Does not mitigate liquefaction potential of fill behind the seawall and resulting vertical settlement.
- Improves Bulkhead Wall and Wharf performance, but those structures are still substandard and need mitigation.

Jet Grout Mitigation – On Land

This concept involves creating a mass of improved soil on the landward side of the existing bulkhead wall. A series of overlapping jet grout columns are installed to resist the lateral spreading of the seawall. Approximately 35 to 40% of the soil is improved. An example layout of jet grout columns is shown on ***Figure 3-4***. This proposed mitigation is similar to the seawall improvements currently being undertaken at the Port of Seattle. This mitigation scheme is applicable to most, if not all, seawall sections although the impacts to existing infrastructure behind the seawall must be evaluated. A combination of jet grout mitigation on land and compaction grouting of sand fill beneath the existing seawall may be feasible for Seawall Sections 8a and 8b near the Ferry Building and Ferry Plaza (***Figure 3-6***). Due to extensive subsurface improvements within this section of the seawall, mitigation concepts require consideration of their impact to these improvements including BART tunnels, the San Francisco Muni Turnback Structure, utilities, pile foundations, the old rock seawall, etc.

Advantages of the jet grout mitigation – on land are:

- Greatly limits lateral spreading.
- No need to change existing ground elevation.
- Can allow raising of ground elevation in future.
- Partially mitigates liquefaction potential of fill behind the seawall and resulting vertical settlement within the treatment zone.

Disadvantages of the jet grout mitigation – on land are:

- Landside disruption during construction.
- Costly ground improvement technique.
- Improves Bulkhead Wall and Wharf performance, but those structures are still substandard and need mitigation.
- Some movement of the bulkhead wall and rock dike are still possible but will be much improved.

This alternative, by itself, is estimated to range in cost between $35,000 to $85,000 per lineal foot of seawall.

<u>Create New Seawall Structure</u>

When evaluating the dual challenges of improving the seismic reliability of the seawall along the Northern Waterfront and raising the site grades to address sea level rise, the creation of a new seawall structure outboard of the existing seawall is compelling. The new seawall can be constructed at the desired elevation. For conceptual and cost estimating purposes, we assumed that the grade is raised about 5 feet from existing site grades to El. +16.5 feet NAVD88. This mitigation option is not without its own set of challenges and would require detailed study and design. Some of the obvious challenges include creating a new seawall along alignments that have existing piers and buildings, and the environmental issues involved with creating new bay fill.

A schematic of the proposed new seawall structure is provided on ***Figure 3-6.*** On a conceptual level, the general approach for this Deep Soil Mixing – Offshore (Option A) system includes:

- Construct a sheet pile / king pile wall bayside of the existing seawall.
- Fill behind the wall to above water level (El. +10 ft.) to provide a working pad for DSM equipment.
- Implement DSM through the sand fill and young bay mud, keying into underlying sediments. DSM will progress from the land side to the sheet pile / king pile wall. Install anchor piles in DSM columns land side and connect to sheet pile / king pile wall for added stability as work progresses toward new wall.
- Jet grout zone of unimproved soil between sheet pile / king pile wall and the DSM wall.
- Fill above DSM to desired grade.
- Install wick drains (and possibly surcharge fill) through the new fill and young bay mud in unimproved soil zones between the present seawall and the DSM improvement zone to accelerate consolidation-related settlement and mitigate settlement-related issues for future waterfront development at the location of treatment.

A second option was also developed to a conceptual level that provides a DSM treated zone between two structural systems with a tie beam connecting them (**Figure 3-7**). The outboard edge would be the same sheet pile / king pile system as in Option A. The inboard structural system would consist of permanent king piles (without the sheet piles). The shearing resistance of this system is improved, and the width of the DSM treatment is expected to be reduced to about 70% of Option A.

On a conceptual level, the general approach for this Deep Soil Mixing – Offshore (Option B) system includes:

- Construct a sheet pile / king pile wall bayside of the existing seawall.
- Fill behind the wall to the desired grade (El. +16 ft. assumed)
- Implement DSM through the sand fill and young bay mud, keying into underlying sediments. DSM will progress from the land side to the sheet pile / king pile wall.
- Install anchor piles in DSM columns on landward side of DSM treatment zone.
- Tie sheet pile / king pile wall to anchor piles with tie beams.
- Jet grout zone of unimproved soil between sheet pile / king pile wall and the DSM wall.
- Install wick drains (and possibly surcharge fill) through the new fill and young bay mud in unimproved soil zones between the present seawall and the DSM improvement zone to mitigate consolidation-related settlement.

Advantages of the offshore deep soil mixing options are:

- Greatly limits lateral spreading.
- Raises grade to address sea level rise concerns.
- Creates new land for development opportunities.
- Less disruptive to activities landward of the seawall.

Disadvantages of the offshore deep soil mixing options are:

- Impacts to existing finger piers and other structures built outboard of the existing seawall.
- Potential permitting issues with new bay fill.
- Does not mitigate liquefaction potential of fill behind seawall and resulting vertical settlement.

This alternative, by itself, is estimated to range in cost between $30,000 to $55,000 per lineal foot of seawall.

Ground Mitigation Alternatives Comparison

Each ground mitigation alternative has relative advantages and disadvantages with respect to constructability, construction cost and duration, and the ability to address one or more other significant issues such as environmental concerns, sea level rise adaptability, disruption of nearby roadways (specifically, the Embarcadero), tenant disruption, and impacts on utilities. A summary of these issues for the ground mitigation alternatives discussed in this report is presented on ***Table 3-1***.

Table 3-1: Mitigation Alternatives – Soil Strengthening Concepts

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
		Long Term (Phase 2)												
G-2	Applicable to all seawall sections. Must evaluate impacts to infrastructure behind the seawall.	Lessen vertical and lateral deformations of fill behind seawall	Mitigate liquefaction of fill below The Embarcadero	Stone Columns (selectively use Compaction Grouting, Chemical Grouting or Rapid Impact Compaction)	• Demolish existing pavements within the Embarcadero promenade and roadway. • Relocate or protect subsurface utilities and other subterranean structures. • Clear obstructions with pre-drilling. • Install stone columns using the dry bottom feed process. • Evaluate sections where compaction grouting, chemical grouting or Rapid Impact Compaction is preferable to stone columns.	2' of seawall per rig shift (15 stone columns per rig shift)	Lower cost mitigation once site is cleared.	Minor.	Does not address sea level rise.	Very disruptive.	Other than access, not disruptive.	Need to relocate or protect subsurface utilities. Impacts due to vibrations from stone column installation must be addressed.	• Lower cost mitigation once site is cleared. • Mitigates vertical settlement from liquefaction.	• May have limited applicability due to subsurface improvements. • Disruptive to The Embarcadero. • Limited improvement to lateral spread of seawall and resulting damage.
G-6	Seawall Section 46, 8a and 8b	Stabilize existing seawall at Seawall Section 46 and improve seawall performance at Seawall Sections 8a and 8b	Mitigate liquefaction of sand fill within rock dike section	Compaction Grouting	• Work zone from wharf deck at Seawall Section 46 and below Ferry Building and Ferry Platform at Seawall Sections 8a and 8b. • Pre-drill holes through rock dike. • Inject low-viscosity grout into sand fill below rock dike to densify sand fill.	75 rig shifts for 236 ft. of seawall (250 cy of treated soil volume per rig shift)	Moderate cost. Difficult access at Seawall Sections 8a and 8b will increase cost for this section.	Minor.	Does not address sea level rise.	No.	Minor.	Minor.	• Potentially less construction impacts than other ground improvement methods. • Nearly eliminates lateral spreading and resulting damage for Seawall Section 46.	• Not applicable at most seawall sections.

Notes:
1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Table 3-1: Mitigation Alternatives – Soil Strengthening Concepts (cont'd)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
		Long Term (Phase 2)												
G-1	Applicable to portions of all seawall sections except 8a. Must evaluate impacts to existing overwater bulkhead buildings and piers.	Stabilize existing seawall	Mitigate lateral spreading	Jet Grout Buttress	• Identify work zone which may include Embarcadero promenade and roadway, wharf deck and overwater work. • For wharf deck and overwater work, create cofferdam to contain jet grout spoils. • Pre-drill holes through rock dike. • Install jet grout columns to improve young bay deposits underlying rock dike section and tie into rock dike.	150 cy of soilcrete volume per rig shift	Expensive.	Need to contain jet grout spoils for wharf deck and overwater work.	Yes, although may increase treatment zone to account for a future raise in grade.	Disruptive to NB / WB traffic and to the Embarcadero Promenade.	Potentially disruptive to gain access to improvement zone through building slabs.	Likely can work around utilities.	• Nearly eliminates lateral spreading and resulting damage to piles, subsurface utilities, etc. that are subjected to large lateral displacements.	• Very expensive and disruptive. • Does not mitigate liquefaction potential of fill behind seawall and resulting vertical settlement.
G-1a	Applicable to portions of all seawall sections except 8a. Must evaluate impacts to infrastructure behind the seawall.	Stabilize existing seawall	Mitigate lateral spreading	Jet Grout Buttress with Inclined Drilling	• Identify work zone within Embarcadero promenade and roadway. • Relocate or protect subsurface utilities and other subterranean structures. • Pre-drill holes through rock dike. • Install jet grout columns to improve young bay deposits underlying rock dike section and tie into rock dike.	75 cy of soilcrete volume per rig shift	Expensive. More expensive than vertical drilling (G-1) due to decreased production rates and increased drilling footage for same volume of improvement.	Minor.	Yes, although may increase treatment zone to account for a future raise in grade.	Disruptive to NB / WB traffic and to the Embarcadero Promenade.	Other than access, minor disruption.	Need to relocate or protect subsurface utilities.	• Nearly eliminates lateral spreading and resulting damage to piles, subsurface utilities, etc. that are subjected to large lateral displacements.	• Very expensive and disruptive. • Does not mitigate liquefaction potential of fill behind seawall and resulting vertical settlement.
G-3	Applicable to portions of all seawall sections except 8a. Must evaluate impacts to existing overwater bulkhead buildings and piers.	Create new seawall structure	Mitigate lateral spreading and raise grade for sea level rise	Deep Soil Mixing – Offshore (Option A)	• Construct a sheet pile / king pile wall bayside of the existing seawall. • Fill behind the wall to above water level (El. +10 ft.) to provide a working pad for DSM equipment. • Implement DSM through the sand fill and young bay mud, keying into underlying sediments. DSM will progress from the land side to the sheet pile / king pile wall. Install anchor piles in DSM columns land side and connect to sheet pile / king pile wall for added stability as work progresses toward new wall. • Jet grout zone of unimproved soil between sheet pile / king pile wall and the DSM wall. • Fill above DSM to desired grade. • Install wick drains and possibly surcharge fill through the new fill and young bay mud in unimproved soil zones between the present seawall and the DSM improvement zone to mitigate consolidation-related settlement.	500 cy of soilcrete volume per rig shift	Expensive.	New bay fill will need to be permitted through BCDC.	Yes. Concept developed to address sea level rise.	Increased truck traffic but most work is offshore.	Very disruptive within treatment zones.	Minor since work is offshore.	• Nearly eliminates lateral spreading and resulting damage to piles, subsurface utilities, etc. that are subjected to large lateral displacements. • Raises grade to address sea level rise concerns. • Creates new land for development opportunities. • Less disruptive to activities landward of the seawall.	• Impacts to existing finger piers and other structures built outboard of the existing seawall. • Potential permitting issues with new bay fill. • Does not mitigate liquefaction potential of fill behind seawall and resulting vertical settlement.

Notes:

1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Table 3-1: Mitigation Alternatives – Soil Strengthening Concepts (cont'd)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
		Long Term (Phase 2)												
G-4	Applicable to portions of all seawall sections except 8a. Must evaluate impacts to existing overwater bulkhead buildings and piers.	Create new seawall structure	Mitigate lateral spreading and raise grade for sea level rise	Deep Soil Mixing – Offshore (Option B)	• Construct a sheet pile / king pile wall bayside of the existing seawall. • Fill behind the wall to desired grade (El. +16.5 ft. assumed). • Implement DSM through the sand fill and young bay mud, keying into underlying sediments. DSM will progress from the land side to the sheet pile / king pile wall. • Install anchor piles in DSM columns on landward side of DSM treatment zone. • Tie sheet pile / king pile wall to anchor piles with tie beams. • Jet grout zone of unimproved soil between sheet pile / king pile wall and the DSM wall. • Install wick drains and possibly surcharge fill through the new fill and young bay mud in unimproved soil zones between the present seawall and the DSM improvement zone to mitigate consolidation-related settlement.	500 cy of soilcrete volume per rig shift	Expensive. Slightly lower cost alternative to No. G-3.	New bay fill will need to be permitted through BCDC.	Yes. Concept developed to address sea level rise.	Increased truck traffic but most work is offshore.	Very disruptive within treatment zones.	Minor since work is offshore.	• See No. G-3 for advantages. • Lessens DSM treatment zone width from Option A above.	• See No. G-3 for disadvantages.

Notes:
1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding

Table 3-1: Mitigation Alternatives – Soil Strengthening Concepts (cont'd)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
		Long Term (Phase 2)												
G-5	Applicable to all seawall sections. Must evaluate impacts to infrastructure behind the seawall.	Stabilize existing seawall	Mitigate lateral spreading	Jet Grout Mitigation – On Land	• Demolish existing pavements within the Embarcadero promenade and roadway. • Relocate or protect subsurface utilities and other subterranean structures. • Pre-drill holes through rock dike. • Install jet grout columns to improve young bay deposits and artificial fill within treatment zone.	150 cy of soilcrete volume per rig shift	Very expensive for ground modification portion of work.	Minor.	Yes, although may modify treatment zone layout to account for a future raise in grade.	Very disruptive to the Embarcadero Promenade, NB / WB traffic lanes and, at certain seawall sections, to transit infrastructure.	Would need to coordinate improvement sequence to maintain access for tenants.	Need to relocate or protect subsurface utilities.	• Nearly eliminates lateral spreading and resulting damage to piles, subsurface utilities, etc. that are subjected to large lateral displacements. • Partially mitigates liquefaction potential of fill behind seawall and resulting vertical settlement within treatment zone.	• Very expensive and disruptive. • Some movement bayside of the seawall still possible.

Notes:

1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Table 3-1: Mitigation Alternatives – Soil Strengthening Concepts (cont'd)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
		Long Term (Phase 2)												
G-7	Seawall Sections 8a and 8b	Stabilize existing seawall at Sections 8a and 8b (Ferry Plaza)	Mitigate liquefaction of sand fill below bulkhead wall and mitigate lateral spreading	Compaction Grouting and Jet Grout Mitigation – On Land	Compaction Grouting • Work zone from Ferry Building base slab. • Pre-drill holes through rock dike. • Inject low-viscosity grout into sand fill below bulkhead wall to densify sand fill.	40 rig shifts for 450 ft. of seawall (250 cy of treated soil volume per rig shift)							• Eliminates liquefaction potential of sand fill below bulkhead wall.	• Difficult access to compaction grouting zone below Ferry Building.
					Jet Grout Mitigation – On Land • Demolish existing pavements within the Embarcadero promenade and roadway. • Relocate or protect subsurface utilities and other subterranean structures. • Pre-drill holes through rock dike. • Install jet grout columns to improve young bay deposits and artificial fill within treatment zone. NOTE: Further analysis of stabilizing effects of Ferry Building foundation, BART San Francisco Transition Structure, BART tunnels and Muni Turnback Structure may be warranted to evaluate need for jet grout mitigation option. Compaction grouting zone would be expanded if the analysis indicates jet grouting is not needed for adequate seawall and Ferry Building performance.	150 cy of soilcrete volume per rig shift	Very expensive for ground modification portion of work.	Minor.	Yes, although may modify treatment zone layout to account for a future raise in grade.	Very disruptive to the Embarcadero Promenade, NB / WB traffic lanes and to transit infrastructure.	Would need to coordinate improvement sequence to maintain access for tenants.	Need to relocate or protect subsurface utilities.	• Nearly eliminates lateral spreading and resulting damage to piles, subsurface utilities, etc. that are subjected to large lateral displacements. • Mitigates liquefaction potential of fill behind seawall and resulting vertical settlement within treatment zone.	• Very expensive and disruptive. • Some movement bayside of the seawall still possible. • Mitigation concept requires consideration of impacts to and constructability around BART tunnels, Muni Turnback Structure, utilities, pile foundations, old rock seawall, etc.

Notes:

1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Description	Seawall Section Applicability	Performance Objective	Purpose
Stone Columns.	Applicable to all seawall sections. Must evaluate impacts to infrastructure behind the seawall.	Lessen vertical and lateral deformations of fill behind seawall.	Mitigate liquefaction of fill below The Embarcadero.

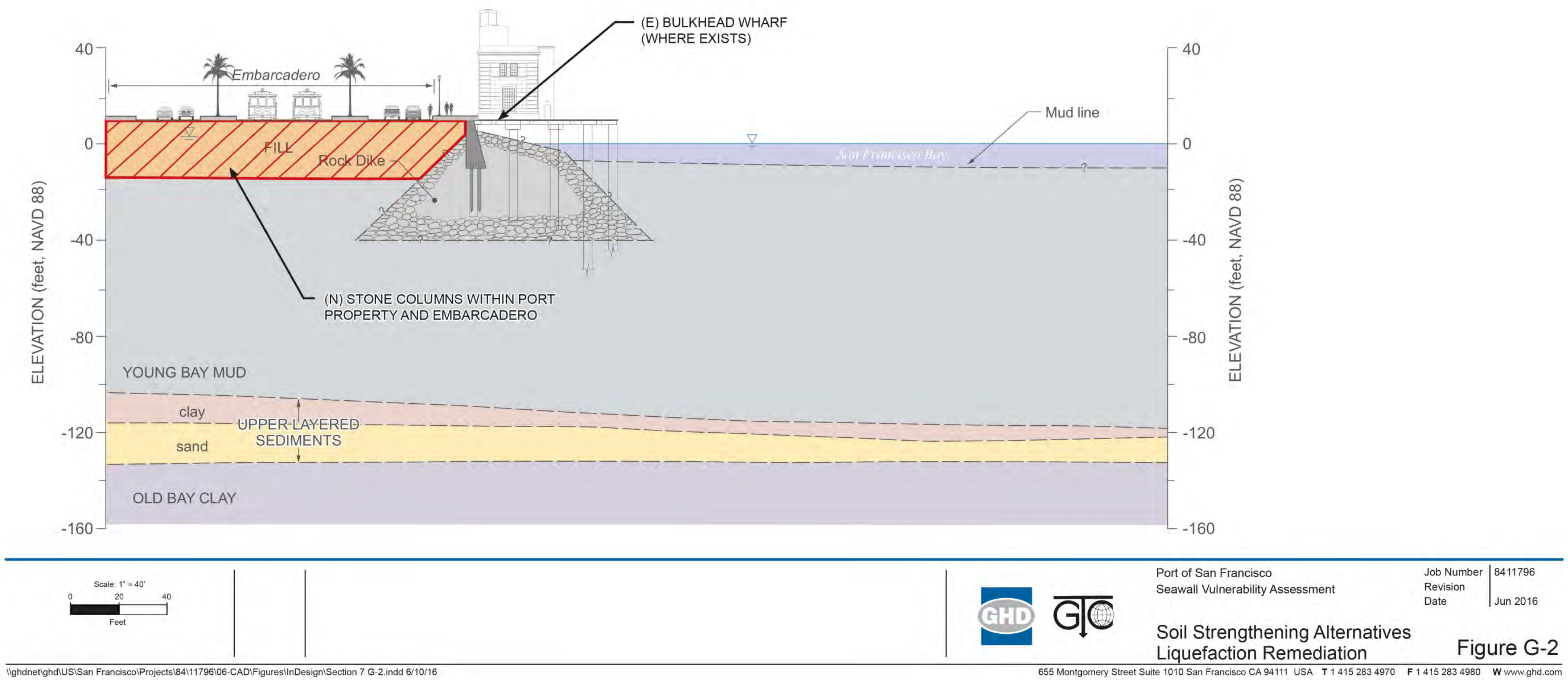
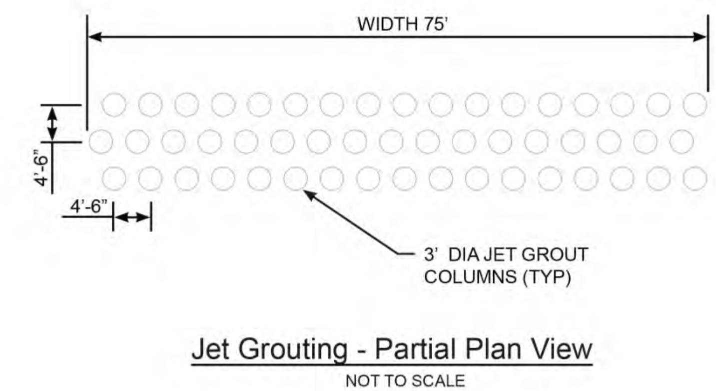


Figure 3-1: Mitigation Alternative G-2 – Soil Rehabilitation Using Stone Columns

Description	Seawall Section Applicability	Performance Objective	Purpose
Jet Grout Buttress.	Applicable to portions of all seawall sections except 8a. Must evaluate impacts to existing overwater bulkhead buildings and piers.	Stabilize existing seawall.	Mitigate lateral spreading.



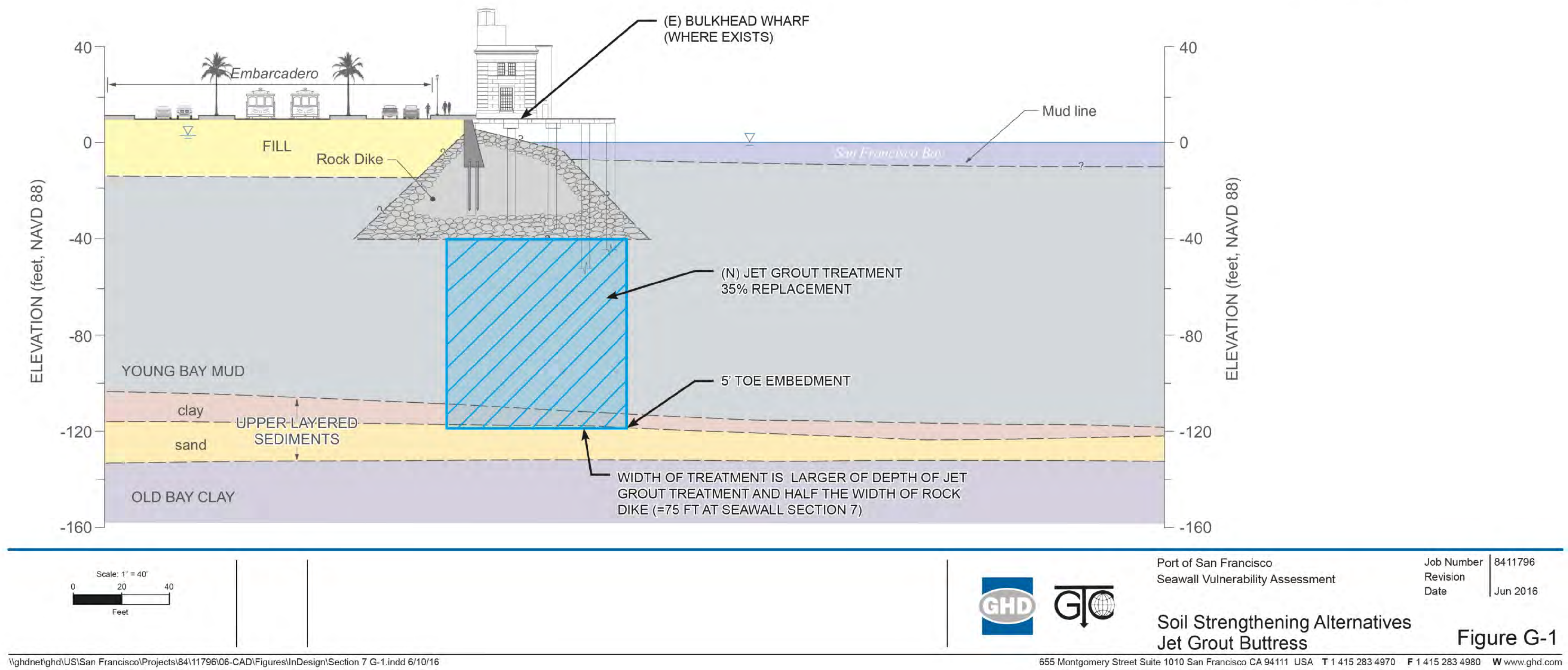


Figure 3-2: Mitigation Alternative G-1 – Soil Rehabilitation Using Jet Grout Buttress

Description	Seawall Section Applicability	Performance Objective	Purpose
Jet Grout Buttress - Inclined Drilling.	Applicable to portions of all seawall sections except 8a. Must evaluate impacts to existing overwater bulkhead buildings and piers.	Stabilize existing seawall.	Mitigate lateral spreading.

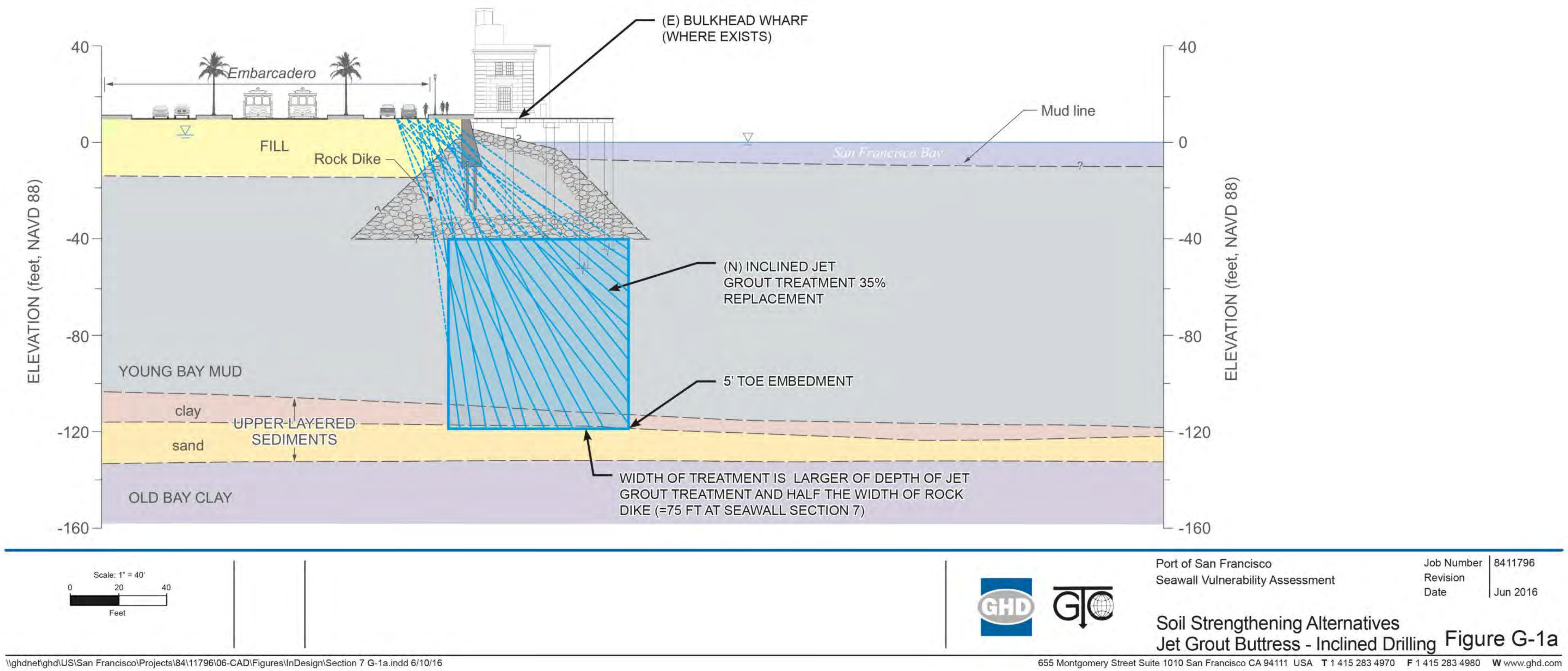
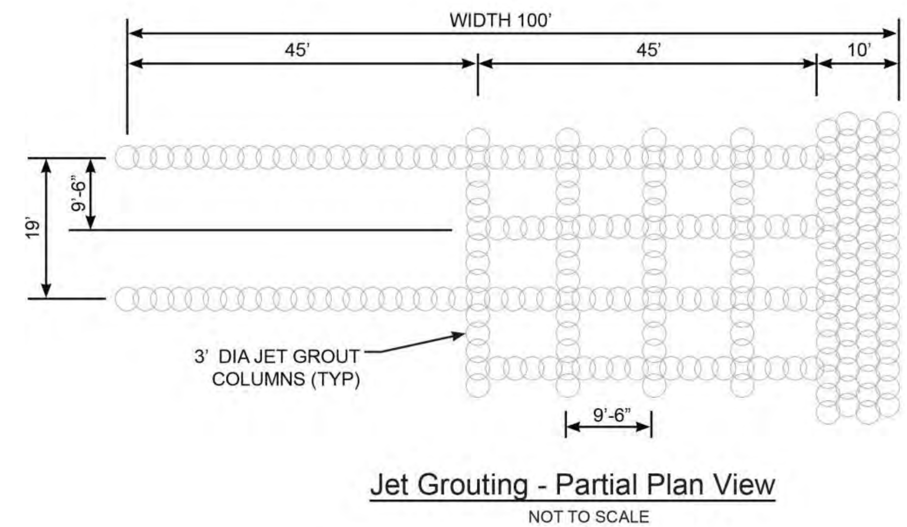


Figure 3-3: Mitigation Alternative G-1A – Soil Rehabilitation Using Jet Grout Buttress

Description	Seawall Section Applicability	Performance Objective	Purpose
Jet Grout Mitigation – On Land.	Applicable to all seawall sections. Must evaluate impacts to infrastructure behind the seawall.	Stabilize existing seawall.	Mitigate lateral spreading.



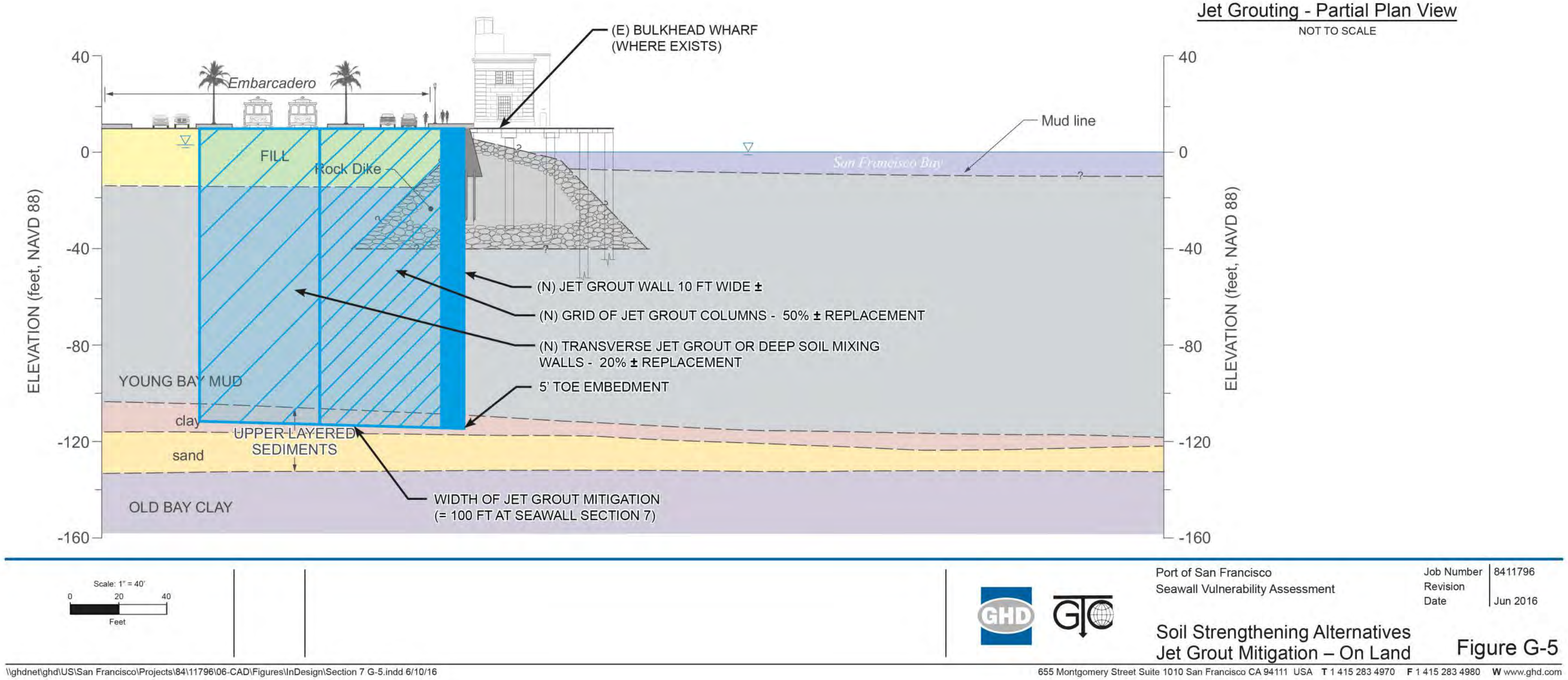


Figure 3-4: Mitigation Alternative G-5 – Soil Rehabilitation Using Jet Grout Mitigation on Land

Description	Seawall Section Applicability	Performance Objective	Purpose
Compaction Grouting.	Seawall Section 46.	Stabilize existing seawall at Seawall Section 46.	Mitigate liquefaction of sand fill within rock dike section.

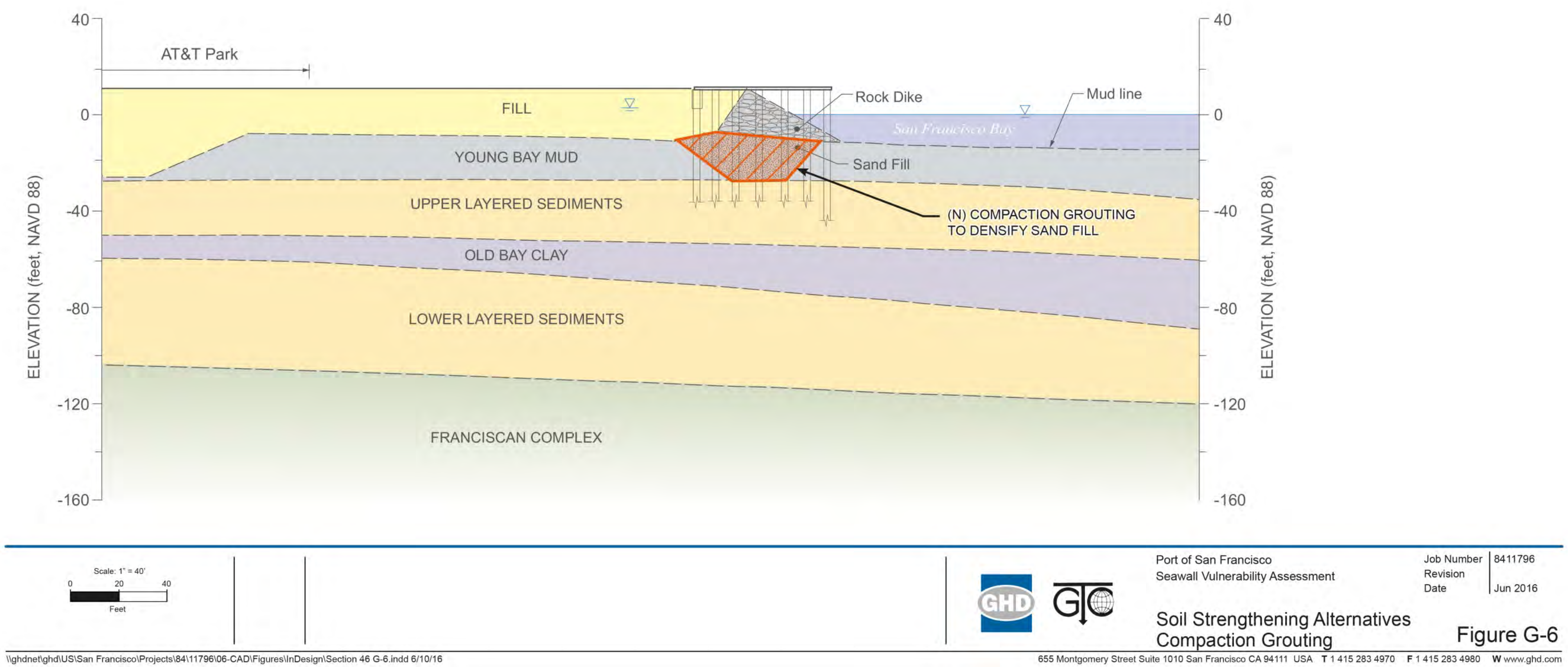
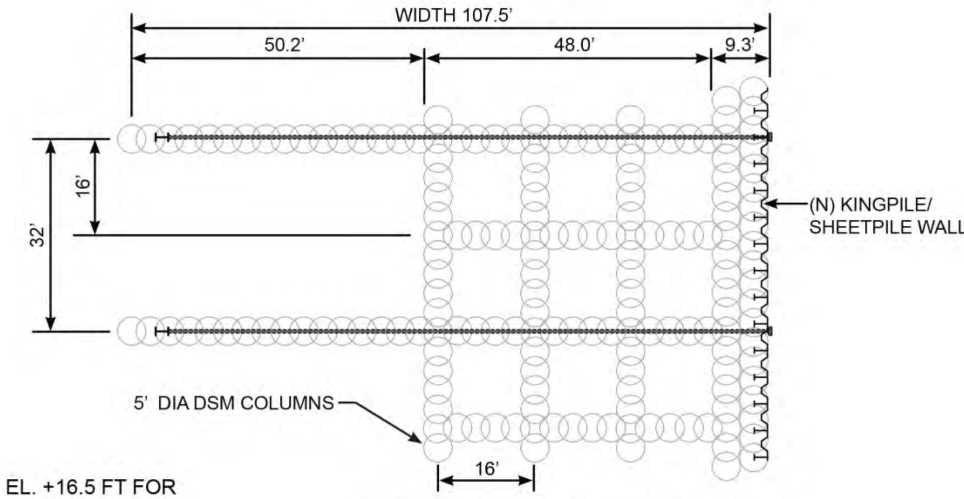


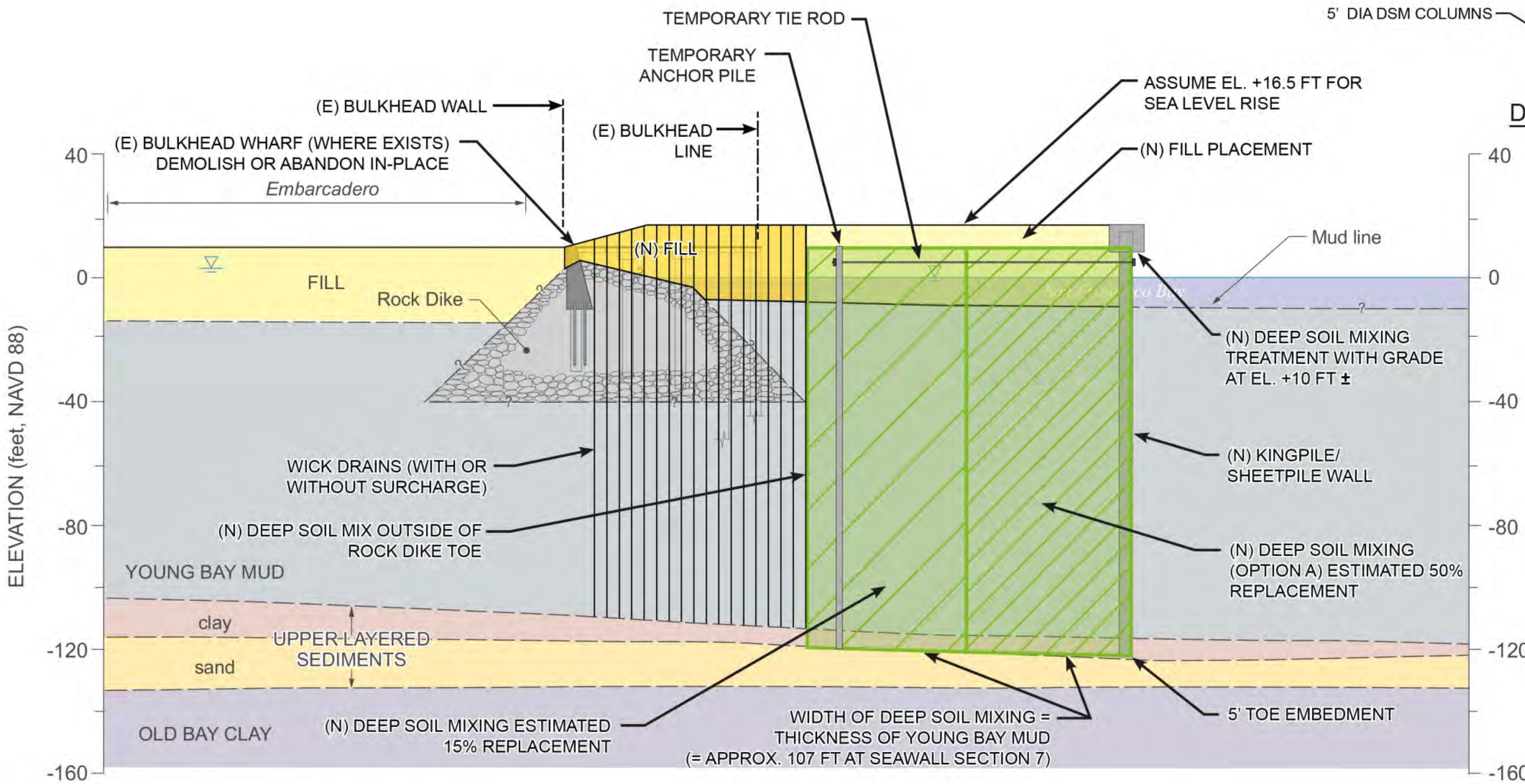
Figure 3-5: Mitigation Alternative G-6 – Soil Rehabilitation Using Compaction Grouting

Description	Seawall Section Applicability	Performance Objective	Purpose
Deep Soil Mixing – Offshore (Option A).	Applicable to portions of all seawall sections except 8a. Must evaluate impacts to existing overwater bulkhead buildings and piers.	Create new seawall structure.	Mitigate lateral spreading and raise grade for sea level rise.



DSM Option A - Partial Plan View

NOT TO SCALE



Scale: 1" = 40'
0 20 40
Feet

Port of San Francisco
Seawall Vulnerability Assessment

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Revision	
Date	Jun 2016

Soil Strengthening Alternatives
Deep Soil Mixing (Option A)

Figure G-3

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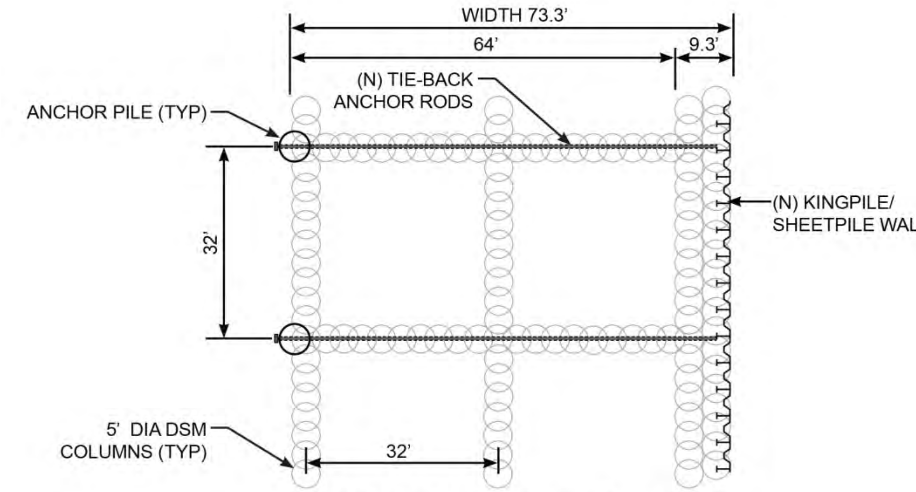
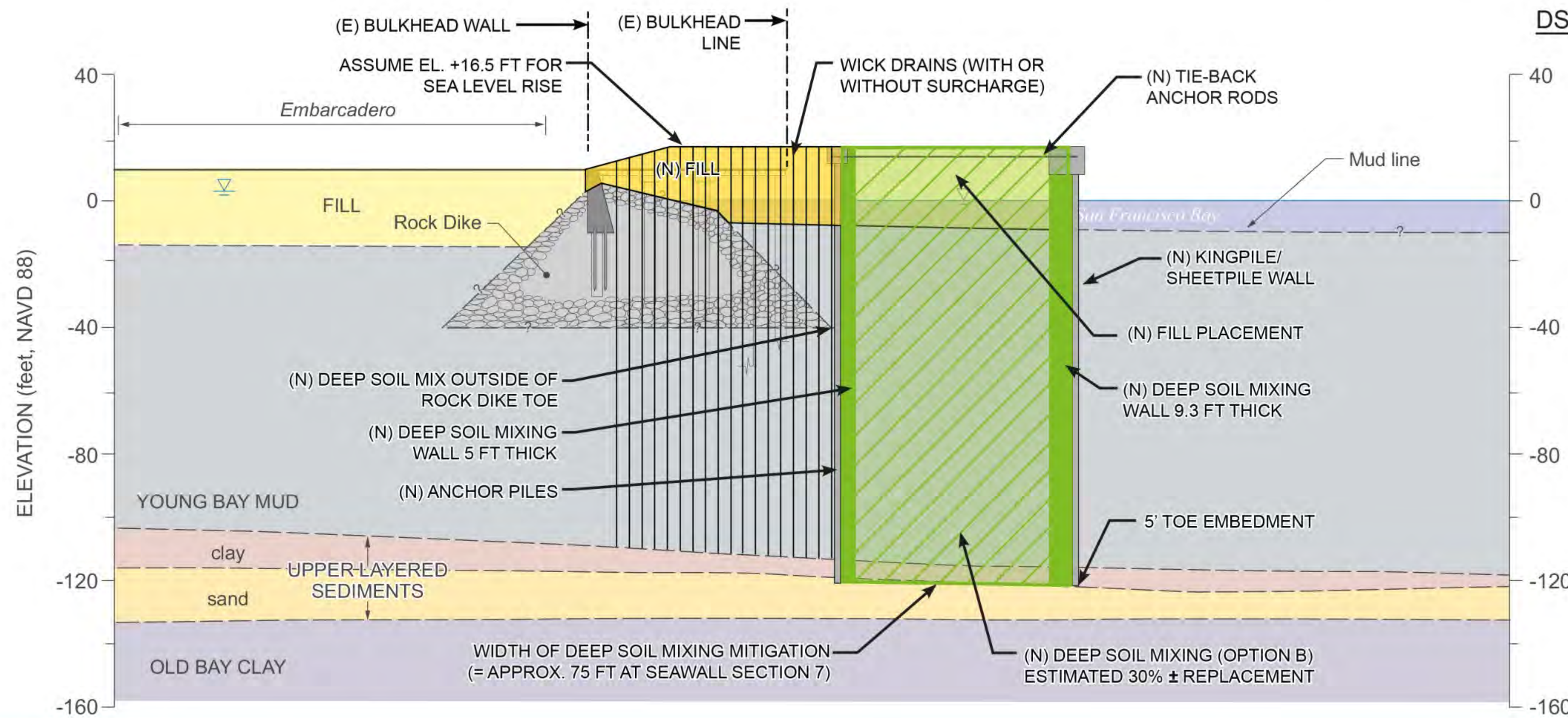
Figure 3-6: Mitigation Alternative G-3 – Soil Rehabilitation Using Deep Soil Mixing Offshore (Option A)

Description	Seawall Section Applicability	Performance Objective	Purpose
Deep Soil Mixing – Offshore (Option B).	Applicable to portions of all seawall sections except 8a. Must evaluate impacts to existing overwater bulkhead buildings and piers.	Create new seawall structure.	Mitigate lateral spreading and raise grade for sea level rise.



DSM Option B - Partial Plan View

NOT TO SCALE



Scale: 1" = 40'
0 20 40
Feet

Port of San Francisco
Seawall Vulnerability Assessment
Soil Strengthening Alternatives
Deep Soil Mixing (Option B)
with Anchor Piles

Job Number	8411796
Revision	
Date	Jun 2016

Figure G-4

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Figure 3-7: Mitigation Alternative G-4 – Soil Rehabilitation Using Deep Soil Mixing Offshore (Option B)

Description	Seawall Section Applicability	Performance Objective	Purpose
Compaction Grouting and Jet Grout Mitigation – On Land.	Seawall Sections 8a and 8b.	Stabilize existing seawall at Sections 8a and 8b (Ferry Plaza).	Mitigate liquefaction of sand fill below bulkhead wall and mitigate lateral spreading.

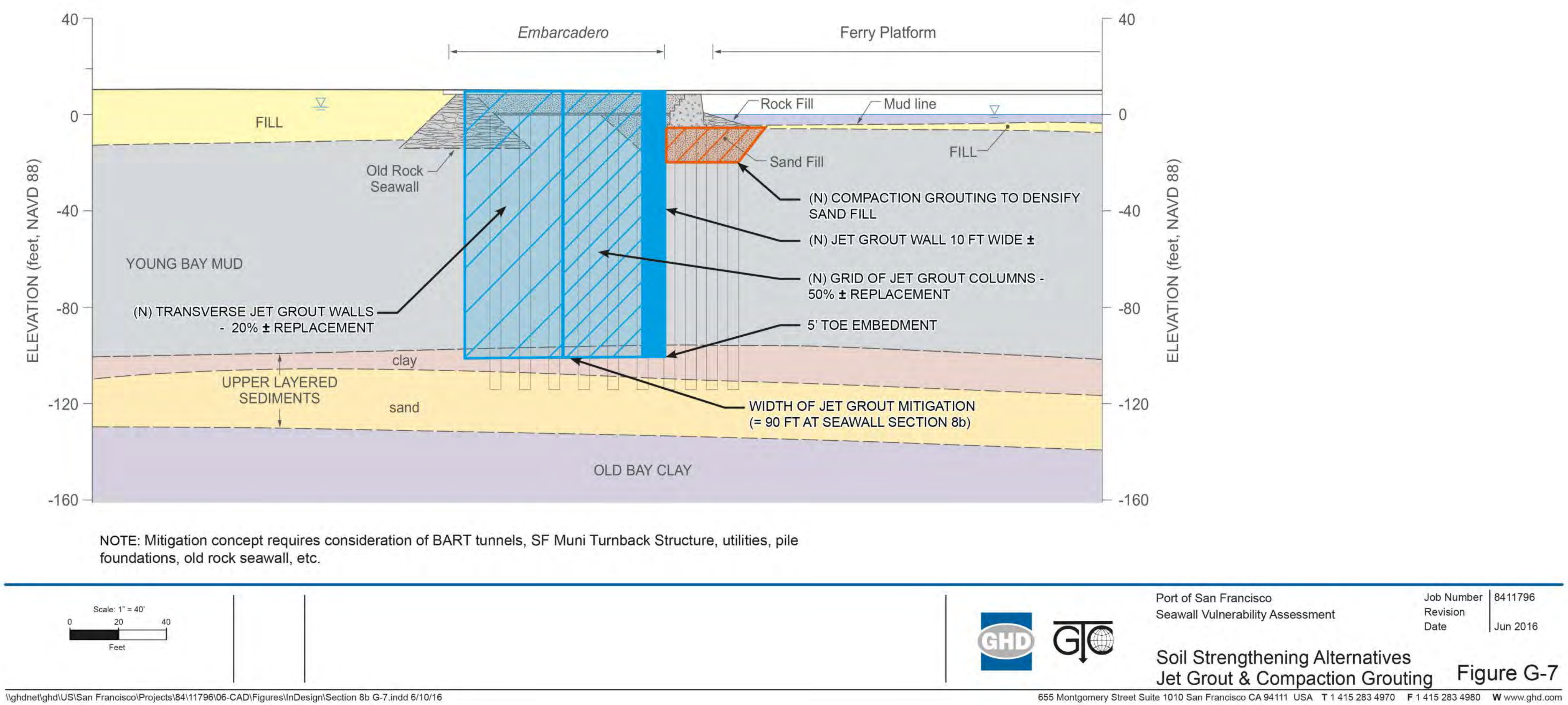


Figure 3-8: Mitigation Alternative G-7 – Soil Rehabilitation Using Jet Grout and Compaction Grouting

3.3. Structural Mitigation Alternative Descriptions

The JV team reviewed mitigation concepts that will address the primary structural vulnerability of the seawall bulkhead wall and bulkhead wharves. As noted previously, the effects of lateral spread and liquefaction can be very damaging to existing structures and infrastructure. At the Northern Seawall this includes severe damage to existing pile foundations supporting the bulkhead wharves as the piles pass through the zone of potential sliding.

Structural mitigation concepts developed consisted of two approaches, the first addressing strengthening components of the seawall, primarily the bulkhead wall and bulkhead wharves and the second, consisting of replacement of the bulkhead wharf or adding a new bulkhead structure.

Due to the various aspects of vulnerability to the seawall, a combination of geotechnical and structural mitigation alternatives will be needed. The alternatives considered in this study fall into three types, each with similar variations on mitigation of the existing seawall structure itself.

- Existing bulkhead wharf strengthening
- Bulkhead wharf replacement – "Super" bulkhead wharf
- Bulkhead wharf replacement – improved earth structure

Collapse Hazard Retrofits

These concepts include rehabilitation and strengthening retrofits used to minimize the collapse hazard of existing bulkhead wharves assuming the seawall lateral spreading hazard is not mitigated. These are expected to improve life safety while keeping the asset in use for a reasonable period of time, such as 10-20 years, until seawall lateral spreading is mitigated or until a major renovation, change of occupancy or other major investment is needed. It is unlikely that these types of retrofit measures will be capable of preventing significant damage in moderate earthquakes, and large earthquakes are expected to damage many of these retrofitted structures beyond economical repair.

The performance target for the collapse hazard retrofits would be Collapse Prevention following an approximately 225 year return period seismic event. In this scenario, the bulkhead wall and bulkhead wharf structures will remain standing following the ground shaking. There is expected to be significant damage to the concrete bulkhead wall and bulkhead wharf piles and pile / deck connections. Many of the timber and concrete piles will have sheared and fractured. The bulkhead wall may be far out of plumb and experienced significant vertical settlement. The bulkhead buildings will have suffered significant damage, however the occupants are able to safely leave the structure. The structure should not collapse during or following the target earthquake level; the primary performance objective is to protect the public.

Two types of earthquake induced loading on the seawall bulkhead wall and bulkhead wharves were considered for the vulnerability study:

- Seismic inertial loading: the structure experiences seismic induced oscillating lateral accelerations. Structure component damage due to lateral displacements during the earthquake shaking, typically occurs at the tops of piles of seawall bulkheads, bulkhead wharfs and finger piers, including at pile locations underground. .The structure may or may not return to its original configuration, with or without some permanent displacement offset.
- Seismic kinematic loading: the weak underground soil layer liquefies and induces global soil layer displacements, most likely towards the bay, described in this report as "soil lateral sliding". Structure located above this sliding layer more or less displaces with the sliding layer. Structure components that pass into or through this sliding layer, typically piles, are exposed to large displacement induced

stresses that are expected to lead to the failure of the pile structure in the vicinity of the soil sliding layer. The failed piles lose the ability to resist any significant lateral or vertical load and result in partial or total collapse of the supported structures above.

Near Term – Limited Rehabilitation / Strengthening Objective

Performance Target = Collapse Prevention following 225 year return period seismic event

Bulkhead and bulkhead wharf structures remaining standing only barely stable. There is significant damage to concrete bulkhead and wharf piles and deck connections. Many of the timber and concrete piles have sheared and fractured. The bulkhead may be far out of plumb and experienced significant vertical settlement. The bulkhead buildings have suffered significant damage, however occupants are able to safely leave the structure. Structure should not collapse during or following a large earthquake – primary objective is to protect public.

Long Term – Enhanced Vulnerability Mitigation Objective

Target = Life Safety performance following 975 year return period seismic event, Collapse Prevention at 1500+ year return period EQ

New bulkhead and pile-supported wharf structures remain relatively plumb and stable and have significant residual capacity. Damage may be substantial but structures are intact and remain stable. Long term mitigation will also address sea level rise by providing higher deck and grade elevations at the waterfront.

Seawall Bulkhead Wall – Collapse Hazard Mitigation Concepts

The mitigation concepts below utilize different methods to increase the stability of the bulkhead wall and improve the structure's resistance to overturning and sliding during a seismic event. It is important to note that these mitigation concepts due not address the global stability issues of the rock dike due to weak soil sliding.

S-1 Bulkhead Wall with Grouted Tie-Backs: Applicable to seawall bulkhead wall only. Demolish existing structure in front of and above existing bulkhead as needed. Install new grouted tie-back anchors into rock dike or other competent landside soil strata and connect to bulkhead wall. As an option, increase existing bulkhead wall height to accommodate sea level rise. Replace any demolished existing structure as required and construct to present-day design codes.

Accommodates short term seismic life safety issues

Does not accommodate long term soil lateral sliding

May accommodate sea level rise.

This alternative by itself (***Figure 3-9)***, is estimated to cost from $ 6,000 to $15,000 per lineal foot of seawall depending on the seawall section considered.

S-2 Bulkhead Wall with Pile and Cap Strut in Front of Seawall: Applicable to seawall bulkhead wall only. Demolish existing structure in front of existing bulkhead as needed. Construct new pile and cap strut system in front of and connected to existing bulkhead wall. As an option, increase existing bulkhead wall height to accommodate sea level rise. Replace any demolished existing structure as required and construct to present-day design codes.

Accommodates short term seismic life safety issues

Accommodates long term soil lateral sliding with the use of steel pipe piles or similar

May accommodate sea level rise.

This alternative, by itself (***Figure 3-10)***, is estimated to cost from $ 11,000 to $14,500 per lineal foot of seawall depending on the seawall section considered.

S-3 Bulkhead Wall with Tie-Back Anchor Piles: Applicable to seawall bulkhead wall only. Demolish existing infrastructure landward of the existing bulkhead wall as needed, install new anchor piles and construct a new anchor pile wall. Demolish existing structure in front of and above existing bulkhead wall as needed. Install new tie-back anchors to anchor pile wall and connect to bulkhead wall. As an option, increase existing bulkhead wall height to accommodate sea level rise. Replace any demolished existing structure as required and construct to present-day design codes.

Accommodates short term seismic life safety issues

Accommodates long term soil lateral sliding with the use of steel pipe piles or similar

May accommodate sea level rise.

This alternative, by itself (***Figure 3-11***), is estimated to cost from $ 10,000 to $16,000 per lineal foot of seawall depending on the seawall section considered.

S-4 Added Revetment: Applicable to seawall bulkhead wall only. Provide sufficient revetment to accommodate life safety seismic issues for landside infrastructure. As an option, may raise top of revetment elevation to accommodate sea level rise.

Accommodates short term seismic life safety issues

Does not accommodate long term soil lateral sliding

May accommodate sea level rise.

This alternative, by itself (***Figure 3-12***), is estimated to cost from $ 7,500 to $10,000 per lineal foot of seawall depending on the seawall section considered.

Existing Bulkhead Wharf – Collapse Hazard Mitigation Concepts

The purpose of this concept is to improve near-term life safety and reduce the collapse hazard to an acceptable level. A full code level retrofit may not be feasible. This level of mitigation does not address sea level rise and flooding.

Improvements and strengthening are made to existing piles where warranted by seismic inertial analysis. The purpose of the wharf beam strengthening is to support the existing deck and buildings should the existing piles fail under lateral sliding, resulting in significantly increased effective beam spans in the vicinity of such failed piles.

The purpose of the new steel pile at edge of the wharf is to survive the lateral sliding displacement and support the existing deck and buildings should the adjacent existing piles fail under lateral sliding. They may provide a slight increase in lateral stiffness but that is not a primary goal, unless the piles are larger diameter.

On the Bulkhead Wharf and Bulkhead Wall Retrofits, the intent is to reduce the collapse hazard to an acceptable level. The primary deficiencies appear to be:

Bulkhead Wall movement/support pile failure – resulting in settlement and potential loss of vertical support if wall tilts far enough.

Seawall support is needed in the form of piles or tie-backs to preclude wall movement. Steel pipe piles for may be used for wall support or tie-back anchors, piles to penetrate through the soil sliding layer.

Bulkhead Wall / deck connection fracture / unseating – results in partial collapse of the bulkhead wharf deck. This retrofit wall/deck connection will be included in all mitigation concepts where the existing wharf deck structure is to remain.

Bulkhead Wharf Piles, Shear failure due to lateral spreading – results in settlement and loss of vertical support. Wall support is required in the form of piles or tie-backs to preclude seawall movement. Possibly use of steel pipe piles for wall or tie-back anchors, piles to penetrate through the soil sliding layer.

Bulkhead Wharf Piles, shear/moment failure due to ground shaking – results in loss of vertical support, short piles primarily. Retrofit pile/deck connection is included in all wharf mitigation concepts. Potential pile failures below ground then become an issue. Resolve this by replacing offending piles with piles of adequate capacity. Or provide additional increased stiffness piles to reduce demand on the existing critical elements.

- Increase global lateral stiffness of bulkhead wharf structures by adding steel pipe piles.
- Steel pipe piles have well defined hysteresis curves and well defined plastic hinges with a high level of ductility. They make a good choice for waterfront construction in regions with high seismic forces and have historically performed well with moderate to large seismic ground motions. Larger diameter pipe piles can absorb large lateral forces through shear in addition to flexural bending.
- Wharves with attached finger piers can be strengthened by using large diameter steel pipe piles, transfer slabs and collector beams. A seismic joint is added between the structures to accommodate their differing lateral displacements.
- The rehabilitation philosophy is aimed at decreasing the displacement demands of the bulkhead wharves.

Bulkhead Wharf Pile/Deck Connection Failure – poorly detailed non-ductile connection, can lead to loss of support from deck and/or pile damage in the joint region. Retrofit of pile/deck connection is included in all mitigation concepts where the existing wharf deck structure is to remain.

Mitigation concept components will be highlighted in a typical wharf/seawall section. Retrofits will be reviewed to mitigate inertial and kinematic issues with as minimal disruption to the existing structure as possible. Use of the rock dike for vertical support of the bulkhead wharf will be reviewed. New walls, grade beams or enlarged pile footings are suggested to prevent collapse of the wharf structure. At locations where existing piles are expected to shear at the toe of the rock dike, new piles or other vertical support may be added to prevent collapse of the wharf structure.

S-11 (S-11a) Bulkhead Wharf Mitigation – Wharf Rehabilitation and Bulkhead Stabilization: This mitigation alternative is presented on *Figure 3-13* and *Figure 3-14*. Applicable to seawall and bulkhead wharfs only. Retrofit bulkhead wharf to seawall beam connections. Install steel pipe piles bayside of bulkhead wharf to accommodate soil lateral sliding. Retrofit existing deck beams to accommodate deck effective increased spans for existing piles affected by soil lateral sliding. Demolish existing structure in front of and above existing seawall as needed. Install new grouted tie-back anchors into competent landside soil strata and connect to seawall. Replace any demolished existing structure as required and construct to present-day design codes.

Accommodates short term seismic life safety issues

Accommodates long term soil lateral sliding with the use of steel pipe piles or similar

Does not accommodate sea level rise.

This alternative, by itself, is estimated to cost from $ 43,000 to $130,000 per lineal foot of seawall depending on the seawall section considered.

S-13 Bulkhead Wharf Mitigation – Wharf Rehabilitation and Seawall with Pile and Cap Strut In Front of Seawall: This mitigation alternative is presented on *Figure 3-15* and *Figure 3-16*. Applicable to seawall and bulkhead wharfs only. Retrofit bulkhead wharf to seawall beam connections. Install steel pipe piles bayside of bulkhead wharf to accommodate soil lateral sliding. Retrofit existing deck beams to accommodate deck effective increased spans for existing piles affected by soil lateral sliding. Demolish existing structure in front of and above existing seawall as needed. Install new steel pipe piles and cap bayside of seawall and connect to seawall. Replace any demolished existing structure as required and construct to present-day design codes.

Accommodates short term seismic life safety issues

Accommodates long term soil lateral sliding with the use of steel pipe piles or similar

Does not accommodate sea level rise.

This alternative, by itself, is estimated to cost from $ 43,000 to $132,000 per lineal foot of seawall depending on the seawall section considered.

S-14 Bulkhead Wharf Mitigation – Wharf Rehabilitation with Jet Grouting: This mitigation alternative is presented on ***Figure 3-17***. Applicable to seawall and bulkhead wharfs only. Retrofit bulkhead wharf to bulkhead wall beam connections. Install steel pipe piles bayside of bulkhead wharf to accommodate soil lateral sliding, if required. Retrofit existing deck beams to accommodate deck effective increased spans for existing piles affected by soil lateral sliding. Demolish existing structure in front of and above existing seawall as needed. Install new steel pipe piles and cap bayside of seawall bulkhead wall and connect to bulkhead wall. Replace any demolished existing structure as required and construct to present-day design codes.

Accommodates short term seismic life safety issues

Accommodates soil lateral sliding with the use of steel pipe piles or similar if jet grouting cannot achieve required strengthening of weak soil layer.

Does not accommodate sea level rise.

This alternative, by itself, is estimated to cost from $ 72,000 to $198,000 per lineal foot of seawall depending on the seawall section considered.

Short Term Structural Mitigation Alternatives Comparison

Each short term structural mitigation alternative has relative advantages and disadvantages with respect to constructability, construction cost and duration, and the ability to address one or more other significant issues such as environmental concerns, sea level rise adaptability, disruption of nearby roadways (specifically, the Embarcadero), tenant disruption, and impacts on utilities. A summary of these issues for the short term structural mitigation alternatives discussed in this report is presented on ***Table 3-2***.

Table 3-2: Mitigation Alternatives Summary – Structural Concepts (Near Term)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
	Near Term (Phase 1)													
S-1	Applicable to all seawall sections with concrete bulkhead. Must evaluate impacts to infrastructure behind the seawall.	Improve life-safety by lessening lateral deformation of concrete bulkhead	Stabilize concrete bulkhead by adding lateral restraint	Stabilize concrete bulkhead by adding lateral restraint	• Limited demolition required at promenade and bulkhead wharf for access to drill and install grouted tie-back anchors from bayside of seawall • Micropiles installed where wingwalls present • CIP concrete wale constructed along face of seawall. • Promenade and bulkhead wharf are impacted.	5-6 months per 500 LF seawall section		• Minor only during construction	• None	• Promenade impacted, little to no impact on roadway	• Yes, where bulk-head wharf buildings are present	• None, Grouted tie-backs assumed to avoid or go below utilities. Conflicting utilities may warrant relocation.	• Relatively low cost • Provides improved short term seismic life safety performance for bulkhead structures	• Does not mitigate long term soil lateral sliding or bulkhead wharf seismic vulnerability • Does not accommodate sea level rise • Addresses seawall stability only • Partial demolition of bulkhead wharf may be required / disruption fairly significant • Utilities and other subgrade infrastructure may present an obstruction
S-2	Sections 8, 9a, 9b, 13 and P46	Improve life-safety by lessening lateral deformation of concrete bulkhead	Stabilize concrete bulkhead by adding lateral restraint	Seawall with Cap Strut and Pile	• Demolition as required at promenade and bulkhead wharf for access to install steel pile • CIP pile caps and struts constructed at face of seawall • Promenade and bulkhead wharf are impacted.	4-6 months per 500 LF seawall section		• Minor only during construction	• None	• Promenade impacted, little to no impact on roadway.	• Yes, where bulk-head wharf buildings are present	• None	• Provides short term seismic life safety performance for seawall structures • Partially mitigate soil lateral sliding if closely spaced steel pipe piles are used (multiple rows may be required)	• Does not accommodate sea level rise • Addresses seawall stability only • Partial demolition of bulkhead wharf and buildings is required

Notes:
1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Table 3-2: Mitigation Alternatives Summary – Structural Concepts (cont'd)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
	Near Term (Phase 1)													
S-3	Sections 9a, 9b, 13 and P46	Improve life-safety by lessening lateral deformation of concrete bulkhead	Stabilize concrete bulkhead by adding lateral restraint	Seawall with Tie-back Anchor Piles	• Demolish existing infrastructure landward of the existing seawall as needed • Install new anchor piles • Trenching for tie-back rod placement • Piles installed using track crane • Install new tie-back anchors to anchor pile wall and connect to seawall • Promenade and Embarcadero roadway will be impacted	5-6 months per 500 LF seawall section		• Minor only during construction	• None	• Promenade impacted, Embarcadero roadway impacted for anchor pile installation	• Yes, where bulk-head wharf buildings are present	• Possible conflict between existing utilities and horizontal tie-backs and anchor piles. Conflicting utilities may warrant relocation.	• Provides short term seismic life safety performance for seawall structures	• Does not accommodate long term soil lateral sliding • Does not accommodate sea level rise • Addresses seawall stability only • Significant impacts to promenade and Embarcadero roadway • Utilities and other subgrade infrastructure may present an obstruction

Notes:
1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Table 3-2: Mitigation Alternatives Summary – Structural Concepts (cont'd)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
	Near Term (Phase 1)													
S-4	Sections 9a, 13 and P46	Improve life-safety by lessening lateral deformation of concrete bulkhead	Stabilize concrete bulkhead by increasing lateral resistance using larger revetment.	Added Revetment	• Minor amount of dredging is required using barge-mounted excavator • New revetment requires flatter slope on the revetment • Benched area provided at toe of revetment • Placement of rock performed using crane and rock barge • Water areas in front of seawall are impacted.	2 months per 500 LF seawall section		• Minor, due to dredging, some open water is eliminated due to presence of new revetment	• None	• None, unless landside equipment is used	• None, alter-native not applicable under piers and bulkhead wharfs	• None	• Provides short term seismic life safety performance for seawall structures	• Not applicable where bulkhead wharf is present • Does not accommodate long term soil lateral sliding • Does not accommodate sea level rise • Addresses seawall stability only • Potential for long term settlement may require additional rock placement over time • Minor dredging required • Environmental permitting required due to in-water work

Notes:
1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Table 3-2: Mitigation Alternatives Summary – Structural Concepts (cont'd)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
	Near Term (Phase 1)													
S-11	Applicable to most seawall sections. Must evaluate impacts to existing buried infrastructure for installation of grouted tie-backs.	Improve life-safety of bulkhead wharf and seawall structures	• Improve life-safety of bulkhead wharf structure • Stabilize concrete bulkhead by adding lateral restraint • Steel wharf pile is provided to survive the lateral sliding displacement and support the existing deck and buildings should adjacent existing piles fail under soil lateral sliding	Near Term Structural Rehabilitation of Bulkhead Wharf and Seawall with Grouted Tie-backs	• Demolish existing structure in front of and above existing seawall as needed • Install steel pipe piles bayside of bulkhead wharf to accommodate soil lateral sliding • Retrofit bulkhead wharf to seawall beam connections • Pile/wharf deck connections strengthened • Existing wharf piles are strengthened using jacket encapsulation where required • Retrofit existing deck beams to accommodate increased effective wharf deck spans when existing piles damaged by soil lateral sliding • Install new grouted tie-back anchors into competent landside soil strata and connect to seawall • Replace any demolished existing structure as required	14 to 16 months per 500 LF seawall section		• Minor during construction	• None	• None	• Yes, existing bulkhead wharf buildings may be temporarily closed, relocated or demolished	• None, outside of bulkhead wharf buildings. • Grouted tie-backs assumed to avoid or go below utilities. Conflicting utilities may warrant relocation.	• Provides short term seismic life safety performance • Bulkhead buildings may remain • Minimizes impact to Embarcadero roadway •	• Does not accommodate sea level rise • Does not mitigate long term soil lateral sliding (kinematic loading) without installation of closely spaced steel pipe piles • Partial demo of existing wharf and supported buildings needed to install bay-side piles • See S-1 for additional disadvantages

Notes:

1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Table 3-2: Mitigation Alternatives Summary – Structural Concepts (cont'd)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
	Near Term (Phase 1)													
S-13	Applicable to many seawall sections. Must evaluate disruption to promenade and bulkhead buildings.	Improve near term life-safety of bulkhead wharf and seawall structures	• Improve life-safety of bulkhead wharf structure • Stabilize concrete bulkhead by adding lateral restraint • Steel wharf pile is provided to survive the lateral sliding displacement and support the existing deck and buildings should adjacent existing piles fail under soil lateral sliding	Near Term Structural Rehabilitation of Bulkhead Wharf and Seawall with Steel Pipe Piles and Cap	• Demolish existing structure in front of and above existing seawall as needed • Install steel pipe piles and cap bayside of bulkhead wharf to accommodate soil lateral sliding. • Retrofit bulkhead wharf to seawall beam connections • Pile/wharf deck connections strengthened • Retrofit existing deck beams to accommodate deck effective increased spans for existing piles affected by soil lateral sliding • Install new steel pipe piles and cap bayside of seawall and connect to seawall using strut.	14 to 16 months per 500 LF seawall section		• Minor during construction	• None	• None	• Yes, existing bulkhead wharf buildings may be temporarily closed, relocated or demolished	• None, outside of bulkhead wharf buildings	• Provides short term seismic life safety performance • Bulkhead buildings may remain • New steel piles supporting providing lateral restraint to seawall can be closely spaced to mitigate soil lateral sliding	• Does not accommodate sea level rise • Does not accommodate long term soil lateral sliding (kinematic loading) without installation of closely spaced steel pipe piles • Partial demo of existing wharf and supported buildings needed to install bay-side piles • See S-2 for additional disadvantages

Notes:

1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Table 3-2: Mitigation Alternatives Summary – Structural Concepts (cont'd)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
	Near Term (Phase 1)													
S-14	Applicable at many seawall sections. Must evaluate disruption to promenade and bulkhead buildings.	Improve near term life-safety of bulkhead wharf and seawall structures. Addition of jet grouting per Mitigation Concept G-5 can mitigate soil lateral sliding.	See S-11 and G-5	See S-11 and G-5	See S-11 and G-5. Also, • Demolish existing pavements within the Embarcadero promenade and roadway • Relocate or protect subsurface utilities and other subterranean structures • Pre-drill holes through rock dike. Install jet grout columns to improve young bay deposits and artificial fill within treatment zone	16 to 18 months per 500 LF seawall section		• Yes, minor during construction	• None	• Yes, major promenade and roadway disruption for Concept G-5	• Yes, existing bulkhead wharf buildings may be temporarily closed, relocated or demolished	• None, outside of bulkhead wharf buildings. • Grouted tie-backs assumed to avoid or go below utilities. Conflicting utilities may warrant relocation.	• See S-11 and G-5 • Addition of jet grouting per Mitigation Concept G-5 can mitigate soil lateral sliding • Landside and waterside work can be phased	See S-11 and G-5

Notes:
1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Description	Seawall Section Applicability	Performance Objective	Purpose
Seawall with Grouted Tie-Backs.	Applicable to all seawall sections where bulkhead is accessible. Must evaluate impacts to existing infrastructure for installation of tie-backs.	Improve life-safety by lessening lateral deformation of concrete bulkhead.	Stabilize concrete bulkhead by adding lateral restraint.

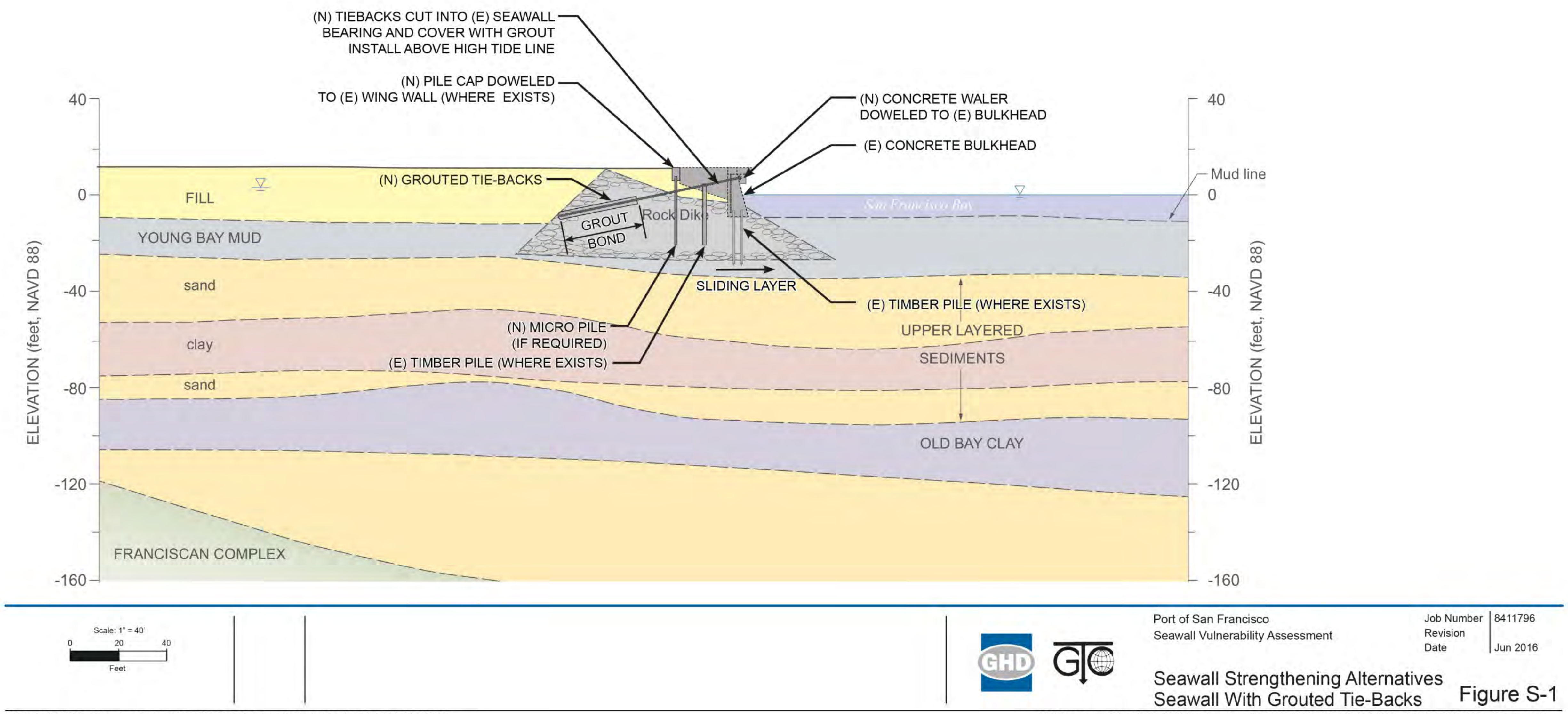


Figure 3-9: Mitigation Alternative S-1 – Seawall with Grouted Tiebacks

Description	Seawall Section Applicability	Performance Objective	Purpose
Seawall with Cap Strut and Pile.	Sections 8, 9a, 13 and P46.	Improve life-safety by lessening lateral deformation of concrete bulkhead.	Stabilize concrete bulkhead by adding lateral restraint.

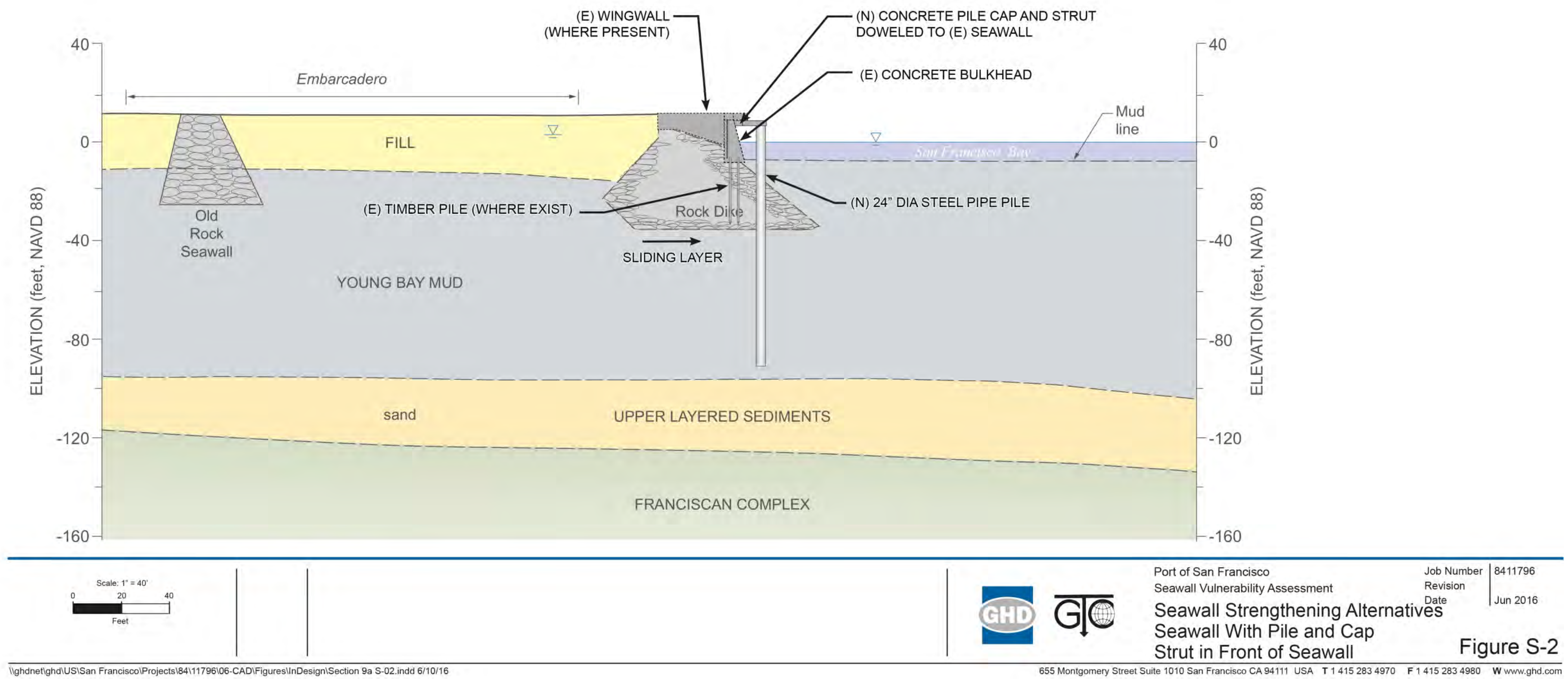


Figure 3-10: **Mitigation Alternative S-2 – Seawall with Pile and Cap Strut in Front of Seawall**

Description	Seawall Section Applicability	Performance Objective	Purpose
Seawall with Tie-back Anchor Piles.	Sections 9b, 13 and P46.	Improve life-safety by lessening lateral deformation of concrete bulkhead.	Stabilize concrete bulkhead by adding lateral restraint.

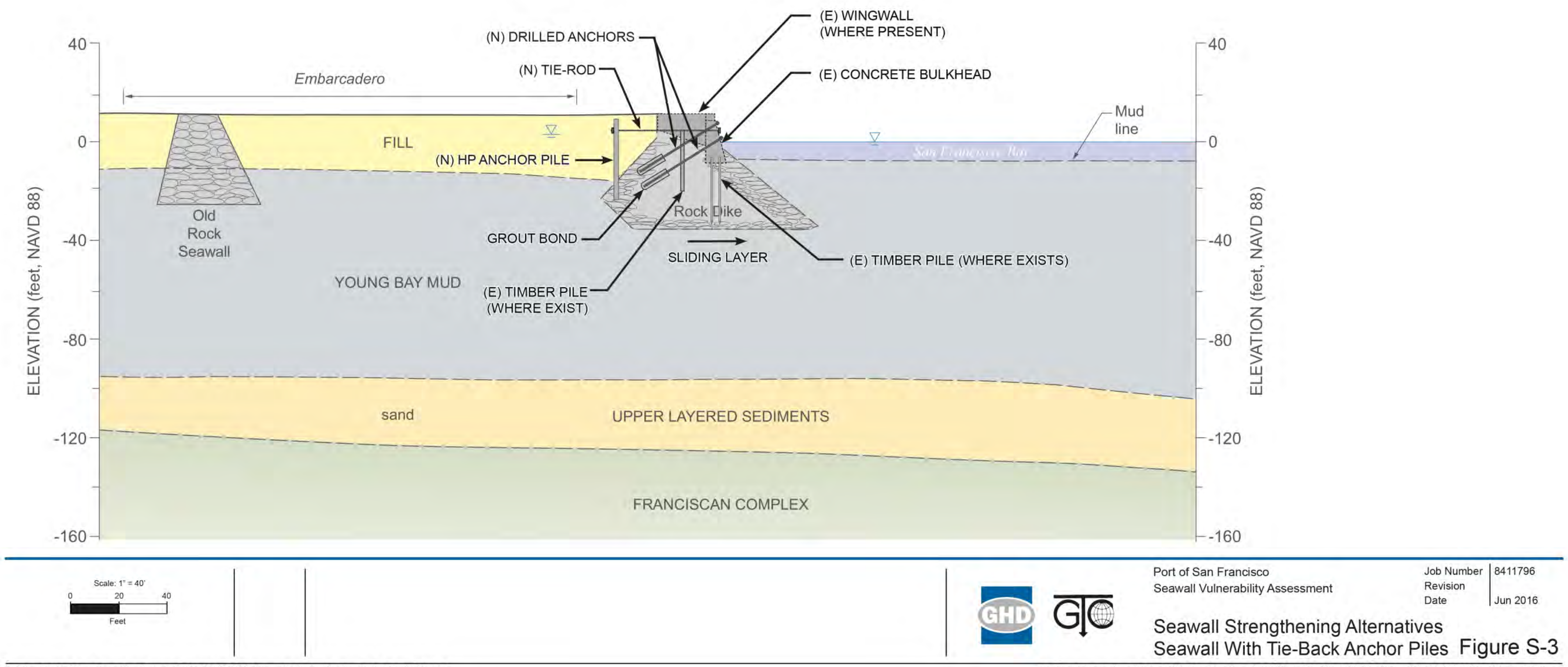


Figure 3-11: Mitigation Alternative S-3 – Seawall with Tie-Back Anchor Piles

Description	Seawall Section Applicability	Performance Objective	Purpose
Added Revetment.	Sections 9a, 13 and P46.	Improve life-safety by lessening lateral deformation of concrete bulkhead.	Stabilize concrete bulkhead by increasing lateral resistance using larger revetment.

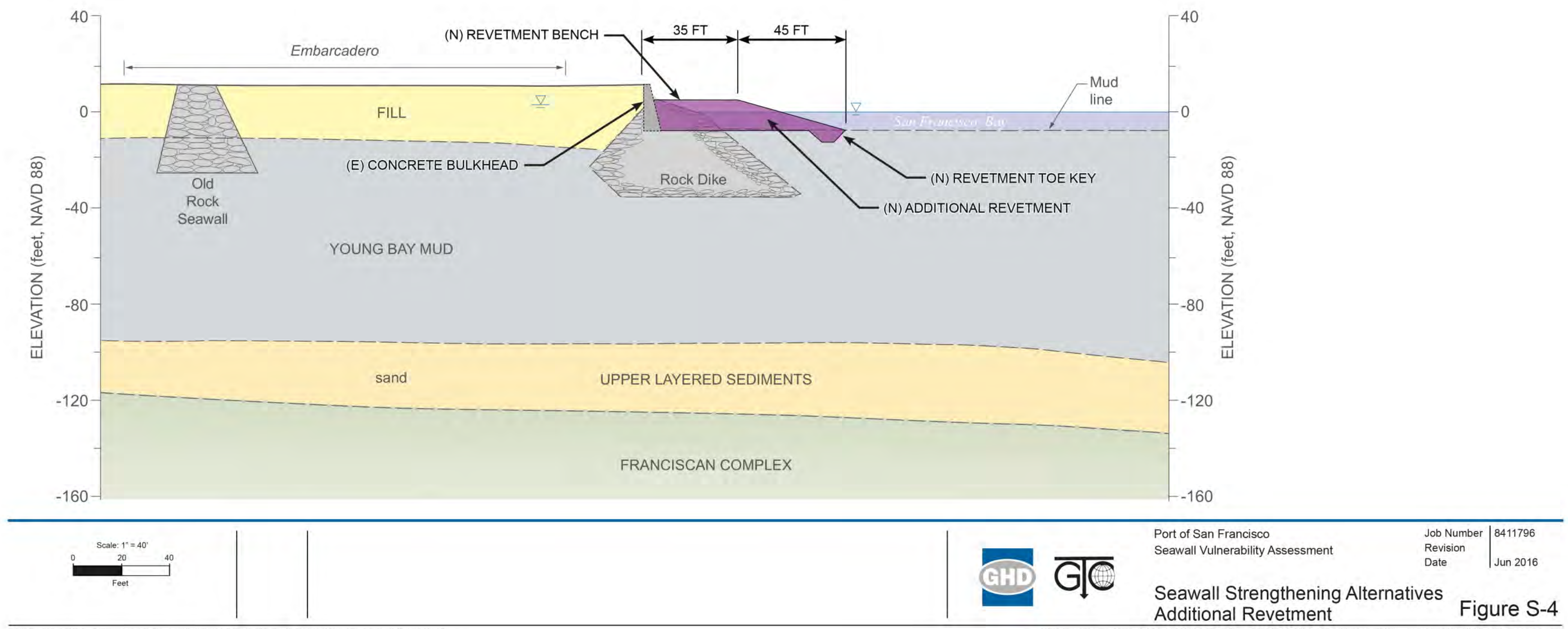


Figure 3-12: **Mitigation Alternative S-4 – Additional Revetment**

Description	Seawall Section Applicability	Performance Objective	Purpose
Near Term Structural Strengthening of Bulkhead Wharf and Bulkhead Stabilization.	Applicable at most sections with bulkhead wharf. Must evaluate impacts to existing subsurface infrastructure for installation of anchor piles.	Improve life-safety of bulkhead wharf and bulkhead structures.	• Improve life-safety of bulkhead wharf structure • Stabilize concrete bulkhead by adding lateral restraint • Steel pile provided to survive the lateral sliding displacement and support the existing deck and buildings should adjacent existing piles fail under soil lateral sliding

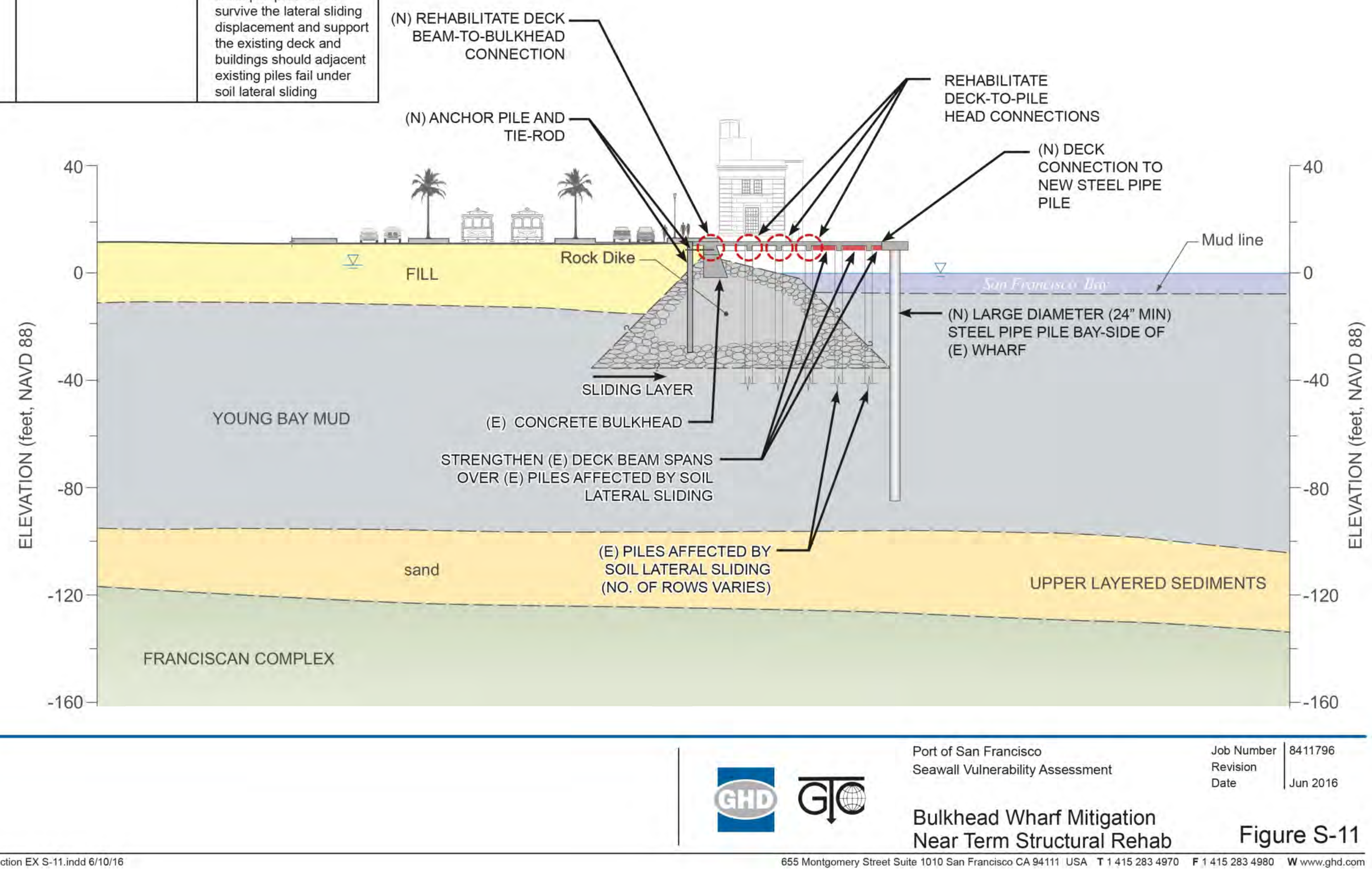


Figure 3-13: **Mitigation Alternative S-11 – Near Term Structural Rehabilitation (Wide Bulkhead Wharf)**

Description	Seawall Section Applicability	Performance Objective	Purpose
Near Term Structural Strengthening of Bulkhead Wharf and Bulkhead Stabilization.	Applicable at most sections with bulkhead wharf. Must evaluate impacts to existing subsurface infrastructure for installation of anchor piles.	Improve life-safety of bulkhead wharf and bulkhead structures.	• Improve life-safety of bulkhead wharf structure • Stabilize concrete bulkhead by adding lateral restraint • Steel pile provided to survive the lateral sliding displacement and support the existing deck and buildings should adjacent existing piles fail under soil lateral sliding

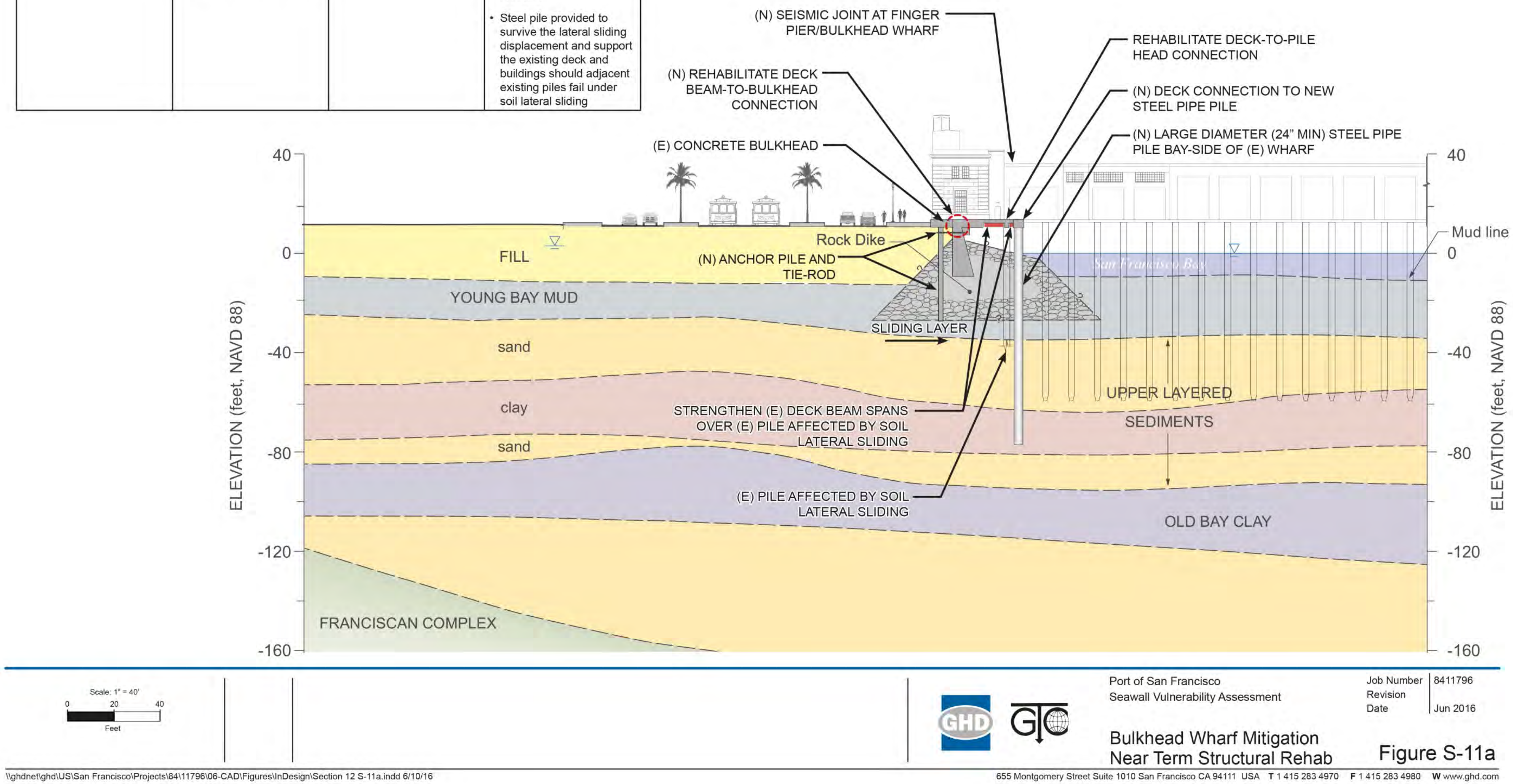


Figure 3-14: **Mitigation Alternative S-11a – Near Term Structural Rehabilitation (Narrow Bulkhead Wharf)**

Description	Seawall Section Applicability	Performance Objective	Purpose
Near Term Structural Strengthening of Bulkhead Wharf and Bulkhead Stabilization.	Applicable to many seawall sections. Must evaluate disruption to promenade and bulkhead buildings.	Improve life-safety of bulkhead wharf and bulkhead structures.	• Improve life-safety of bulkhead wharf structure • Stabilize concrete bulkhead by adding landside pile and lateral restraint • Steel wharf pile provided to survive the lateral sliding displacement and support the existing deck and buildings should adjacent existing piles fail under soil lateral sliding

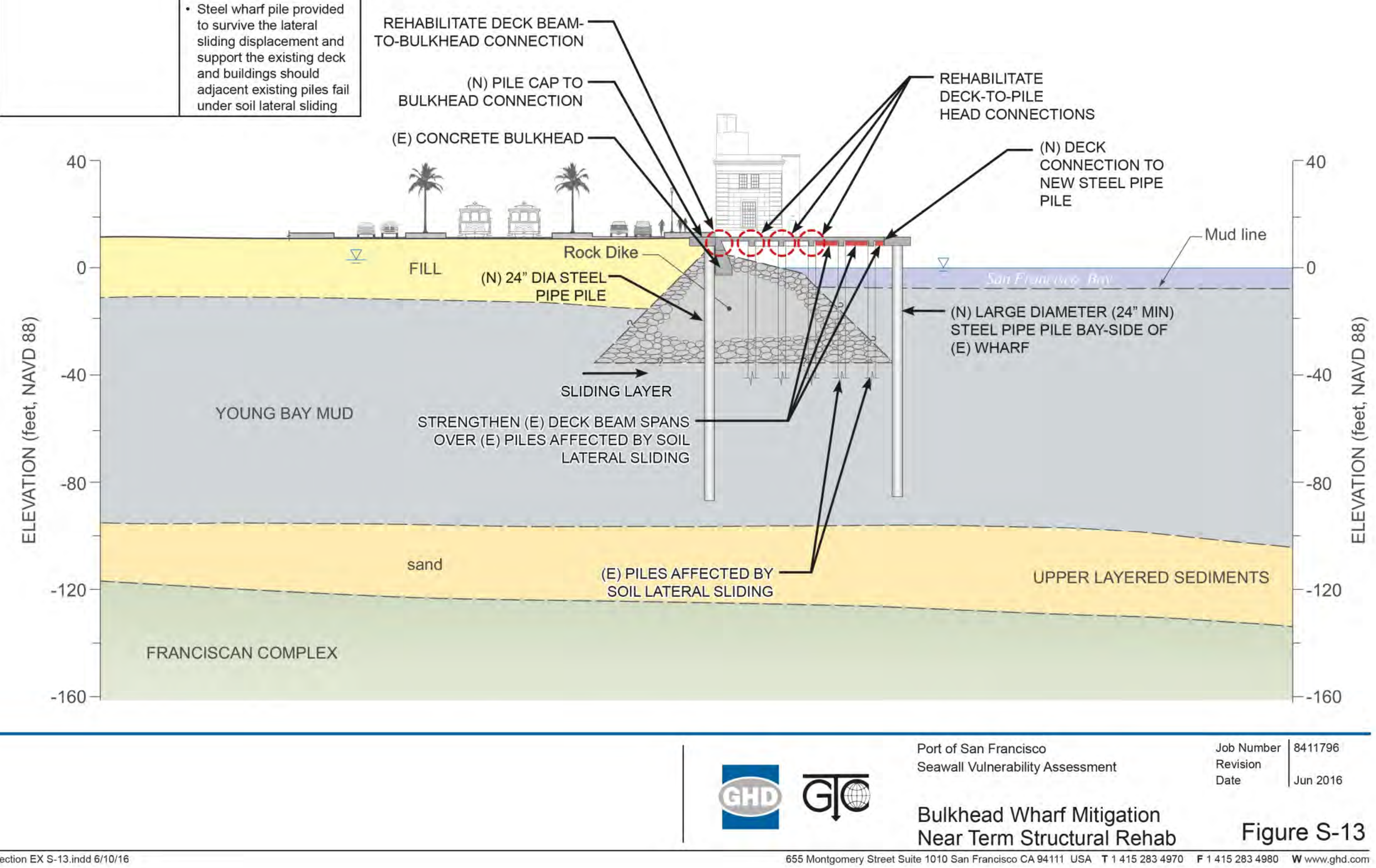
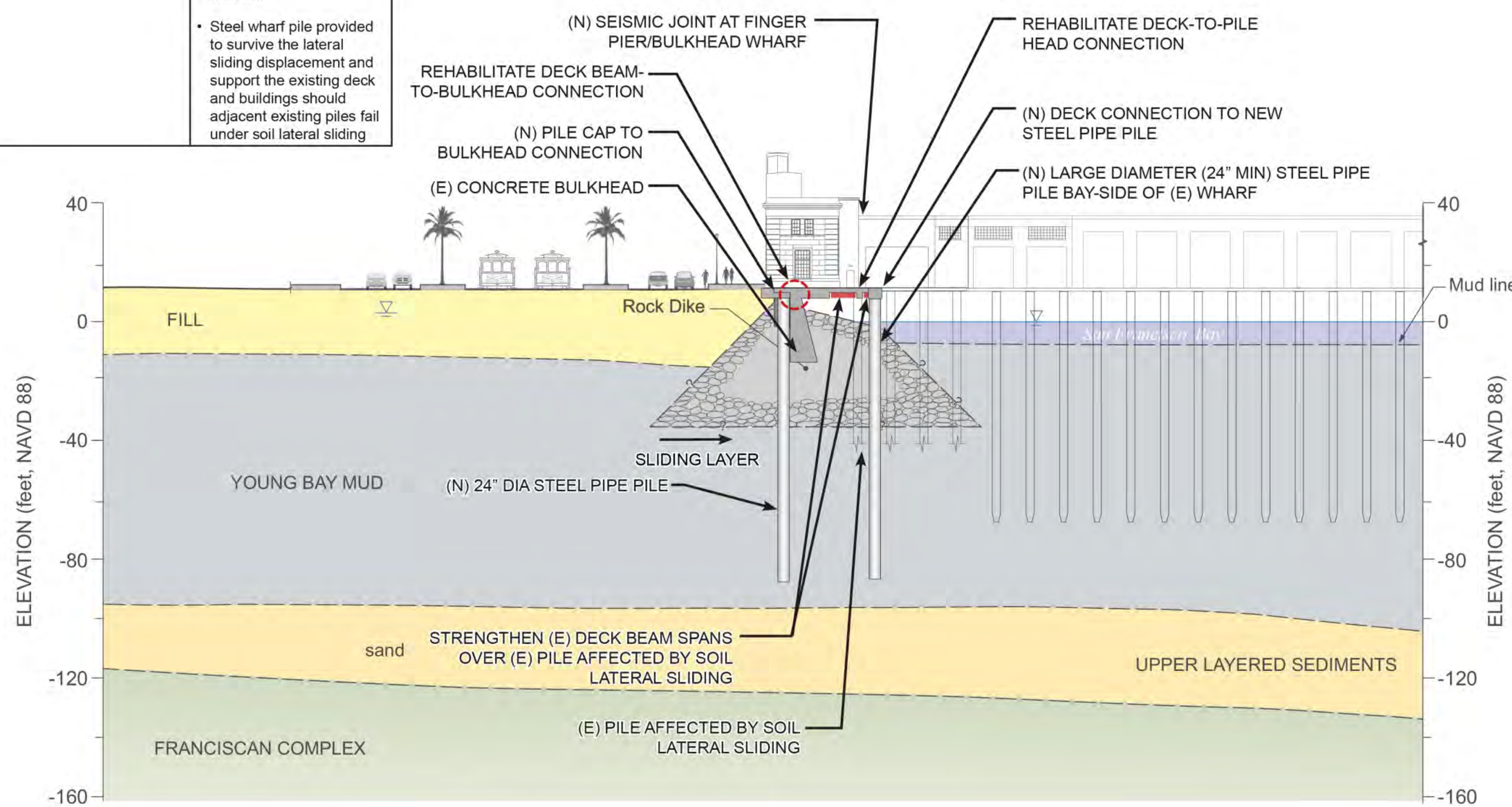


Figure 3-15: Mitigation Alternative S-13 – Wharf Rehabilitation and Seawall with Pile and Cap Strut in Front of Seawall

Description	Seawall Section Applicability	Performance Objective	Purpose
Near Term Structural Strengthening of Bulkhead Wharf and Bulkhead Stabilization.	Applicable to many seawall sections. Must evaluate disruption to promenade and bulkhead buildings.	Improve life-safety of bulkhead wharf and bulkhead structures.	• Improve life-safety of bulkhead wharf structure • Stabilize concrete bulkhead by adding landside pile and lateral restraint • Steel wharf pile provided to survive the lateral sliding displacement and support the existing deck and buildings should adjacent existing piles fail under soil lateral sliding



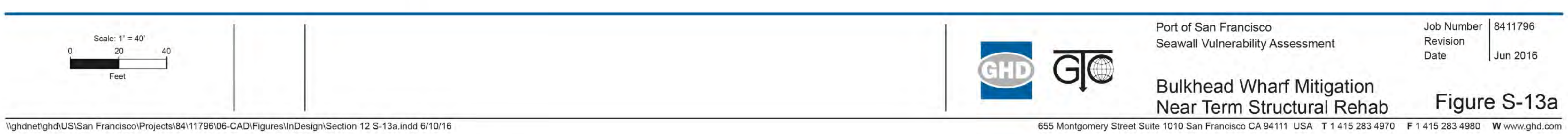
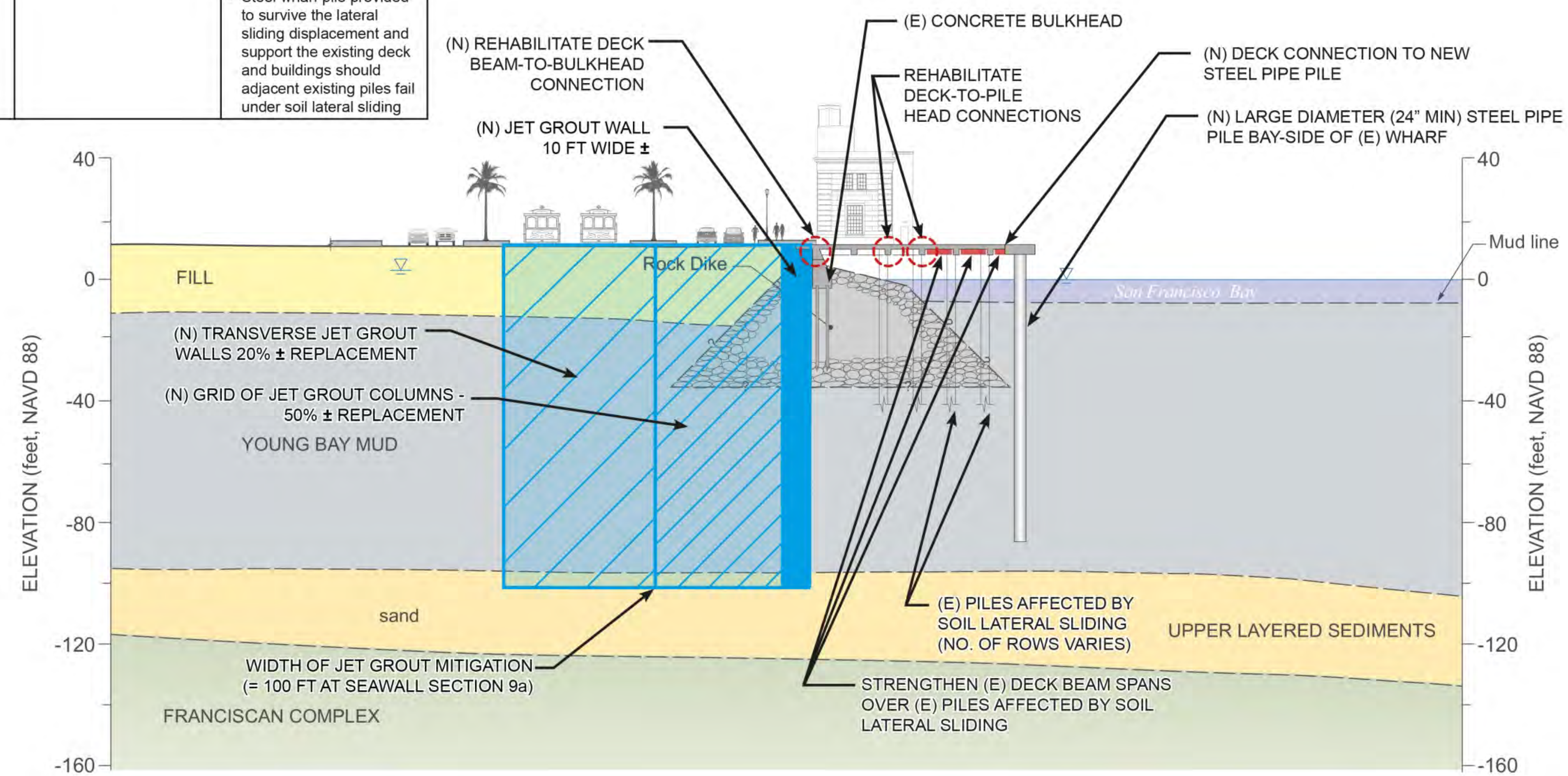


Figure 3-16: **Mitigation Alternative S-13a – Wharf Rehabilitation and Seawall with Pile and Cap Strut in Front of Seawall**

Description	Seawall Section Applicability	Performance Objective	Purpose
Improve near term life-safety of bulkhead wharf and seawall structures.	Applicable to many seawall sections. Must evaluate disruption to promenade and bulkhead buildings.	Improve life-safety of bulkhead wharf and bulkhead structures. Addition of jet grouting per Mitigation Concept G-5 can mitigate soil lateral sliding.	• Improve life-safety of bulkhead wharf structure • Stabilize concrete bulkhead by adding landside pile and lateral restraint • Steel wharf pile provided to survive the lateral sliding displacement and support the existing deck and buildings should adjacent existing piles fail under soil lateral sliding



Scale: 1" = 40'
0 20 40
Feet

Port of San Francisco
Seawall Vulnerability Assessment

Job Number 8411796
Revision
Date Jun 2016

Bulkhead Wharf Mitigation
Near Term Structural Rehab

Figure S-14

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Figure 3-17: Mitigation Alternative S-14 – Wharf Rehabilitation and Jet Grouting

Bulkhead Wharf Replacement – Super Bulkhead Wharf

This mitigation concept provides a new bulkhead wharf with sufficient strength and lateral stiffness to stabilize the bulkhead wall and rock dike without requiring soil improvement. The work will include demolition or temporary relocation of existing buildings on the bulkhead wharf. Existing bulkhead wharf will be demolished along with any supported infrastructure. Section of adjoining finger pier will be removed where needed for construction barge access. A temporary or permanent transfer span may be used for access from new bulkhead wharf to the pier. Replace existing bulkhead wharf structure with new pile-supported bulkhead wharf structure using large diameter steel pipe piles along with a thick, stiff reinforced concrete deck structure. Replace previously supported and relocated infrastructure or replace with new construction in-kind but construct to present-day design codes.

Steel pipe piles are used in the wharf pile rows adjacent to the rock dike will have spacing mitigate the soil lateral sliding or to survive displacement imposed by soil lateral sliding if the weak soil layer is relatively thin. The actual size, spacing and number of pile rows will be determined by geotechnical considerations.

The bulkhead wall is strengthened by providing supplemental steel pipe piles or connecting wharf piles to the wall. The new piles can resist the bulkhead lateral loads, connected to the wharf deck. Tiebacks or ground improvement of the soil wedge behind, or landside buttress walls tied to dike or connected to first pile row may also be used.

Seismic joints will be needed between finger piers and new bulkhead wharf. A permanent transfer span may be needed to connect the wharf structure and the pier following completion of construction.

Accommodates short term seismic life safety issues

Accommodates long term soil lateral sliding with the use of steel pipe piles.

Accommodates sea level rise.

- New wharf deck supported by large diameter closely spaced steel pipe piles
- Lessens lateral spreading, but does not eliminate.
- Bulkhead buildings need to be replaced.
- Sea Level Rise - construct wharf deck to higher elevation, limited future raising.

S-23 Bulkhead Wharf Replacement – Super Bulkhead Wharf: This mitigation alternative is presented on ***Figure 3-18***. Applicable to seawall and bulkhead wharfs only. Demolish existing bulkhead wharf along entire seawall section. Demolish existing infrastructure as needed. Install new steel pipe piles and cap bayside of seawall and connect to seawall. Replace existing bulkhead wharf structure with new piled bulkhead wharf structure of same plan dimensions, with closely spaced steel pipe piles to mitigate soil lateral sliding (precast concrete piles used elsewhere). Replace previously supported infrastructure with new construction in-kind but construct to present-day design codes.

Accommodates short term seismic life safety issues

Accommodates long term soil lateral sliding with the use of steel pipe piles or similar

Accommodate sea level rise if constructed to a higher elevation.

This alternative, by itself, is estimated to cost from $ 63,000 to $160,000 per lineal foot of seawall depending on the seawall section considered.

Bulkhead Wharf Replacement – Standard Bulkhead Wharf

This mitigation concept provides a new bulkhead wharf with soil strengthening using jet grouting to stabilize the bulkhead wall and rock dike. The work will include demolition or temporary relocation of existing buildings on the bulkhead wharf. Existing bulkhead wharf will be demolished along with any supported infrastructure. Section of adjoining finger pier will be removed where needed for construction barge access. A temporary or permanent transfer span may be used for access from new bulkhead wharf to the pier. Replace existing bulkhead wharf structure with new pile-supported bulkhead wharf structure using precast concrete piles along with a stiff reinforced concrete deck structure. Replace previously supported and relocated infrastructure or replace with new construction in-kind but construct to present-day design codes.

Stabilization of the bulkhead wall is achieved by reducing lateral pressures from the soil improvement. Seismic joints will be needed between finger piers and new bulkhead wharf. A permanent transfer span may be needed to connect the wharf structure and the pier following completion of construction.

The mitigation concept accommodates short term seismic life safety issues and provides improved seismic performance.

Accommodates sea level rise by using higher wharf deck elevation.

- New wharf deck supported by 24” diameter precast concrete piles
- Reduces lateral spreading through use of soil strengthening.
- Bulkhead buildings need to be replaced.
- Sea Level Rise - construct wharf deck to higher elevation, limited future raising.

S-26 Bulkhead Wharf Replacement – Standard Bulkhead Wharf and Soil Strengthening: This mitigation alternative is presented on *Figure 3-19*. Applicable to seawall and bulkhead wharfs only. Demolish existing bulkhead wharf along entire seawall section. Demolish existing infrastructure as needed. Replace existing bulkhead wharf structure with new piled bulkhead wharf structure of same plan dimensions, using precast concrete piles and cast-in-place concrete deck. Replace previously supported infrastructure with new construction in-kind but construct to present-day design codes. Incorporates use of jet grouting to reduce lateral pressures on bulkhead and wharf pile displacement demand.

Accommodates short term seismic life safety issues

Accommodates long term soil lateral sliding with the use of steel pipe piles or similar

Accommodate sea level rise if constructed to a higher elevation.

This alternative, by itself, is estimated to cost from $ 76,000 to $220,000 per lineal foot of seawall depending on the seawall section considered.

Bulkhead Wharf Replacement – Improved Earth Structure

This concept consists of using a king pile sheet pile (combi-wall) bulkhead with anchor pile and tie-rods in combination with Deep Soil Mixing (DSM).

Tie back anchors are installed at regular intervals and restrain the top of the wall and the area behind the wall would be backfilled. Preliminary sizing for the anchored combi-wall concept consists of a W40x372 king and sheet pile system is presented in ***Figure 3-20***.

The mitigation concept uses waterside construction in the bulkhead wharf zone along with landside construction for jet grouting under the rock dike.

The tied-back bulkhead concept can be located at any distance from the existing seawall and bulkhead wharf. As shown in ***Figure 3-20***, it reclaims a minimum amount of bay water. It could be located entirely to the bay-side claiming the maximum amount of bay waters. The alternative assumes a potential reconstruction of the entire waterfront.

The purpose of the anchor pile wall is to provide lateral support for the combi-wall bulkhead. The anchor wall consists of driven H-Piles or pipe piles with a concrete cap that is connected to the tie-backs from the combi-wall. The cap might be on the order of 4 feet deep and 8 feet wide to connect the staggered H-piles and the tie rods. The cap is considered permanent. Without an anchor wall (or similar), a cantilever bulkhead wall of reasonable sizing is not close to feasible at wall heights of 27 feet or so (needed with present water depths and to accommodate sea level rise) under the design pressures assumed, although a solid king-pile cantilever wall can be made to work. If the design pressures were reduced by at least a factor of 2, perhaps a cantilever wall would suffice. Alternatively, revetment can be provided along a new cantilever wall to reduce the effective wall height to get a feasible wall configuration and eliminate the need for the anchor pile wall. DSM is required to reduce the lateral pressures acting on the bulkhead.

The purpose, type, and extent of landside soil improvement is to reduce the extent of lateral sliding and reduce the active soil pressures on the new bulkhead combi-wall. Type, preliminary sizing and extent of new bulkhead wall are being developed.

A permanent transfer span may be needed to connect the new bulkhead and the pier following completion of construction.

- Installation of an anchored combi-wall consisting of steel wide flange sections and sheet piling
- Sheetpile wall at bulkhead line, fill with soil and improve soil mass using DSM.
- Lessens lateral spreading
- Bulkhead buildings need replacement
- Sea Level Rise – Provides foundation for future raising

<u>S-32 Bulkhead Wharf Replacement – Improved Earth Structure with Tie-Back Anchor Piles:</u> This mitigation alternative is presented on *Figure 3-20*. Applicable to seawall and bulkhead wharfs only. Demolish existing infrastructure supported by bulkhead wharfs. Demolish existing bulkhead wharf in its entirety or, alternatively, abandon structure in place as appropriate. Install H-pile anchor wall landside of existing seawall. Landside of existing bulkhead wharf, install king pile combi-sheet pile wall of a height to accommodate sea level rise. Improve soil backfill between these two structures using DSM (Options A and B per Concepts G-3 and G-4.) Install tie-backs. The new improved wharf is assumed to be 150 feet wide on average. Replace previously supported infrastructure with new construction in-kind but construct to present-day design codes.

Accommodates short term seismic life safety issues

Accommodates long term soil lateral sliding with the use of steel pipe piles or similar

Accommodate sea level rise if constructed to a higher elevation.

This alternative, by itself, is estimated to cost from $ 40,000 to $185,000 per lineal foot of seawall depending on the seawall section considered.

Long Term Structural Mitigation Alternatives Comparison

Each long term structural mitigation alternative has relative advantages and disadvantages with respect to constructability, construction cost and duration, and the ability to address one or more other significant issues such as environmental concerns, sea level rise adaptability, disruption of nearby roadways (specifically, the Embarcadero), tenant disruption, and impacts on utilities. A summary of these issues for the long term structural mitigation alternatives discussed in this report is presented on ***Table 3-3***.

Table 3-3: Mitigation Alternatives Summary – Structural Concepts (Long Term)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
	Long Term (Phase 2)													
S-23	Applicable at several seawall sections. Removal of existing bulkhead wharf buildings must be reviewed. Removal of finger pier section is required where present.	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures	• Stabilize concrete bulkhead to meet seismic demand by adding lateral restraint • Improve near term life safety of bulkhead wharf structure and mitigate soil lateral sliding by use of closely spaced stiff piles	Super Bulkhead Wharf with pile and cap strut in front of seawall	• Demolish existing bulkhead wharf along section (work may be phased) • Demolish existing infrastructure as needed • Install pile cap and strut connection to bulkhead. • Replace existing bulkhead wharf structure with new piled bulkhead wharf structure with closely spaced steel pipe piles (concrete piles used on outer rows). • Replace previously supported infrastructure with new construction in-kind • Permanent transfer span may be required for access to finger pier	18 – 20 months per 500 LF seawall section		• Demolition debris, minor concerns during construction	• Yes, new wharf constructed at higher elevation	• Yes, during bulkhead wharf demolition	• Yes, on bulkhead wharfs and finger piers. Buildings may be closed, relocated or demolished	• Yes, utility service to bulkhead wharf and finger piers	• Mitigates short term seismic life safety issues • Mitigates long term soil lateral sliding by providing closely spaced steel pipe piles • Accommodates sea level rise by providing higher wharf deck elevation • Minimizes impact to promenade and Embarcadero roadway	• Historic bulkhead buildings must be temporarily relocated or demolished • Partial demolition of adjacent finger pier is required for construction

Notes:

1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Table 3-3: Mitigation Alternatives Summary – Structural Concepts (Long Term) (cont'd)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
	Long Term (Phase 2)													
S-26	Applicable at several seawall sections. Removal of existing bulkhead wharf buildings must be reviewed. Removal of finger pier section is required where present.	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures Addition of jet grouting per Figure G-5 can mitigate soil lateral sliding and reduce displacement demand on wharf piles.	• Address long term performanc e of bulkhead wharf structure • Stabilize concrete bulkhead by adding lateral restraint • This mitigation concept uses waterside construction in the bulkhead wharf zone along with landside construction for jet grouting under the rock dike	Super Bulkhead Wharf with Soil Strengthening	See S-23 and G-5	18 – 22 months per 500 LF seawall section		• Demolition debris, minor concerns during construction	• Yes, new wharf constructed at higher elevation	• Yes, during bulkhead wharf demolition	• Yes, on bulkhead wharfs and finger piers. Buildings may be closed, relocated or demolished	• Yes, utility service to bulkhead wharf and finger piers	• Mitigates short term seismic life safety issues • Mitigates long term soil lateral sliding by use of soil strengthening (jet grouting) • Jet grouting can be landside operation • Accommodates sea level rise by providing higher wharf deck elevation • Landside soil strengthening (jet grouting) and wharf replacement can be conducted simultaneously • New wharf pile displacement demand greatly reduced by soil strengthening • Landside and waterside work may be phased • Large diameter steel wharf piles may be used to stabilize concrete bulkhead	• Historic bulkhead buildings must be temporarily relocated or demolished • Partial demolition of adjacent finger pier is required for construction • Promenade and Embarcadero roadway are impacted by jet grouting operations (see G-5 description)

Notes:
1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Table 3-3: Mitigation Alternatives Summary – Structural Concepts (Long Term) (cont'd)

No.	Seawall Section Applicability	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Significant Considerations							Advantages	Disadvantages
						Estimated Construction Duration	Relative Cost	Environ-mental Concerns	Sea Level Rise Adaptability	Embarcadero Disruption	Tenant Disruption	Utility Impacts		
	Long Term (Phase 2)													
S-32	Applicable at nearly all seawall sections. Removal of existing bulkhead wharf buildings must be reviewed. Removal of finger pier section is required where present.	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures	• Soil strengthening is performed to reduce extent of lateral sliding and reduce the active soil pressures on the new bulkhead combi-wall • Concept uses waterside construction in the bulkhead wharf zone along with landside construction for installation of stone columns for mitigation of ground displacement due to liquefaction	Improved Earth Structure with tie-back anchor piles	• Demolish existing infrastructure supported by bulkhead wharfs • Demolish existing bulkhead wharf in its entirety or, alternatively, abandon structure in place as appropriate • Bayward of existing bulkhead wharf, install king pile combi-sheet pile wall of a height to accommodate sea level rise • Improve soil backfill landside of the combi-wall using deep soil mixing • Install anchor piles and tie-back rods • New improved wharf is assumed to be 150 feet wide on average • Replace previously supported infrastructure with new construction in-kind • Permanent transfer span may be required for access to finger pier	18 - 20 months per 500 LF seawall section		• Significant filling of the bay. Demolition debris, minor concerns during construction	• Yes, new wharf constructed at higher elevation	• Yes, during bulkhead wharf demolition. Yes, during new wharf construction	• Yes, on bulkhead wharfs and finger piers. Buildings will be demolished	• Yes, utility service to bulkhead wharf and finger piers	• Mitigates both short and long term vulnerability • Provides increased waterfront commercial/retail area and allows for greater public access • Width of DSM buttress (increased Bay fill) can be reduced by using anchor piles and tie-beams (see G-4) • King pile bulkhead lateral restraint using permanent ground anchors or, anchor piles/tie-rods is dependent on height of wall and thickness of weak clay layer at different sections	• Bulkhead buildings must be temporarily relocated or demolished • Partial demolition of adjacent finger pier is required for construction • Significant environmental permitting due to Bay fill • DSM spoils will need to be reused as fill or hauled offsite • Promenade and Embarcadero roadway are impacted by installation of anchor piles and tie-rods at sections where required • See G-3, G-4 and S-1 for additional disadvantages

Notes:
1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

Description	Seawall Section Applicability	Performance Objective	Purpose
New Bulkhead Wharf with Bulkhead Stabilization.	Applicable at several seawall sections. Removal of existing bulkhead wharf buildings must be reviewed. Removal of finger pier section is required where present.	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures.	• Stabilize concrete bulkhead to meet seismic demand by adding lateral restraint • Improve near term life safety of bulkhead wharf structure and mitigate soil lateral sliding by use of closely spaced stiff piles

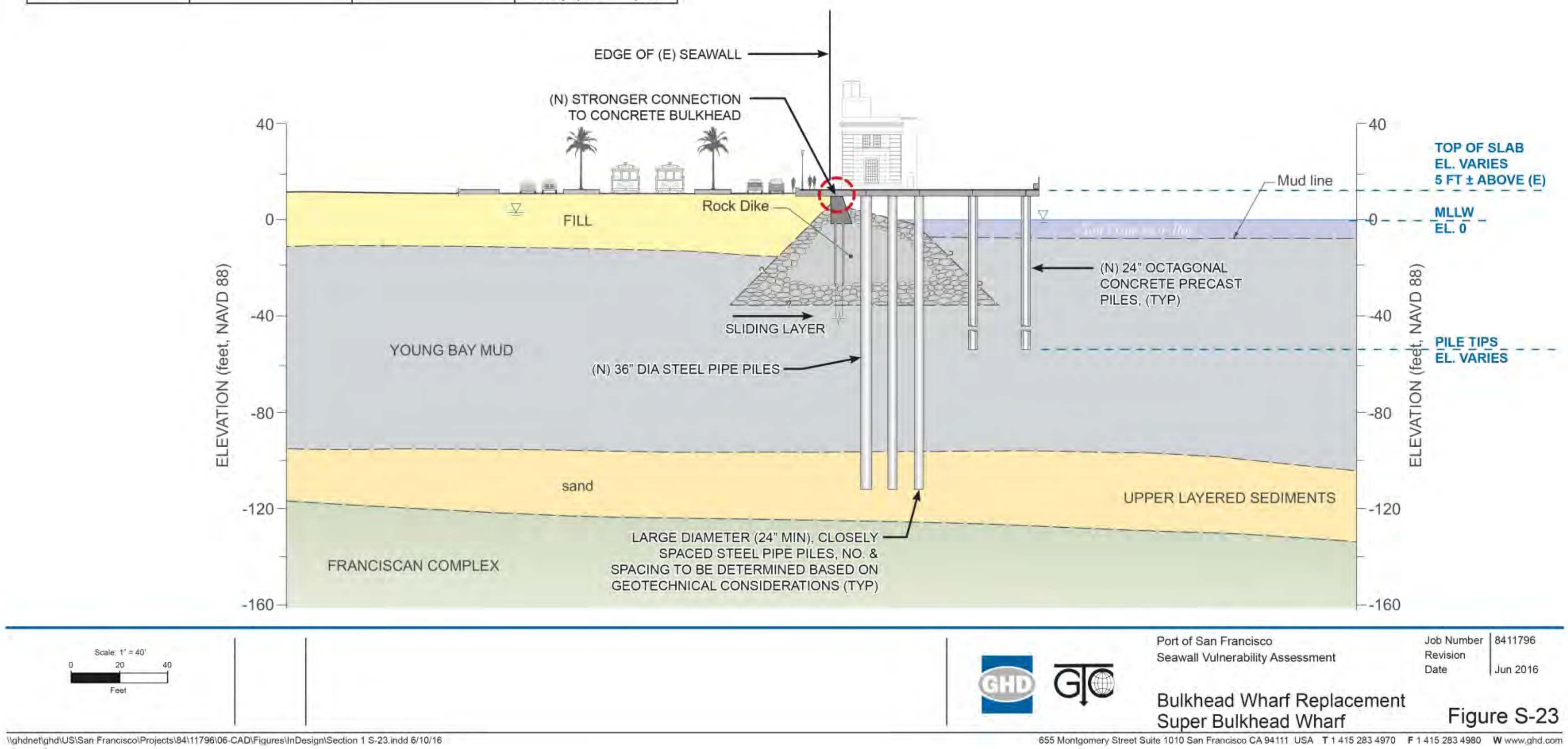

Figure 3-18: Mitigation Alternative S-23 – Super Bulkhead Wharf and Seawall with Pile and Cap Strut in Front of Seawall

Description	Seawall Section Applicability	Performance Objective	Purpose
New Bulkhead Wharf with Soil Strengthening.	Applicable at several seawall sections. Removal of existing bulkhead wharf buildings must be reviewed. Removal of finger pier section is required where present.	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and bulkhead structures. Addition of jet grouting per Figure G-5 can mitigate soil lateral sliding and reduce displacement demand on wharf piles.	• Address long term performance of bulkhead wharf structure • Stabilize concrete bulkhead by reducing lateral pressures and soil lateral sliding • All concrete wharf construction is possible with mitigated soil lateral sliding

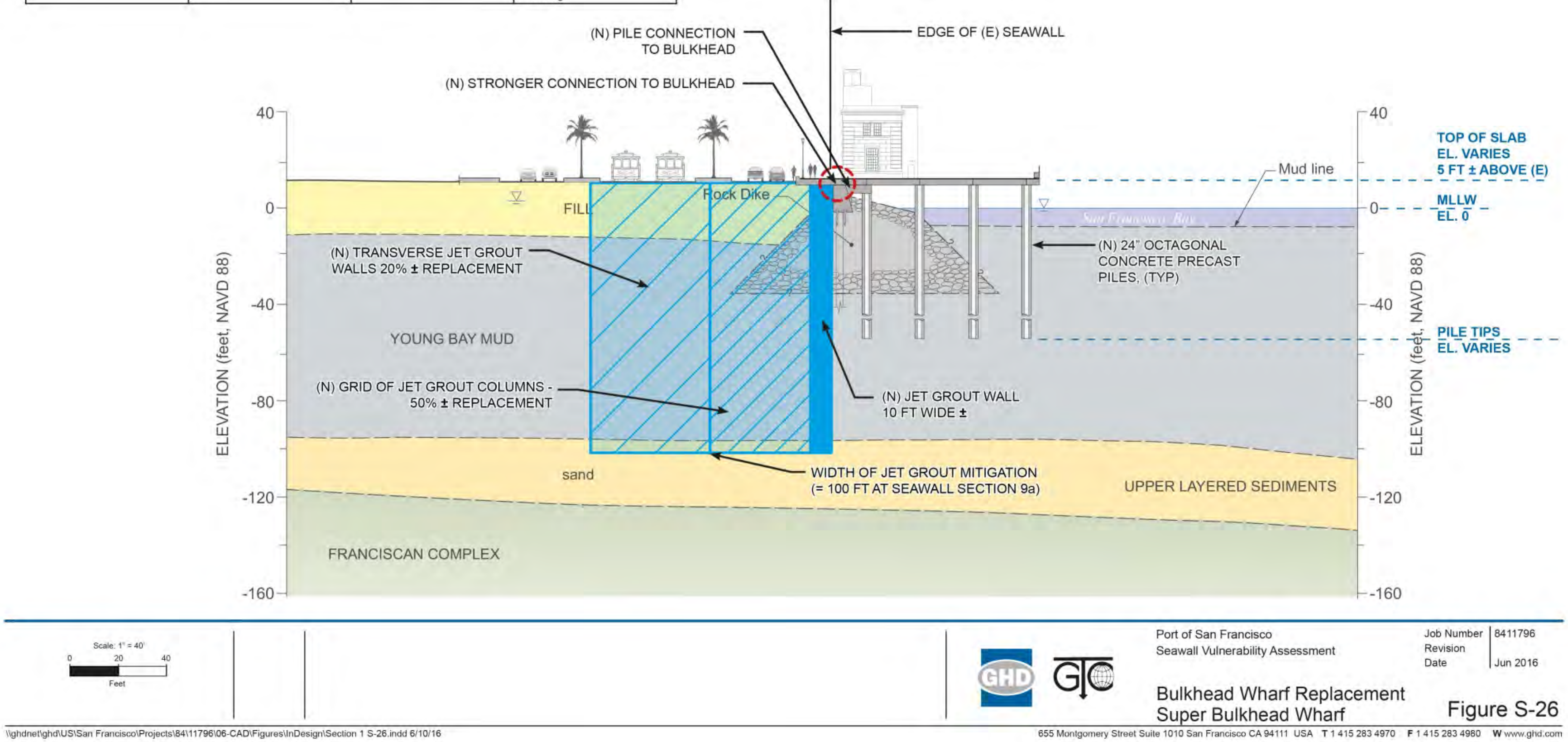

Figure 3-19: Mitigation Alternative S-26 – Super Bulkhead Wharf and Jet Grouting

Description	Seawall Section Applicability	Performance Objective	Purpose
Improved Bulkhead Structure.	Applicable at nearly all seawall sections. Removal of existing bulkhead wharf buildings must be reviewed. Removal of finger pier section is required where present.	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures.	• Address long term performance of bulkhead wharf structure • Stabilize concrete bulkhead by reducing lateral pressures and soil lateral sliding • Soil strengthening is performed to reduce extent of lateral sliding and reduce the active soil pressures on the new bulkhead combi-wall • Concept uses waterside construction in the bulkhead wharf zone along with landside construction for installation of stone columns for mitigation of ground displacement due to liquefaction

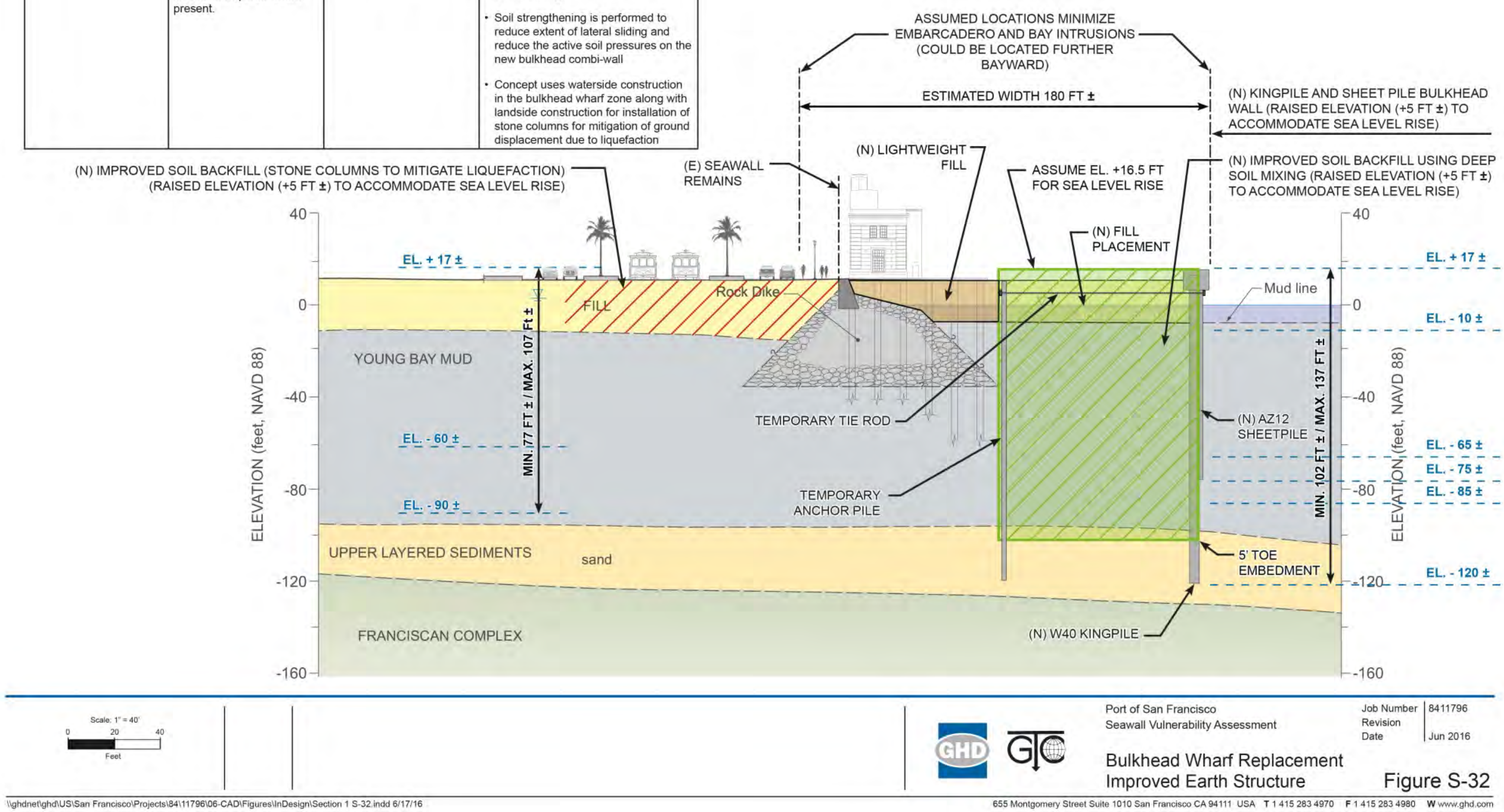

Figure 3-20: Mitigation Alternative S-32 – Improved Earth Structure with Tie-Back Anchor Piles

4. Rough Order Magnitude (ROM) Cost and Construction Duration Estimates for Mitigation Alternatives

4.1. Introduction

Rough Order of Magnitude Construction Cost Estimates

Rough Order of Magnitude (ROM) construction cost estimates have been developed for the mitigation concepts. Unit costs were developed based on relevant experience and knowledge, historical cost information, recent bid history of similar waterfront projects, vendor quotes from recent projects for similar items where applicable, recent contractor quotes for similar items where applicable and discussion with marine construction contractors. The cost estimates included a contingency of 25% to 40% depending on the degree of unknowns. The estimates also include amounts for environmental clearance, permitting, preliminary and final design and construction management. The construction estimates also include underground infrastructure and utilities along with existing buildings and surface features that will be encountered during construction. Traffic and pedestrian disruption and road closures along the Embarcadero were also included in the cost estimates.

The ROM estimated costs are presented on ***Table 4-1*** and ***Table 4-2*** below. The largest cost is installation of the soil strengthening and new bulkhead wharf and earth structures.

4.2. ROM Cost Estimates for Geotechnical Mitigation Alternatives

ROM construction costs were developed for all geotechnical mitigation alternatives considered in the Phase 3 study. The scope of geotechnical alternatives will vary by seawall section, being dependent upon the width and depth of treatment, among other things. Thus, costs per foot of seawall are developed but they vary with seawall section. ***Table 4-1*** summarizes these costs. The scope of construction work included in the cost estimates consists of demolition, contractor mobilization, operation and drilling /grouting rate for rig and equipment, protection of environment and nearby infrastructure, and restoration of concrete promenade, pavement and infrastructure following completion of mitigation work.

Table 4-1: ROM Cost Estimates for Geotechnical Mitigation

	Ground Mitigation Alternatives ROM Construction Cost		
Ground Mitigation Alternative	**Maximum ($/Foot)**	**Minimum ($/Foot)**	**Average ($/Foot)**
G-1	**$63,286**	**$11,216**	**$32,189**
G-1A	**$117,347**	**$18,005**	**$57,923**
G-2	**$34,588**	**$8,085**	**$13,264**
G-3	**$51,629**	**$12,084**	**$31,912**
G-4	**$50,171**	**$11,822**	**$29,469**
G-5	**$85,547**	**$20,553**	**$50,998**
G-6	**$11,388**	**$11,388**	**$11,388**
G-7	**$160,538**	**$160,538**	**$160,538**

Notes:

1. ROM construction costs vary by section due to width and depth of mitigation.

4.3. ROM Cost Estimates for Structural Mitigation Alternatives

ROM construction costs were developed for all structural mitigation alternatives considered in the Phase 3 study. The scope of structural alternatives will vary by seawall section, being dependent upon dimensions and extent of the strengthened area, among other things. Thus, costs per foot of seawall are developed but they vary with seawall section. ***Table 4-2*** summarizes these costs. The scope of work included in the cost estimates consists of demolition, contractor mobilization, strengthening and rehabilitation of concrete wharf and bulkhead structures, installation of ground anchors, seismic retrofit of bulkhead wharf and installation of king pile bulkhead where applicable, soil strengthening, protection of environment and nearby infrastructure, and restoration of concrete promenade, pavement and infrastructure following completion of mitigation work.

Table 4-2: ROM Cost Estimates for Structural Mitigation

	Structural Mitigation Alternatives ROM Construction Cost		
StructuralMitigation Alternative	**Maximum ($/Foot)**	**Minimum ($/Foot)**	**Average ($/Foot)**
S-1	$14,412	$6,071	$8,460
S-2	$14,067	$10,867	$12,711
S-3	$15,499	$9,807	$12,010
S-4	$10,108	$7,193	$8,650
S-11	$128,563	$42,785	$63,219
S-13	$131,333	$43,428	$63,940
S-14	$197,567	$71,836	$103,349
S-23	$211,823	$61,903	$95,588
S-26	$221,500	$74,891	$114,540
S-32	$264,071	$61,020	$110,283

Notes:

1. ROM construction costs vary by section due to width and depth of mitigation.

4.4. Construction Duration Estimates for Mitigation Alternatives

Estimates were developed for expected construction duration for the various geotechnical and structural mitigation alternatives. The type and method of construction was considered with the estimates. The construction duration estimates considered demolition, contractor mobilization, excavation, operation and drilling /grouting rate for rig and equipment needed for soil stabilization, protection of environment and nearby infrastructure, and restoration of concrete promenade, pavement and infrastructure following completion of the geotechnical mitigation work. Utility coordination and relocation including water, sewer, electrical, communications, drainage, traffic signal, ITS, and other roadway construction elements including temporary traffic control, sidewalk, driveways, curb ramps, landscaping, and striping. Business access is assumed to be maintained at all times. Generally, land-based construction along the San Francisco waterfront using drill rigs and cranes is expected to take less time than similar construction using barge-based equipment from the waterside.

Table 4-3: Construction Duration Estimates for Geotechnical Mitigation

	Construction Duration Estimates Geotechnical Mitigation		
Ground Mitigation Alternative	Maximum (days per 500 LF seawall)	Minimum (days per 500 LF seawall)	Average (days per 500 LF seawall)
G-1	320	290	305
G-1A	600	570	590
G-2	360	300	330
G-3	290	260	275
G-4	270	250	260
G-5	325	300	315
G-6	160	140	150
G-7	360	320	340

Table 4-4: Construction Duration Estimates for Structural Mitigation

	Construction Duration Estimates Structural Mitigation		
Structural Mitigation Alternative	Maximum (days per 500 LF seawall)	Minimum (days per 500 LF seawall)	Average (days per 500 LF seawall)
S-1	250	180	220
S-2	220	160	200
S-3	240	180	220
S-4	75	60	70
S-11	510	420	470
S-13	510	420	470
S-14	570	450	510
S-23	630	540	590
S-26	690	570	630
S-32	630	540	590

5. Economic Impact Study Results

5.1. Economic Impact Study

An impact study was performed to provide an estimate of economic impact under two earthquake scenarios in order to establish the economic risk for each seawall section associated with the seismic events.

The following revenue factors were considered in the study:

Revenue to the Port of San Francisco including leases, business activity and revenue, damage to commercial property, private housing and employment. The Port's properties generate approximately $2 billion in annual spending, property leases provide approximately $50 million in rent and provide $500 million in employee wages. Property lease revenue, business revenue and employee income costs are considered variable cost items that grow with time.

Estimated property damage and losses using bulkhead wharf structural damage plots for two earthquake scenarios, (M8.0 San Andreas – median estimate (approximately 225 year return period) and a larger earthquake with a 975 year return period.

- Disruption to tourism spending in San Francisco. The City of San Francisco receives annually approximately 18 million visitors, $11 billion spending and has a $3 billion payroll for approximately 87,000 related jobs. The tourism industry also generated $665 million in taxes for the City of San Francisco in 2014.
- Replacement cost of existing Port-owned infrastructure. Replacement costs are considered capital cost items.

5.2. Economic Damage Estimates

An estimate of the economic damage under two earthquake scenarios was performed in order to establish the economic risk for each seawall section associated with such events. The two earthquake scenarios are:

- Life safety (M8.0 San Andreas – median estimate) and collapse (975-year return period) earthquakes consisting of seismic inertial loading without soil lateral sliding. It is assumed this scenario will be addressed by <u>short-term</u> mitigation alternatives applied to the seawall and bulkhead wharf structures.
- Life safety (M8.0 San Andreas – median estimate) and collapse (975-year return period) earthquakes consisting of seismic inertial loading with soil lateral sliding. It is assumed this scenario will be addressed by <u>long-term</u> mitigation alternatives applied to the seawall and bulkhead wharf structures.

The economic value of various cost items deemed significant to this study were determined as follows:

- Replacement cost of existing Port infrastructure – a cost breakdown was provided by the Port for each Port property, subdivided into substructure and superstructure costs. Estimated replacement costs for the seawall structure itself were not provided by the Port but were estimated by the GHD-GTC JV team. The data was further delineated into landside, bulkhead wharf, and finger pier locations, based on the description/location of each item, for subsequent use in determining estimated economic damage associated with each seawall section.
- Lease revenue of existing Port infrastructure – the monthly and annual lease revenue from each Port property was developed and assigned to its associated seawall section. This data was subsequently used to estimate lost lease revenue to the Port associated with each seawall section.

- Business revenue of existing Port infrastructure - the annual business income to the Port or commercial tenants from each Port property was developed and assigned to its associated seawall section. This data was subsequently used to estimate lost business revenue to the Port and its tenants associated with each seawall section.
- Employee income from existing Port infrastructure - the annual employee income from each Port property was developed and assigned to its associated seawall section. This data was subsequently used to estimate lost employment income to the Port's and associated tenant's employees associated with each seawall section. Employee base salary was used, factored by 2.08 to cover overhead and benefit costs.

The replacement costs are considered capital cost items. The remaining lease revenue, business revenue and employee income losses are considered variable cost items that grow with time. This total economic value is tabulated for each seawall section on ***Table 5-1*** assuming time increments of zero, six months and one year for assessing maximum possible economic risk over time. The total economic risk for the entire Northern Seawall is $1.607 billion capital cost plus $2.131 billion per year variable cost. Expanding this risk beyond one year should include appropriate cost escalation.

Table 5-1: Port Asset Economic Risk Values by Seawall Section

MAXIMUM EXPOSED RISK								
Seawall Section	Property Damage Loss	Annual Rents to Port Loss	Business Loss	Employment Loss	Total Loss by Section Day 0	Total Loss by Section 1 Month	Total Loss by Section 6 Months	Total Loss by Section 1 Year
	($)	($/yr)	($/yr)	($/yr)	($)	($)	($)	($)
FW	$101,051,735	$18,371,293	$220,244,370	$179,997,073	$101,051,735	$135,936,130	$310,358,104	$519,664,473
B	$13,396,250	$5,206,170	$42,252,410	$31,770,201	$13,396,250	$19,998,649	$53,010,641	$92,625,032
A	$21,915,000	$788,457	$0	$7,169,670	$21,915,000	$22,578,177	$25,894,064	$29,873,128
1	$79,340,000	$4,632,776	$166,647,025	$167,305,423	$79,340,000	$107,555,435	$248,632,613	$417,925,225
2	$199,992,250	$3,273,885	$11,907,750	$83,088,766	$199,992,250	$208,181,450	$249,127,450	$298,262,651
3	$117,161,250	$3,627,030	$0	$161,122,820	$117,161,250	$130,890,404	$199,536,175	$281,911,100
4	$194,982,000	$1,610,149	$11,251,125	$8,583,246	$194,982,000	$196,769,043	$205,704,261	$216,426,521
5	$145,580,750	$4,338,227	$15,050,000	$166,129,462	$145,580,750	$161,040,557	$238,339,595	$331,098,440
6	$65,850,000	$2,998,620	$16,987,500	$104,390,631	$65,850,000	$76,214,729	$128,038,375	$190,226,750
7	$103,425,750	$2,819,462	$79,030,125	$216,147,432	$103,425,750	$128,258,835	$252,424,259	$401,422,768
8a	$65,028,500	$1,847,151	$20,476,537	$162,407,323	$65,028,500	$80,422,751	$157,394,006	$249,759,512
8b	$36,355,000	$292,697	$25,682,708	$6,360,080	$36,355,000	$39,049,624	$52,522,743	$68,690,486
8	$29,536,000	$0	$0	$0	$29,536,000	$29,536,000	$29,536,000	$29,536,000
9a	$11,841,250	$37,767	$457,313	$2,233,961	$11,841,250	$12,068,670	$13,205,770	$14,570,290
9b	$29,443,750	$306,093	$22,473,000	$18,227,587	$29,443,750	$32,860,973	$49,947,090	$70,450,430
9	$97,237,250	$2,259,558	$2,766,375	$0	$97,237,250	$97,656,078	$99,750,216	$102,263,183
10	$151,147,000	$1,768,933	$2,693,250	$4,187,293	$151,147,000	$151,867,790	$155,471,738	$159,796,476
11a	$1,700,000	$0	$0	$0	$1,700,000	$1,700,000	$1,700,000	$1,700,000
11	$3,530,000	$0	$7,875,000	$5,201,875	$3,530,000	$4,619,740	$10,068,438	$16,606,875
12	$110,455,750	$1,767,706	$4,214,125	$0	$110,455,750	$110,954,236	$113,446,665	$116,437,581
13	$8,300,000	$279,830	$0	$95,120,000	$8,300,000	$16,249,986	$55,999,915	$103,699,830
P46	$5,565,000	$4,862,109	$0	$0	$5,565,000	$5,970,176	$7,996,055	$10,427,109
CB	$13,890,000				$13,890,000	$13,890,000	$13,890,000	$13,890,000
TOTALS	$1,606,724,485	$61,087,912	$650,008,613	$1,419,442,843	$1,606,724,485	$1,784,269,432	$2,671,994,169	$3,737,263,852

For assessing economic risk for the two earthquake scenarios, the following was assumed:

- A seawall failure results in a 100 percent loss of the seawall structure and a partial loss of the bulkhead structure as a function of the number of bulkhead wharf spans affected by the failure. For short term failure, the failure is deemed to occur in the first bulkhead wharf bay only, either due to the first pile row failing or due to a failure at the wharf deck to seawall connection. The number of bulkhead wharf spans affected by failure is assumed to be one at bulkhead seawalls and at cut-off walls. Any adjoining finger piers are assumed to be damaged to a similar percentage to account for unknowns in this study but the variable economic losses attributed to a pier is assumed to be 100 percent since access to the pier will be lost until repairs are made.
- A bulkhead wharf failure results in a partial loss of the bulkhead structure as a function of the number of bulkhead wharf spans affected by the failure. For long term failure, the number of bulkhead wharf spans affected by failure is assumed to be those affected by soil lateral sliding plus the short term induced failures discussed above. Any adjoining finger piers are assumed to be damaged to a similar percentage to account for unknowns in this study and the variable economic losses attributed to a pier is assumed to be the same percentage since access to the viable portions of the pier may be made relatively quickly.

Economic Damage Due to Seismic Inertial Load Only – Short Term Mitigation Risk

The estimated economic risk that is addressed by short term mitigation alternatives is determined by estimating the percent of Port infrastructure that is expected to be damaged along with the associated percentage of variable economic risk for each seawall section. ***Table 5-2*** summarizes these economic risk values. The total economic risk for the entire Northern Seawall is $685 million capital cost plus $590 million per year variable cost.

Economic Damage Due to Soil Lateral Sliding Load Only – Long Term Mitigation Risk

The estimated economic risk that is addressed by long term mitigation alternatives is determined by estimating the percent of Port infrastructure that is expected to be damaged along with the associated percentage of variable economic risk for each seawall section. ***Table 5-3*** summarizes these economic risk values. The total economic risk for the entire Northern Seawall is $1.15 billion capital cost plus $2.01 billion per year variable cost.

Table 5-2: Port Asset Economic Risk Values by Seawall Section – Short Term (ST) Mitigation

TOTAL EXPOSED RISK - SEISMIC INERTIAL - ADDRESSED BY SHORT-TERM MITIGATION ALTERNATIVES									
Seawall Section	ST % Wharf Damage	Property Damage Loss	Annual Rents to Port Loss	Business Loss	Employment Loss	Total Loss by Section Day 0	Total Loss by Section 1 Month	Total Loss by Section 6 Months	Total Loss by Section 1 Year
		($)	($/yr)	($/yr)	($/yr)	($)	($)	($)	($)
FW	40%	$40,420,694	$7,348,517	$88,097,748	$71,998,829	$40,420,694	$54,374,452	$124,143,242	$207,865,789
B	25%	$3,349,063	$1,301,543	$10,563,103	$7,942,550	$3,349,063	$4,999,662	$13,252,660	$23,156,258
A	25%	$5,478,750	$197,114	$0	$1,792,418	$5,478,750	$5,644,544	$6,473,516	$7,468,282
1	25%	$19,835,000	$1,158,194	$41,661,756	$41,826,356	$19,835,000	$26,888,859	$62,158,153	$104,481,306
2	25%	$49,998,063	$818,471	$2,976,938	$20,772,191	$49,998,063	$52,045,363	$62,281,863	$74,565,663
3	25%	$29,290,313	$906,757	$0	$40,280,705	$29,290,313	$32,722,601	$49,884,044	$70,477,775
4	25%	$48,745,500	$402,537	$2,812,781	$2,145,812	$48,745,500	$49,192,261	$51,426,065	$54,106,630
5	25%	$36,395,188	$1,084,557	$3,762,500	$41,532,365	$36,395,188	$40,260,139	$59,584,899	$82,774,610
6	25%	$16,462,500	$749,655	$4,246,875	$26,097,658	$16,462,500	$19,053,682	$32,009,594	$47,556,688
7	25%	$25,856,438	$704,865	$19,757,531	$54,036,858	$25,856,438	$32,064,709	$63,106,065	$100,355,692
8a	15%	$9,754,275	$277,073	$3,071,481	$24,361,098	$9,754,275	$12,063,413	$23,609,101	$37,463,927
8b	15%	$5,453,250	$43,905	$3,852,406	$954,012	$5,453,250	$5,857,444	$7,878,411	$10,303,573
8	20%	$5,907,200	$0	$0	$0	$5,907,200	$5,907,200	$5,907,200	$5,907,200
9a	0%	$0	$0	$0	$0	$0	$0	$0	$0
9b	100%	$29,443,750	$306,093	$22,473,000	$18,227,587	$29,443,750	$32,860,973	$49,947,090	$70,450,430
9	100%	$97,237,250	$2,259,558	$2,766,375	$0	$97,237,250	$97,656,078	$99,750,216	$102,263,183
10	100%	$151,147,000	$1,768,933	$2,693,250	$4,187,293	$151,147,000	$151,867,790	$155,471,738	$159,796,476
11a	0%	$0	$0	$0	$0	$0	$0	$0	$0
11	0%	$0	$0	$0	$0	$0	$0	$0	$0
12	100%	$110,455,750	$1,767,706	$4,214,125	$0	$110,455,750	$110,954,236	$113,446,665	$116,437,581
13	0%	$0	$0	$0	$0	$0	$0	$0	$0
P46	0%	$0	$0	$0	$0	$0	$0	$0	$0
CB	0%	$0				$0	$0	$0	$0
TOTALS		$685,229,982	$21,095,478	$212,949,869	$356,155,732	$685,229,982	$734,413,405	$980,330,522	$1,275,431,063

Table 5-3: Port Asset Economic Risk Values by Seawall Section – Long Term (LT) Mitigation

TOTAL EXPOSED RISK - SEISMIC SOIL LATERAL SLIDING - ADDRESSED BY LONG-TERM MITIGATION ALTERNATIVES									
section	LT % wharf damage	property damage loss	annual rents to port loss	business loss	employment loss	total loss by section day 0	total loss by section 1 month	total loss by section 6 months	total loss by section 1 year
		($)	($/yr)	($/yr)	($/yr)	($)	($)	($)	($)
FW	40%	$80,841,388	$14,697,035	$220,244,370	$179,997,073	$80,841,388	$115,419,595	$288,310,628	$495,779,867
B	25%	$6,698,125	$5,206,170	$42,252,410	$31,770,201	$3,349,063	$4,999,662	$46,312,516	$85,926,907
A	25%	$10,957,500	$788,457	$0	$7,169,670	$5,478,750	$5,644,544	$14,936,564	$18,915,628
1	25%	$39,670,000	$4,632,776	$166,647,025	$167,305,423	$19,835,000	$26,888,859	$208,962,613	$378,255,225
2	25%	$99,996,125	$3,273,885	$11,907,750	$83,088,766	$49,998,063	$52,045,363	$149,131,325	$198,266,526
3	50%	$87,870,938	$3,627,030	$0	$161,122,820	$58,580,625	$65,445,202	$170,245,862	$252,620,787
4	50%	$146,236,500	$1,610,149	$11,251,125	$8,583,246	$97,491,000	$98,384,522	$156,958,761	$167,681,021
5	25%	$72,790,375	$4,338,227	$15,050,000	$166,129,462	$36,395,188	$40,260,139	$165,549,220	$258,308,065
6	50%	$49,387,500	$2,998,620	$16,987,500	$104,390,631	$32,925,000	$38,107,365	$111,575,875	$173,764,250
7	100%	$103,425,750	$2,819,462	$79,030,125	$216,147,432	$103,425,750	$128,258,835	$252,424,259	$401,422,768
8a	30%	$29,262,825	$1,847,151	$20,476,537	$162,407,323	$19,508,550	$24,126,825	$121,628,331	$213,993,837
8b	30%	$16,359,750	$292,697	$25,682,708	$6,360,080	$10,906,500	$11,714,887	$32,527,493	$48,695,236
8	40%	$17,721,600	$0	$0	$0	$11,814,400	$11,814,400	$17,721,600	$17,721,600
9a	0%	$0	$0	$0	$0	$0	$0	$0	$0
9b	100%	$29,443,750	$306,093	$22,473,000	$18,227,587	$29,443,750	$32,860,973	$49,947,090	$70,450,430
9	100%	$97,237,250	$2,259,558	$2,766,375	$0	$97,237,250	$97,656,078	$99,750,216	$102,263,183
10	100%	$151,147,000	$1,768,933	$2,693,250	$4,187,293	$151,147,000	$151,867,790	$155,471,738	$159,796,476
11a	0%	$0	$0	$0	$0	$0	$0	$0	$0
11	0%	$0	$0	$0	$0	$0	$0	$0	$0
12	100%	$110,455,750	$1,767,706	$4,214,125	$0	$110,455,750	$110,954,236	$113,446,665	$116,437,581
13	0%	$0	$0	$0	$0	$0	$0	$0	$0
P46	0%	$0	$0	$0	$0	$0	$0	$0	$0
CB	0%	$0				$0	$0	$0	$0
TOTALS		$1,149,502,126	$52,233,948	$641,676,300	$1,316,887,007	$1,149,502,126	$1,317,068,564	$2,154,900,757	$3,160,299,388

Seawall Economic Valuation

The existing seawall infrastructure is valued based on the following assumed replacement cost (present-day dollars):

- Existing timber piles at $5,000 per pile
- Existing timber lagging at $100 per cubic foot
- Existing concrete piles at $10,000 per pile
- Existing concrete bulkhead walls at $1,000 per cubic yard
- Existing concrete cutoff walls at $1,000 per cubic yard
- Existing seawall structure in the Fisherman's wharf area at $5,000 per lineal foot
- Existing seawall structure between the Fisherman's wharf area and Section 13 at $10,000 per lineal foot
- Existing seawall structure at Sections 13, P46 and China Basin at $15,000 per lineal foot

The impact study assumed $350/square foot for the bulkhead wharves and finger piers, $250/square foot for pier sheds and bulkhead buildings and $50/square foot for parking areas for replacement costs.

This section of the report summarizes the approach and methodology adopted in assessing the economic impacts of potential damage to the San Francisco seawall in the event of a major seismic event. It should be noted that this is summary level information specific to Port owned assets and ignores the broader implications that such an event would naturally have on the broader San Francisco and Bay Area economy.

5.3. Economic Vulnerability Assessment

Introduction

The GHD-GTC Joint Venture (JV) team assessed potential impacts of major seismic events on a portion of the San Francisco seawall. The waterfront area assessed was the portion of the seawall roughly from Aquatic Park to the AT&T Ball Park.

The objective of the economic impact analysis was confined to assessing the potential economic impacts of damage to the seawall, consisting of the bulkhead supported by the rock dike and adjacent bulkhead wharf structures. The scope was narrowly defined to measure the direct impacts that might be experienced from business interruption on each of the sections should they become inaccessible for a period of time. It was recognized that any seismic event would have broader economic consequences throughout the City, as well as the region, however, that analysis is being conducted by the Controller's Office of Economic Analysis using a nationally adopted model to measure the impacts of major catastrophic events. Therefore, the Port desired to focus solely on the potential impacts of Port owned and operated assets.

Overview

In assessing the information made available and gathered for this engagement the approach was to largely parallel the format of a more detailed HAZUS-MH 2.1 analysis modeling effort what will be undertaken subsequent to the present engagement. HAZUS is the standard nationally adopted framework for assessing the impacts of natural disasters that was developed subsequent to the destruction of the World Trade Center in New York in September of 2001, and is overseen by the Federal Emergency Management Agency (FEMA). It is a GIS based overlay to standard software that allows detailed assessments of physical damage, economic loss, social impacts, business interruption, and a variety of other consequences resulting from floods, hurricanes, seismic events, and other catastrophes.

Because HAZUS is a relatively new tool it is not yet widely utilized. The Port learned of its existence only during the current engagement and does not yet have the necessary internal resources to employ or effectively use the analytical tool. It was designed to be used at the community level with more than 50,000 inhabitants, for which San Francisco clearly qualifies. While it is customizable to specific sub-markets, the geographic dispersion of Port assets, as well as rather unique operating characteristics of some of these assets, will require more careful assessment of the HAZUS framework, and 'fine tuning' some of the underlying assumptions, in order to be fully applicable to the Port's needs.

Thus, the analysis which follows attempts to lay the groundwork for the subsequent HAZUS modeling, but it is clearly recognized that the results of the later analysis will be more detailed, and that some of the economic impacts shown in subsequent pages will be different than the conclusions from the more structured HAZUS approach.

Approach

The JV team obtained several important documents from the Port and from other sources that help to frame the analysis. The first Port document was detailed information on all of the tenants in Port facilities. While far more data than is needed, the file contains key metrics such as gross leasable square footage by tenant name, monthly fixed rent amounts, and where appropriate, percentage rent amounts. The data file obtained was for the calendar year 2015, and thus represents total rents received, therefore eliminating any need to interpolate monthly income which would be impacted by the seasonal usage pattern of some of the key assets. There are master leases for several larger assets that required a more careful assessment of the individual tenants and discussions with the leasing companies to obtain specific information. ***Table 5-4*** shows a sample of the information contained in the file. Within the study area there are almost 350 separate tenants, excluding the master leases. As will be clarified in subsequent discussions each of the tenants is assigned a seawall section number based on their location along the waterfront.

It should also be noted that there are exceptions to the tenant lease structure that impact any estimate of potential damages and impacts. Several of the larger tenants who made direct investment in Port assets as part of redevelopment efforts are governed by leases that allow recapture of that investment over time. As a consequence, some of the leases may appear to be below market or otherwise different what might be expected in similar businesses or land uses elsewhere. Since it is impossible to predict either future lease terms or timing of a potential seismic event, it is not credible to make projections of how these anomalies may impact the revenues to the Port other than to use current conditions. It should also be noted that there are tenants (mostly parking) for which no lease terms or rents are shown.

Table 5-4: Sample of Tenant Rental Income Data

Facility	Seawall Segme	Customer Name	Total Annualized Rent	Sq Ft.	Function Description
11	1	The Bay Institute Aquarium Foundatio	$ 390,147.00	-	Recreation/Visitor Attraction
1390	1	Pier 39 Limited Partnership	$ 3,646,629.00	1,236,852	Retail
3130	1	Embarcadero Triangle Associates	$ 596,000.04	47,277	Mixed Use
			$ 4,632,776.04	1,284,129	
1330	2	Pacific Bell Wireless, LLC	$ 55,073.40	416	Utilities
1330	2	Priority Parking-CA	$ 24,265.00	-	Parking
1330	2	Pier 39 Limited Partnership	$ 56,905.20	4,920	Storage
1330	2	Andre-Boudin Bakeries, Inc.	$ 14,760.00	1,230	Restaurant Support
1330	2	MetroPCS California, LLC	$ 81,648.00	-	Utilities
1330	2	Art & Glass, Inc.	$ 18,450.00	1,230	Storage
1330	2	Simco Restaurants, Inc.	$ 14,612.40	1,230	Storage
1330	2	Osprey Seafood of California, Inc.	$ 38,613.60	3,460	Fish Processing
1330	2	Osprey Seafood of California, Inc.	$ 3,118.80	230	Office
1330	2	Isis Imports Ltd.	$ 106,486.80	9,055	Storage
1330	2	Alcatraz Enterprises, Inc.	$ 14,612.40	1,230	Storage
1330	2	Bobier, Richard A.	$ 31,291.20	2,460	Storage
1330	2	E.A.N. Corporation	$ 60,811.20	4,920	Storage
1330	2	E.A.N. Corporation	$ 75,074.64	6,074	Storage
1330	2	San Francisco Pier 33, LLC	$ 292,523.00	4,515	Retail
1330	2	San Francisco Pier 33, LLC	$ 270,900.00	9,030	Office
1330	2	M.F.M. Seafood, Inc.	$ 61,656.00	5,138	Fish Processing
1330	2	M.F.M. Seafood, Inc.	$ 5,029.20	381	Office
1330	2	M.F.M. Seafood, Inc.	$ 29,724.00	2,477	Fish Processing
1330	2	M.F.M. Seafood, Inc.	$ 14,652.00	1,221	Fish Processing
1330	2	M.F.M. Seafood, Inc.	$ 14,400.00	1,200	Fish Processing
1330	2	SFCC Public Utilities Commission	$ 43,756.80	3,440	Storage
1330	2	Seafood Suppliers, Inc	$ 63,644.16	6,100	Fish Processing
1330	2	Seafood Suppliers, Inc	$ 7,253.40	2,370	Fish Processing
1330	2	P & T Flannery Seafoods, Inc.	$ 1,356.00	-	Fish Processing
1335	2	RGN Corporation	$ 157,691.00	6,772	Restaurant
1335	2	Northern California World Trade Cent	$ 42,486.00	970	Office
1351	2	Barulich, Jerome M.	$ 12,343.20	556	Office
1351	2	Barulich, Jerome M.	$ 3,065.52	241	Office Storage
1351	2	Pier 39 Limited Partnership	$ 7,581.60	702	Storage
1351	2	Pier 39 Limited Partnership	$ 7,009.20	649	Storage
1351	2	Pier 39 Limited Partnership	$ 5,886.00	545	Storage
1351	2	California Foundation on the Environn	$ 68,840.64	1,804	Office
1351	2	California Foundation on the Environn	$ 41,899.68	1,098	Office
1351	2	Bay.Org	$ 74,514.00	2,258	Office
1351	2	Bay.Org	$ 20,304.00	1,128	Office Storage
1351	2	Herman, Steven H.	$ 52,739.88	1,553	Office
3140	2	Central Parking System	$ 627,276.00	31,115	Parking
3150	2	JPPF Waterfront Plaza, L.P.	$ 751,500.00	54,540	Mixed Use
4015	2	Hillstone Restaurant Group	$ 130.90	-	Utilities
			$ 3,273,884.82	**176,258**	

The second file obtained contains descriptions of the physical assets and all of the systems contained in each building. This file is used for long term capital planning and contains the year of construction for the underlying pier structure and the physical buildings contained thereon, as well as the expected life of the asset. Importantly, it shows the gross square footage of each building and the underlying pier structure. Thus, it is possible to assign replacement cost values to each asset based on type of construction, as well as to treat the pier structures as a separate entity as required by HAZUS. ***Table 5-5*** shows a sample extracted from this file. The reader will note the type of building classifications assigned, which enables summery level estimates of replacement costs in each seawall section based on the type of construction. For instance, the sheds on the pier are listed as 'simple'. Those that have been renovated, such as Pier 3, are listed as 'basic'.

Table 5-5: Sample Building Information

BldgNo	BuildingName	BuildingID	Year Built	GSF	TypeName	SubSystem	Floor	Life	Sum of 10 Year Total
1245	Pier 24 1/2 -Bulkhead/Shed Building	1000	1936	28,000	SIMPLE	f.2. Electrical Rough-in	1	70	62
1245	Pier 24 1/2 -Bulkhead/Shed Building	1000	1936	28,000	SIMPLE	i.1. Fire Protection Systems	1	40	49
1245	Pier 24 1/2 -Bulkhead/Shed Building	1000	1936	28,000	SIMPLE	i.2. Fire Detection Systems	1	20	61
1245	Pier 24 1/2 -Bulkhead/Shed Building Total								589
1245 Total									4,893
1260	Pier 26	770	1912	156,589	Piers	Substructure	1	75	14,716
1260	Pier 26 Total								14,716
1260	Pier 26 - Bulkhead/Shed	956	1912	128,834	SIMPLE	b.2. Building Exteriors (Soft)	1	20	494
1260	Pier 26 - Bulkhead/Shed	956	1912	128,834	SIMPLE	d.1. HVAC - Equipment	1	25	218
1260	Pier 26 - Bulkhead/Shed	956	1912	128,834	SIMPLE	d.2. HVAC - Controls	1	20	99
1260	Pier 26 - Bulkhead/Shed	956	1912	128,834	SIMPLE	e.1. HVAC - Distribution Systems	1	50	816
1260	Pier 26 - Bulkhead/Shed	956	1912	128,834	SIMPLE	f.1. Electrical Equipment	1	30	468
1260	Pier 26 - Bulkhead/Shed	956	1912	128,834	SIMPLE	f.2. Electrical Rough-in	1	70	284
1260	Pier 26 - Bulkhead/Shed	956	1912	128,834	SIMPLE	g.1. Plumbing Fixtures	1	25	112
1260	Pier 26 - Bulkhead/Shed	956	1912	128,834	SIMPLE	g.2. Plumbing Rough-in	1	50	335
1260	Pier 26 - Bulkhead/Shed	956	1912	128,834	SIMPLE	l.2. Interior Finishes	1	15	321
1260	Pier 26 - Bulkhead/Shed Total								3,147
1260 Total									17,862
1265	Pier 26 1/2	771	1927	31,400	Piers	Substructure	1	75	3,243
1265	Pier 26 1/2 Total								3,243
1265	Pier 26.5 - Bulkhead	998	1927	27,300	BASIC	a.3. Roofing - Mmbrn,Built-up,Sh	1	25	346
1265	Pier 26.5 - Bulkhead	998	1927	27,300	BASIC	f.1. Electrical Equipment	1	30	496
1265	Pier 26.5 - Bulkhead	998	1927	27,300	BASIC	f.2. Electrical Rough-in	1	70	867
1265	Pier 26.5 - Bulkhead	998	1927	27,300	BASIC	g.1. Plumbing Fixtures	1	25	213
1265	Pier 26.5 - Bulkhead	998	1927	27,300	BASIC	g.2. Plumbing Rough-in	1	50	616
1265	Pier 26.5 - Bulkhead	998	1927	27,300	BASIC	l.2. Interior Finishes	1	15	453
1265	Pier 26.5 - Bulkhead	998	1927	27,300	BASIC	NEW Fire Detection	1	(blank)	0
1265	Pier 26.5 - Bulkhead Total								2,991
1265 Total									6,234
1270	Pier 27	772	1907	420,690	Piers	Fenders	1	12	426
1270	Pier 27	772	1907	420,690	Piers	Substructure	1	75	494
1270	Pier 27 Total								920
1270	Pier 27 - Office Annex	928	1909	3,552	SMALL	m.1. All Renewal - SMALL 1	1	25	536
1270	Pier 27 - Office Annex Total								536
1270 Total									1,456
1280	Pier 28	773	1912	104,896	Piers	Substructure	1	75	9,451
1280	Pier 28 Total								9,451
1280	Pier 28 - Bulkhead/Shed Building	1042	1912	77,088	SIMPLE	a.3. Roofing - Mmbrn,Built-up,Sh	1	25	977
1280	Pier 28 - Bulkhead/Shed Building	1042	1912	77,088	SIMPLE	b.1. Building Exteriors (Hard)	1	50	258
1280	Pier 28 - Bulkhead/Shed Building	1042	1912	77,088	SIMPLE	b.2. Building Exteriors (Soft)	1	20	148
1280	Pier 28 - Bulkhead/Shed Building	1042	1912	77,088	SIMPLE	d.1. HVAC - Equipment	1	25	130
1280	Pier 28 - Bulkhead/Shed Building	1042	1912	77,088	SIMPLE	d.2. HVAC - Controls	1	20	59
1280	Pier 28 - Bulkhead/Shed Building	1042	1912	77,088	SIMPLE	f.1. Electrical Equipment	1	30	280
1280	Pier 28 - Bulkhead/Shed Building	1042	1912	77,088	SIMPLE	f.2. Electrical Rough-in	1	70	170
1280	Pier 28 - Bulkhead/Shed Building	1042	1912	77,088	SIMPLE	g.1. Plumbing Fixtures	1	25	67
1280	Pier 28 - Bulkhead/Shed Building	1042	1912	77,088	SIMPLE	g.2. Plumbing Rough-in	1	50	201
1280	Pier 28 - Bulkhead/Shed Building	1042	1912	77,088	SIMPLE	l.2. Interior Finishes	1	15	192
1280	Pier 28 - Bulkhead/Shed Building Total								2,482
1280 Total									11,934
1285	Pier 28 1/2	774	1912	4,738	Piers	Substructure	1	75	644
1285	Pier 28 1/2 Total								644
1285	Pier 28 1/2 - Hidive Restaurant	898	1912	1,307	SMALL	m.1. All Renewal - SMALL 1	1	25	197
1285	Pier 28 1/2 - Hidive Restaurant Total								197
1285 Total									841
1290	Pier 29	775	1916	225,374	Piers	Substructure	1	75	15,742
1290	Pier 29 Total								15,742
1290	Pier 29 - *Bulkhead/Shed Building	947	1917	155,279	SIMPLE	a.3. Roofing - Mmbrn,Built-up,Sh	1	25	1,968
1290	Pier 29 - *Bulkhead/Shed Building	947	1917	155,279	SIMPLE	f.1. Electrical Equipment	1	30	564
1290	Pier 29 - *Bulkhead/Shed Building	947	1917	155,279	SIMPLE	l.2. Interior Finishes	1	15	387
1290	Pier 29 - *Bulkhead/Shed Building Total								2,918
1290 Total									18,660
1295	Pier 29 1/2 - Bulkhead Building	1043	1917	52,650	SIMPLE	a.3. Roofing - Mmbrn,Built-up,Sh	1	25	667
1295	Pier 29 1/2 - Bulkhead Building	1043	1917	52,650	SIMPLE	b.2. Building Exteriors (Soft)	1	20	202
1295	Pier 29 1/2 - Bulkhead Building	1043	1917	52,650	SIMPLE	f.1. Electrical Equipment	1	30	191
1295	Pier 29 1/2 - Bulkhead Building	1043	1917	52,650	SIMPLE	g.1. Plumbing Fixtures	1	25	46
1295	Pier 29 1/2 - Bulkhead Building	1043	1917	52,650	SIMPLE	g.2. Plumbing Rough-in	1	50	137
1295	Pier 29 1/2 - Bulkhead Building	1043	1917	52,650	SIMPLE	i.1. Fire Protection Systems	1	40	91
1295	Pier 29 1/2 - Bulkhead Building	1043	1917	52,650	SIMPLE	l.2. Interior Finishes	1	15	131
1295	Pier 29 1/2 - Bulkhead Building Total								1,465
1295 Total									1,465
1310	Pier 31	781	1917	128,785	Piers	Substructure	1	75	11,146
1310	Pier 31 Total								11,146

A third file, critical to accurately listing the assets contained in each of the seawall sections provides maps with a unique four-digit identifier for each parcel or pier. Thus, it is possible to compare the location of each tenant to the appropriate map and allocate it to the proper seawall section. ***Figure 5-1***shows one of the maps for the area from Pier 9 to Pier 35.

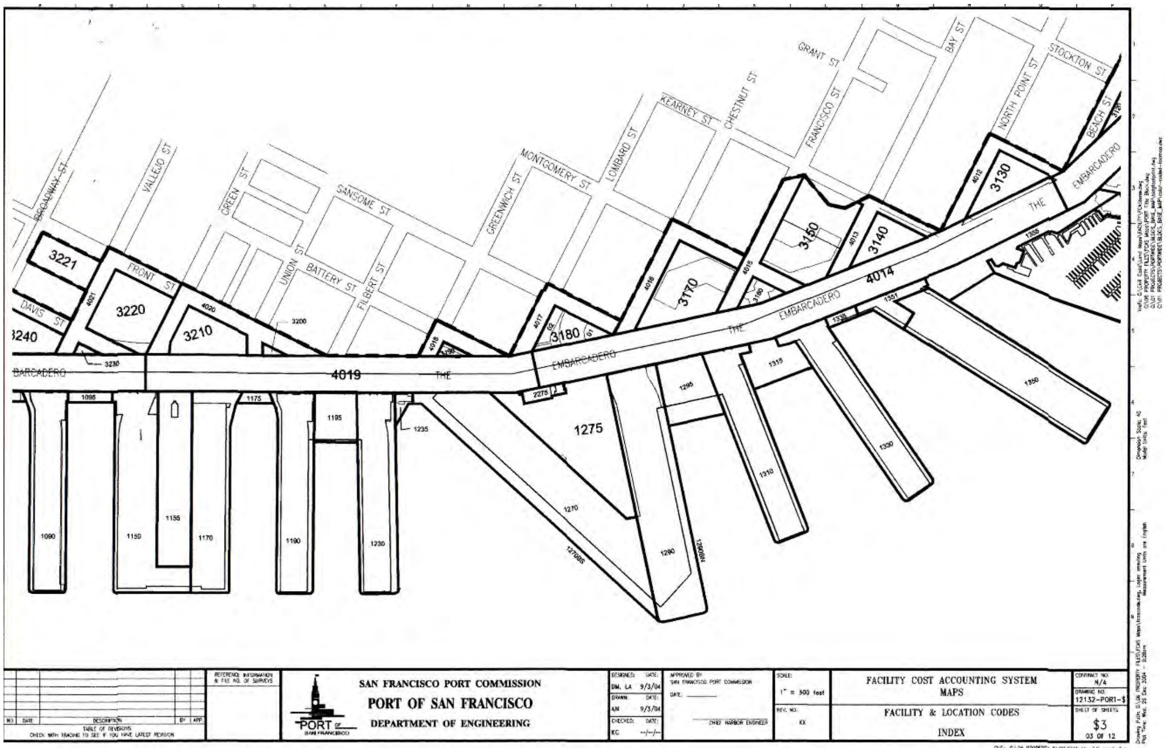

Figure 5-1: Example of Numeric Designations for Port Owned Properties

A fourth file provides a cross check on the above because it provides the identity of each tenant and the detailed characteristics of the lease, i.e. total leased area, size of the building footprint, associated deck space, etc. This is also important to distinguishing between, for instance, a tenant who may occupy a space that is mostly located on a pier, but may also have an occupied space on the seawall. ***Figure 5-2*** shows a portion of one of the maps that displays information for the Waterfront Restaurant, adjacent Exploratorium, and related parking.

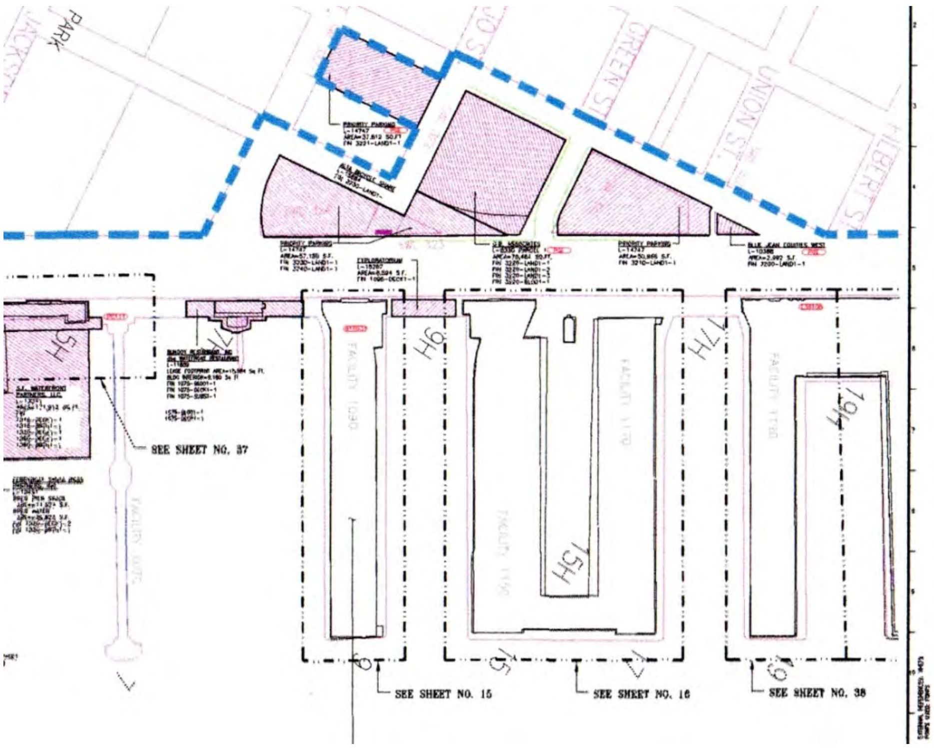

Figure 5-2: Detailed Lease Information on Port Properties

The Port utilizes a unique four-digit numerical identifier. Assets whose numbers begin with a '1' are categorized as piers. Those whose numbers beginning with a "2" are tenants who are on the seawall fronting onto the Embarcadero. Those beginning with a "3" are assets on the opposite side of the Embarcadero, and are either buildings or parking lots. Assets starting with a "4" are tenants/buildings fronting on one of the adjacent streets, but not on the Embarcadero. Numbers that start with the number "5" relate to water assets such as the marina areas adjacent to Pier 39 and South Beach Harbor, as well as minor leases in the Fisherman's Wharf area. There are additional classifications, but none of those assets are within the study area. Thus, for example Pier 3 carries a unique identifier of 1030. Part of the Pier 23 restaurant is identified as 1235 (pier 23 and a half). The Fog City Diner bears the identifier of 3190, also shared with the western part of the Levi office complex. The Raintree Forest Café bears the identifier of 4007.

The various structures and tenants do not align completely with the breaks in the seawall. The major impact is in quantifying the potential impacts related to the Ferry Building, wherein the seawall divides the building into an approximate 44 percent and 56 percent mix. The other seawall sections generally align with piers and adjacent structures. For the analysis we have chosen to group land based assets with the seawall section which fronts directly across the Embarcadero from the major pier feature. Thus, the entirety of Pier 27 is located in Section 3. All of Pier 9 has been allocated to Section 6, and both piers 38 and 40 belong in Section 12. Similar small changes have been made in our definition of the other sections, and should be compared to the base mapping contained and explained in the GHD-GTC JV documentation. It is the Team's opinion that these small adjustments will have only a minor impact on the future HAZUS modeling.

Sub-Analyses

From the above classifications an attempt was made to refine the information as possible impacts to guide the future HAZUS analysis. The analyses concentrated on gross square footage of the built environment in each seawall section, the specific land uses in each as shown in the tenant lease, gross leasable area (GLA), the number of employees that may be impacted in each area, and the likely salary structure that might be impacted by a major break in any seawall section. On a qualitative basis, because so much of the Embarcadero enjoys large public areas, comments were also provided about the likely occupancy of key gathering spaces in the study areas.

Physical Damage Assessment

As noted earlier, Port documents provided gross square footage of the physical spaces in the study area, to include the physical pier structures. These were broken down further by the type of construction, using the 'simple' designation to reflect the basic shed construction, and 'basic' to reflect the more complex and typical structures found at the Ferry Building and Pier 39. 'Parking' refers to surface lots, and leased parking within some of the shed buildings. 'Pier' refers to the substructures themselves. ***Table 5-6*** shows an illustration of how the information was aggregated using Sections 1 and 2 as examples. In this example it should be noted that the GLA of Pier 39 is much larger than the built environment (including the marina uses), but the physical structures are much smaller. In this example the parking garage is also included in 'basic' construction because of the multi-deck construction.

Table 5-7 shows the summary of gross square footage by type in each of the seawall sections differentiated by 'pier', which is the underlying substructure, and 'improvements' by type. It will be noted that one of the sections (11A) has no physical improvements and Section 10 has only the physical pier, covered by surface parking.

Table 5-8 summarizes the replacement costs for the physical assets based upon assumed current construction costs. Intuitively the vertical replacement costs for 'simple' and 'basic' building types should be different. However, these estimates are based on a Port survey of their assets in early 2015 which applied a summary $250 per square foot of space to all structures. The piers were assigned a higher construction costs and a relatively modest cost was applied to surface parking. Intuitively, the ball park (Section 46) may require an upward adjustment.

Table 5-6: Example of Classification By Land Use

				Gross Leasable Square Feet			
Facility	Seawall Segme	Sq Ft.	Function Description	Pier	Parking	Shed	Basic
11	1	-	Recreation/Visitor Attraction				62,930
1390	1	1,236,852	Retail				261,972
3130	1	47,277	Mixed Use				287,500
		1,284,129		241,449	-	-	612,402
1330	2	416	Utilities			416	
1330	2	-	Parking		-		
1330	2	4,920	Storage			4,920	
1330	2	1,230	Restaurant Support			1,230	
1330	2	-	Utilities			-	
1330	2	1,230	Storage			1,230	
1330	2	1,230	Storage			1,230	
1330	2	3,460	Fish Processing			3,460	
1330	2	230	Office			230	
1330	2	9,055	Storage			9,055	
1330	2	1,230	Storage			1,230	
1330	2	2,460	Storage			2,460	
1330	2	4,920	Storage			4,920	
1330	2	6,074	Storage			6,074	
1330	2	4,515	Retail			4,515	
1330	2	9,030	Office			9,030	
1330	2	5,138	Fish Processing			5,138	
1330	2	381	Office			381	
1330	2	2,477	Fish Processing			2,477	
1330	2	1,221	Fish Processing			1,221	
1330	2	1,200	Fish Processing			1,200	
1330	2	3,440	Storage			3,440	
1330	2	6,100	Fish Processing			6,100	
1330	2	2,370	Fish Processing			2,370	
1330	2	-	Fish Processing			-	
1335	2	6,772	Restaurant				6,772
1335	2	970	Office				970
1351	2	556	Office				556
1351	2	241	Office Storage				241
1351	2	702	Storage				702
1351	2	649	Storage				649
1351	2	545	Storage				545
1351	2	1,804	Office				1,804
1351	2	1,098	Office				1,098
1351	2	2,258	Office				2,258
1351	2	1,128	Office Storage				1,128
1351	2	1,553	Office				1,553
3140	2	31,115	Parking		31,115		
3150	2	54,540	Mixed Use				54,540
4015	2	-	Utilities				-
		176,258		136,810	**31,115**	**72,327**	**72,816**

Table 5-7: Gross Square Footage of Space by Seawall Section

SEAWALL SEGMENT #	Description		Pier Substructure	Gross Leasable Square Footage Parking	Shed	"Basic"
FW	Hyde Street to Jones					
		Pier	366,785			
		Improvements		0	293,337	217,329
		Marine Leases				
B	Jones to Powell					
		Pier	0			
		Improvements		74,622	0	36,108
A	Powell to Stockton					
		Pier	67,835			
		Improvements		47,277	0	14,793
1	Stockton to Kearny					
		Pier	241,449			
		Improvements				612,402
		Marina Leases				
2	Kearny to Pier 31 and a half					
		Pier	136,810			
		Improvements		0	112,840	161,390
3	Pier 31 and a Half inclusive of Pier 27					
		Pier	813,398			
		Improvements		0	657,664	20,130
4	Pier 23 and a half to include Pier 19					
		Pier	139,147			
		Improvements		0	104,942	13,252
5	Pier 17 inclusive of Pier 9					
		Pier	447,267			
		Improvements		121,375	256,468	207,430
6	Pier 7 and a half and Pier 7					
		Pier	137,950			
		Improvements		0	0	134,711
7	Pier 3 and Pier 1 to Ferry Plaza edge					
		Pier	253,678			
		Improvements		0	0	192,057
8A	60% of Ferry Building and Ferry Terminals					
		Pier	166,635			
		Improvements		0	0	153,189
8B	40% of Ferry Building, Sinbads, and Pedestrian Pier					
		Pier	54,040			
		Improvements		0	0	143,476
9A	Pier 14 to Folsom Street					
		Pier	0			
		Improvements		0	0	0
9B	Folsom to Harrison Street					
		Pier	0			
		Improvements		0	0	18,000
9	Pier 24 and a half to Bryant Street					
		Pier	297,623			
		Improvements		0	205,922	27,300
10	Pier s 30 and 32 inclusive					
		Pier	542,657			
		Improvements		101,335	0	0
11A	NA					
11	Brannan St , Brannon Street Wharf, and Delancy Street (Parcel 3310)					
		Pier	0			
		Improvements		0	0	336,700
12	Parcel 3320, Piers 38 and 40					
		Pier	304,774			
		Improvements		0	162,763	451,443
		Marina Leases				
13	South Beach Harbor and Parcels 3340 to 3361					
		Pier	0			
		Embarcadero		0	0	33,367
46	Ball Park					
		Pier	0			
		Improvements		0	0	544,858
	Total					
		Pier	**3,970,048**			
		Parking		**344,609**		
		Shed			**1,793,936**	
		Basic				**3,317,935**

Table 5-8: Replacement Cost Estimates for Physical Structures

SEAWALL SEGMENT #	Description	Replacement Cost ($000) Pier	Parking	Shed	Basic
	Replacement Value/Sq Ft.				
	Pier	**$ 350.00**			
	Improvements		**$ 50.00**	**$ 250.00**	**$ 250.00**
FW	Hyde Street to Jones				
	Pier	$ 128,375			
	Improvements		$ 7,151	$ 57,939	$ 153,101
B	Jones to Powell				
	Pier	$ -			
	Improvements		$ 3,731	$ -	$ -
A	Powell to Stockton				
	Pier	$ 23,742			
	Improvements		$ 2,364	$ -	$ -
1	Stockton to Kearny				
	Pier	$ 84,507			
	Improvements		$ -	$ -	$ 153,101
2	Kearny to Pier 31 and a half				
	Pier	$ 47,884			
	Improvements		$ 1,556	$ 18,082	$ 18,204
3	Pier 31 and a Half inclusive of Pier 27				
	Pier	$ 284,689			
	Improvements		$ -	$105,788	$ 11,750
4	Pier 23 and a half to include Pier 19				
	Pier	$ 48,701			
	Improvements		$ -	$ 2,060	$ 2,500
5	Pier 17 inclusive of Pier 9				
	Pier	$ 156,543			
	Improvements		$ 7,564	$ 50,630	$ 158,586
6	Pier 7 and a half and Pier 7				
	Pier	$ 48,283			
	Improvements		$ 63	$ 7,075	$ 23,470
7	Pier 3 and Pier 1 to Ferry Plaza edge				
	Pier	$ 88,787			
	Improvements		$ -	$ -	$ 31,923
8A	60% of Ferry Building and Ferry Terminals				
	Pier	$ 58,322			
	Improvements		$ 178	$ -	$ 37,480
8B	40% of Ferry Building, Sinbads, and Pedestrian Pier				
	Pier	$ 18,914			
	Improvements		$ 300	$ -	$ 2,132
9A	Pier 14 to Folsom Ftreet				
	Pier	$ -			
	Improvements		$ 5	$ 8,123	$ 4,994
9B	Folsom to Harrison Street				
	Pier	$ -			
	Improvements		$ 3,576	$ -	$ 9,367
9	Pier 24 and a half to Bryant Street				
	Pier	$ 104,168			
	Improvements		$ 213	$ 15,048	$ 11,129
10	Pier s 30 and 32 inclusive				
	Pier	$ 189,930			
	Improvements		$ 5,074	$ 497	$ 599
11A	NA				
11	Brannan St , Brannon Street Wharf, and Delancy Street (Parcel 3310)				
	Pier	$ -			
	Improvements		$ -	$ -	$ -
12	Parcel 3320, Piers 38 and 40				
	Pier	$ 106,671			
	Improvements		$ -	$ 71,190	$ 120,505
13	South Beach Harbor and Parcels 3340 to 3361				
	Pier	$ -			
	Embarcadero		$ 1,213	$ -	$ 51,531
46	Ball Park				
	Pier	$ -			
	Improvements		$ 29,322	$ -	$ 150,040
	Total ($000)				
	Pier	**$ 1,389,517**			
	Improvements		**$ 62,309**	**$336,431**	**$ 940,410**

Summary of Assets by Building Land Use

The physical assets were further classified by type of land use in order to estimate other inputs to the economic modeling exercise. The classification was accomplished in conjunction with personal interviews with major tenants and a physical inspection of each of the piers. Information was utilized also from published resources and through examination of the City of San Francisco's Property Information Map, particularly in estimating residential square footage. Since the GLA for many tenants was used it may not align directly with the gross square footage (GSF) of individual spaces, but it is a reasonable approximation of use, particularly in evaluating employee levels, etc. ***Table 5-9*** summarizes land use by type for each of the seawall sections. Pier 39 provided summary information on square footage of food and beverage spaces defined as full service, convenience food, or fast food. These provided good approximations for both employment levels and spending volumes. The same distinction was applied to the Ferry Building based on personal inspections.

Table 5-9: Land Use by Type of Occupant

SEAWALL SEGMENT #	Description	Usage (Sq Ft)										
		Residential	Wholesale	Mixed Use	Office	Retail	Food & Bev	Parking	Storage	Public Attract	Marine Support	Public Use
FW	Hyde Street to Jones											
	Improvements	-	175,963	-	6,615	43,900	158,702	143,024	32,656	63,524	15,158	2,809
B	Jones to Powell											
	Improvements	-	4,174	-	-	33	37,530	71,512	-	23,629	-	-
A	Powell to Stockton											
	Improvements	-	-	-	-	-	-	-	-	60,300	-	-
1	Stockton to Kearny											
	Improvements	-	-	47,277	47,277	76,952	83,149	-	-	-	-	-
2	Kearny to Pier 31 and a half											
	Improvements	-	23,196	54,540	17,880	4,515	6,772	31,115	39,054	-	-	-
3	Pier 31 and a Half inclusive of Pier 27											
	Improvements	-	-	-	47,001	-	-	-	1,757	354,360	457,312	-
4	Pier 23 and a half to include Pier 19											
	Improvements	-	981	-	-	-	10,001	-	7,786	-	-	44
5	Pier 17 inclusive of Pier 9											
	Improvements	-	42,535	-	78,400	-	-	151,277	2,484	555,942	42,386	-
6	Pier 7 and a half and Pier 7											
	Improvements	-	4,818	1,705	74,626	-	15,100	1,267	21,014	9,600	42,511	-
7	Pier 3 and Pier 1 to Ferry Plaza edge											
	Improvements	-	-	-	127,692	-	70,249	-	-	218,000	-	-
8A	60% of Ferry Building and Ferry Terminals											
	Improvements	-	-	-	115,262	-	34,659	3,554	-	101,347	-	-
8B	40% of Ferry Building, Sinbads, and Pedestrian Pier											
	Improvements	-	-	-	-	-	8,528	6,000	-	-	-	-
9A	Pier 14 to Folsom Street											
	Improvements	-	9,207	-	-	-	407	1,282	1,395	-	-	13,689
9B	Folsom to Harrison Street											
	Improvements	-	-	-	-	-	19,976	90	27,311	-	-	87,137
9	Pier 24 and a half to Bryant Street											
	Improvements	-	-	-	41,570	-	2,459	4,265	59,688	-	-	3,086
10	Pier s 30 and 32 inclusive											
	Improvements	-	-	-	1,858	-	2,394	101,471	128	-	-	-
11A	NA											
11	Brannan St , Brannon Street Wharf, and Delancy Street (Parcel 3310)											
	Improvements	203,550	-	-	-	-	-	-	-	-	-	-
12	Parcel 3320, Piers 38 and 40											
	Improvements	267,493	-	475,557	74,231	155	3,615	-	3,652	-	283,800	-
13	South Beach Harbor and Parcels 3340 to 3361											
	Embarcadero	-	-	-	30,167	-	-	-	-	-	-	174,705
46	Ball Park											
	Improvements	-	-	-	-	-	-	586,447	-	560,993	-	55,303
	Total Improvements	**471,043**	**260,873**	**579,079**	**662,579**	**125,554**	**453,541**	**1,101,304**	**196,925**	**1,947,695**	**841,167**	**336,773**

Summary of Spending Impacts

Using the square footage estimates by type of land use it is possible to assign some level of impact on spending that may accrue in the instance of a seismic event. These estimates assume a full year of business interruption, but are calculated only on those land uses that are active retail and food and beverage venues. Office users would also be impacted but without detailed information on type of tenant it is impossible to estimate business interruption impacts. Warehousing and storage space is used primarily in support of the retail and food and beverage uses and therefore have little measurable direct impact. So too, parking venues would be impacted with the reduced visitor traffic for the duration of repair/renovation, but without information on overall utilization and actual number of spaces it is difficult to estimate economic loss. Major venues such as the ballpark and Exploratorium would also be impacted but it is believed quantifying potential impacts for these facilities is best left to the HAZUS modeling process.

Thus, ***Table 5-10*** concentrates solely on the selected land uses based on information provided by Pier 39 and the Ferry Building, and shows the estimated loss of gross spending along the seawall over the course of a year. This is different from the direct economic loss to merchants. For instance, Section 1, which is Pier 39, may have in excess of $150 million loss (gross) over the course of the year, however internal calculations by Pier 39 estimate loss of function costs at approximately $30 million over a similar time frame.

Table 5-10: Potential Loss of Spending (Selected Land Uses) for a One Year Time Frame ($000)

SEAWALL SEGMENT #	Description	Annual Spending / sq. ft. $ 950 Retail	$ 1,125 Food & Bev
FW	Hyde Street to Jones	$ 41,705	$ 178,540
B	Jones to Powell	$ 31	$ 42,221
A	Powell to Stockton	$ -	$ -
1	Stockton to Kearny	$ 73,104	$ 93,543
2	Kearny to Pier 31 and a half	$ 4,289	$ 7,619
3	Pier 31 and a Half inclusive of Pier 27	$ -	$ -
4	Pier 23 and a half to include Pier 19	$ -	$ 11,251
5	Pier 17 inclusive of Pier 9 (Estimated Square footage)	$ 3,800	$ 11,250
6	Pier 7 and a half and Pier 7	$ -	$ 16,988
7	Pier 3 and Pier 1 to Ferry Plaza edge	$ -	$ 79,030
8A	56% of Ferry Building and Ferry Terminals	$ 7,375	$ 13,101
8B	44% of Ferry Building, Sinbads, and Pedestrian Pier	$ 5,795	$ 19,888
9A	Pier 14 to Folsom Ftreet	$ -	$ 457
9B	Folsom to Harrison Street	$ -	$ 22,473
9	Pier 24 and a half to Bryant Street	$ -	$ 2,766
10	Pier s 30 and 32 inclusive	$ -	$ 2,693
11A	NA	$ -	$ -
11	Brannan St , Brannon Street Wharf, and Delancy Street	$ -	$ 7,875
12	Parcel 3320, Piers 38 and 40	$ 147	$ 4,067
13	South Beach Harbor and Parcels 3340 to 3361	$ -	$ -
46	Ball Park (NA. Included in Master Lease)	$ -	$ -
	Total Spending ($000)	**$ 136,247**	**$ 513,762**
	Grand Total	**650,009**	

Employment Impacts

Table 5-11 is intended to reconcile the estimated land uses by type with estimates of employment. Only Pier 39 was able to provide reasonable estimates of employment by type. These were used as benchmarks against published estimates of employees per square foot of building type sourced from the Institute of Transportation Engineers in comparison with the U.S. Department of Energy. Variations obviously exist, and the figures used were based on comparisons and professional judgement. The final HAZUS model may have alternative values, but the figures used in ***Table 5-11*** are believed reasonable. As shown, the figures range from 120 square feet per employee for food and beverage to 780 square feet per employee for 'wholesale' which we have interpreted to be the use for the storage/warehousing space largely contained in most of the sheds on the piers.

Table 5-11: Indicated Numbers of Employees by Seawall Section by Land Use

SEAWALL SEGMENT #	Description	Average Square Feet of Space Per Employee									
		780	200	220	560	120	23,560	1,200	1,000	1,000	2,000
		Wholesale	Mixed Use	Office	Retail	Food & Bev	Parking	Storage	Attractions	Marine Support	Public Use
FW	Hyde Street to Jones	226	-	30	78	1,323	6	27	64	15	1
B	Jones to Powell	5	-	-	0	313	3	-	24	-	-
A	Powell to Stockton	-	-	-	-	-	-	-	60	-	-
1	Stockton to Kearny	-	236	215	137	693	-	-	-	-	-
2	Kearny to Pier 31 and a half	30	273	81	8	56	1	33	-	-	-
3	Pier 31 and a Half inclusive of Pier 27	-	-	214	-	-	-	1	354	457	-
4	Pier 23 and a half to include Pier 19	1	-	-	-	83	-	6	-	-	0
5	Pier 17 inclusive of Pier 9	55	-	356	-	-	6	2	556	42	-
6	Pier 7 and a half and Pier 7	6	9	339	-	126	0	18	10	43	-
7	Pier 3 and Pier 1 to Ferry Plaza edge	-	-	580	-	585	-	-	218	-	-
8A	60% of Ferry Building and Ferry Terminals	-	-	524	-	289	0	-	101	-	-
8B	40% of Ferry Building, Sinbads, and Pedestrian Pier	-	-	-	-	71	0	-	-	-	-
9A	Pier 14 to Folsom Ftreet	12	-	-	-	3	0	1	-	-	7
9B	Folsom to Harrison Street	-	-	-	-	166	0	23	-	-	44
9	Pier 24 and a half to Bryant Street	-	-	189	-	20	0	50	-	-	2
10	Pier s 30 and 32 inclusive	-	-	8	-	20	4	0	-	-	-
11A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11	Brannan St , Brannon Street Wharf, and Delancy Street (Parcel 3310)					58					
12	Parcel 3320, Piers 38 and 40	-	2,378	337	0	30	-	3	-	284	-
13	South Beach Harbor and Parcels 3340 to 3361	-	-	137	-	-	-	-	-	-	87
46	Ball Park /1								800		
	Total	334	2,895	3,012	224	3,838	22	164	2,187	841	141

/1 Ball Park Estimate includes full and part time

Table 5-12 takes the analysis one step further, attempting to calibrate on-site employees by area by time of day. The underlying assessment of damages test sensitivity at three times of day, i.e. 2 PM, 5PM and 2AM in the morning. For these estimates we have used factors against what is assumed to be the base line of 2 PM. For instance, office employment is assumed to be 80 percent of the 2 PM figure at 5 PM, and nothing at 2 AM. On the other hand, full service restaurant employment is estimated to be at 120 percent of the 2 PM figure at 5 PM as these establishments are preparing for the dinner hours. Because of the nature of Section 46, which is the ball park catering to special events, no employee estimates are used by time of day. Available information however, cites total employment of the ball park at approximately 800. In addition to the information shown the estimated residential population is approximately 1,000 based on the number of units in Sections 11 and 12, and assuming 2.3 people per unit. This population is would primarily be impacted at the 2 AM time. Information for selected seawall sections is shown on ***Table 5-12***, as well as a total for the study area by time of day.

Table 5-12: Employment by Time of Day

SEAWALL SEGMENT #	Description	Wholesale	Mixed Use	Office	Retail	Food & Bev	Parking	Storage	Public Attract	Marine Support
FW	Hyde Street to Jones									
	2PM	-	302	198	-	40	-	-	37	471
	5PM		241	159		48	-		45	565
	2AM		3	2		-	-		-	-
B	Jones to Powell									
	2PM	-	-	-	-	-	4	-	-	269
	5PM		-	-		-	3		-	323
	2AM		-	-		-	0		-	-
A	Powell to Stockton									
	2PM	-	-	25	-	-	2	-	-	-
	5PM		-	20		-	2		-	-
	2AM		-	0		-	0		-	-
1	Stockton to Kearny									
	2PM	-	-	-	-	525	12	-	165	700
	5PM		-	-		630	10		198	840
	2AM		-	-		-	0		-	-
2	Kearny to Pier 31 and a half									
	2PM	-	81	685	-	-	1	-	-	94
	5PM		65	548		-	1		-	113
	2AM		1	7		-	0		-	-
3	Pier 31 and a Half, inclusive of Pier 27									
	2PM	-	70	215	-	1	-	-	-	-
	5PM		56	172		1	-		-	-
	2AM		1	2		-	-		-	-
4	Pier 23 and a half to include Pier 19									
	2PM	-	-	68	-	-	-	-	-	79
	5PM		-	55		-	-		-	95
	2AM		-	1		-	-		-	-
5	Pier 17 inclusive of Pier 9									
	2PM	-	150	268	-	256	6	-	-	-
	5PM		120	215		307	5		-	-
	2AM		2	3		-	0		-	-
6	Pier 7 and a half and Pier 7									
	2PM	-	107	457	-	-	-	-	-	45
	5PM		86	365		-	-		-	54
	2AM		1	5		-	-		-	-
7	Pier 3 and Pier 1 to Ferry Plaza edge									
	2PM	-	-	1,084	-	-	-	-	-	-
	5PM		-	867		-	-		-	-
	2AM		-	11		-	-		-	-
8A	Inclusive of 56% of Ferry Building and Ferry Terminals									
	2PM	-	-	386	-	67	-	-	128	23
	5PM		-	308		81	-		154	28
	2AM		-	4		-	-		-	-
8B	44% of Ferry Building, Sinbads, and Pedestrian Pier									
	2PM	-	-	535	-	10	-	-	71	115
	5PM		-	428		12	-		85	138
	2AM		-	5		-	-		-	-
9A	Pier 14 to Folsom Ftreet									
	2PM	-	-	-	-	-	-	-	-	-
	5PM		-	-		-	-		-	-
	2AM		-	-		-	-		-	-
9B	Folsom to Harrison Street									
	2PM	-	-	-	-	-	-	-	-	134
	5PM		-	-		-	-		-	161
	2AM		-	-		-	-		-	-
9	Pier 24 and a half to Bryant Street									
	2PM	-	30	437	-	-	-	-	-	-
	5PM		24	349		-	-		-	-
	2AM		0	4		-	-		-	-
10	Piers 30 and 32 inclusive									
	2PM	-	-	8	-	-	4	-	-	19
	5PM		-	7		-	3		-	23
	2AM		-	0		-	0		-	-
11	Brannan St , Brannon Street Wharf, and half of Delancy Street (Parcel 3310)									
	2PM	122								
	5PM	204	-	50	-	66	2	-	-	37
	2AM	407	-	40		80	1		-	45
12	Parcel 3320, Piers 38 and 40		-	0		-	0		-	-
	2PM	535	-	409	-	173	2	-	-	79
	5PM		-	327		207	1		-	95
	2AM		-	4		-	0		-	-
13	South Beach Harbor and Parcels 3340 to 3361									
	2PM	-	-	152	-	-	-	-	-	-
	5PM		-	121		-	-		-	-
	2AM		-	2		-	-		-	-
	Total									
	2PM	657	740	4,927	-	1,071	32	-	401	2,029
	5PM	204	592	3,991	-	1,351	27	-	482	2,472
	2AM	407	7	89	-	80	2	-	-	45

Lost Wage Impact

In an attempt to measure potential lost wage income resulting from a seismic event within the study area estimated hourly wages were applied to employment by type of land use based on published salary ranges in 2014 for the area from San Francisco to Redwood City by the Bureau of Labor Statistics. Clearly, they range dramatically by employment type. A great deal of the employment in the study area is confined to food service and tourism related retail, and thus confined to lower wage job categories. Actual wages for many of the tourism related uses are currently lower than $15, but San Francisco has adopted $15 as a minimum wage target. For the office uses most of the firms are professional in nature, and thus have a higher than typical salary structure. It should be noted that local salary structures are significantly above those of the United States as a whole.

Table 5-13 shows the potential net loss of employment based salaries by land use and by seawall section for a one-year period of time.

Table 5-13: Annual Wage Loss by Land Use and by Seawall Section ($000)

SEAWALL SEGMENT #	Description	Total by Segment	Estimated Hourly Wage by Type of Employee								
			$ 25.00	$ 30.00	$ 40.00	$ 15.00	$ 15.00	$ 15.00	$ 25.00	$ 20.00	$ 25.00
			Wholesale	Mixed Use	Office	Retail	Food & Bev	Parking	Storage	Attractions	Marine Support
FW	Hyde Street to Jones	$ 62,068	$ 11,562	$ -	$ 2,466	$ 2,411	$ 40,667	$ 187	$ 1,395	$ 2,604	$ 777
B	Jones to Powell	$ 10,955	$ 274	$ -	$ -	$ 2	$ 9,617	$ 93	$ -	$ 969	$ -
A	Powell to Stockton	$ 2,472	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,472	$ -
1	Stockton to Kearny	$ 57,692	$ -	$ 14,538	$ 17,621	$ 4,225	$ 21,307	$ -	$ -	$ -	$ -
2	Kearny to Pier 31 and a half	$ 28,651	$ 1,524	$ 16,771	$ 6,664	$ 248	$ 1,735	$ 41	$ 1,668	$ -	$ -
3	Pier 31 and a Half inclusive of Pier 27	$ 55,560	$ -	$ -	$ 17,519	$ -	$ -	$ -	$ 75	$ 14,529	$ 23,437
4	Pier 23 and a half to include Pier 19	$ 2,960	$ 64	$ -	$ -	$ -	$ 2,563	$ -	$ 333	$ -	$ -
5	Pier 17 inclusive of Pier 9	$ 57,286	$ 2,795	$ -	$ 29,222	$ -	$ -	$ 197	$ 106	$ 22,794	$ 2,172
6	Pier 7 and a half and Pier 7	$ 35,997	$ 317	$ 524	$ 27,815	$ -	$ 3,869	$ 2	$ 897	$ 394	$ 2,179
7	Pier 3 and Pier 1 to Ferry Plaza edge	$ 74,534	$ -	$ -	$ 47,594	$ -	$ 18,001	$ -	$ -	$ 8,938	$ -
8A	60% of Ferry Building and Ferry Terminals	$ 56,003	$ -	$ -	$ 42,961	$ -	$ 8,881	$ 5	$ -	$ 4,155	$ -
8B	40% of Ferry Building, Sinbads, and Pedestrian Pier	$ 2,193	$ -	$ -	$ -	$ -	$ 2,185	$ 8	$ -	$ -	$ -
9A	Pier 14 to Folsom Ftreet	$ 770	$ 605	$ -	$ -	$ -	$ 104	$ 2	$ 60	$ -	$ -
9B	Folsom to Harrison Street	$ 6,285	$ -	$ -	$ -	$ -	$ 5,119	$ 0	$ 1,166	$ -	$ -
9	Pier 24 and a half to Bryant Street	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
10	Pier s 30 and 32 inclusive	$ 1,444	$ -	$ -	$ 693	$ -	$ 613	$ 132	$ 5	$ -	$ -
11	Brannan St , Brannon Street Wharf, and Delancy Street (Parcel 3310)	$ 1,794	$ -	$ -	$ -	$ -	$ 1,794	$ -	$ -	$ -	$ -
12	Parcel 3320, Piers 38 and 40	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
13	South Beach Harbor and Parcels 3340 to 3361	$ 32,800	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 32,800	$ -
	Total By Category		$ 17,141	$ 31,833	$ 192,555	$ 6,886	$ 116,457	$ 666	$ 5,705	$ 89,655	$ 28,565
	Grand Total	$ 489,463									

Loss of Rent to the Port

The final exhibit attempts to show potential rental loss to the Port in the event of a seismic event based on different time frames. The underlying assumption is that regardless of where on a section of the seawall damage may occur the business interruption would impact businesses in that section almost universally. For instance, a break in Section 1(Pier 39), whether on the seawall or merely impacting the pier itself, would negatively impact business patterns throughout the pier, and perhaps adjacent land uses as well. ***Table 5-14*** provides a very conservative measure of impacts directly to the Port by seawall section based on reported 2015 rents for a one month, six months, and one-year time frame. These are very conservative and illustrate direct rental impacts only, independent of any insurance considerations that either the Port or individual tenants may have in place. It also ignores lease terms that still bind tenants contractually.

Table 5-14: Potential Loss of Rent to San Francisco Port Authority

SEAWALL SEGMENT #	Description	Monthly Rent	Total 6 Month Rent	Total Annual Rent
FW	Hyde Street to Jones	$ 1,530,941	$ 9,185,647	$ 18,371,293
B	Jones to Powell	$ 433,848	$ 2,603,085	$ 5,206,170
A	Powell to Stockton	$ 65,705	$ 394,229	$ 788,457
1	Stockton to Kearny	$ 386,065	$ 2,316,388	$ 4,632,776
2	Kearny to Pier 31 and a half	$ 272,824	$ 1,636,942	$ 3,273,885
3	Pier 31 and a Half, inclusive of Pier	$ 302,252	$ 1,813,515	$ 3,627,030
4	Pier 23 and a half to include Pier	$ 134,179	$ 805,074	$ 1,610,149
5	Pier 17 inclusive of Pier 9	$ 361,519	$ 2,169,114	$ 4,338,227
6	Pier 7 and a half and Pier 7	$ 249,885	$ 1,499,310	$ 2,998,620
7	Pier 3 and Pier 1 to Ferry Plaza	$ 234,955	$ 1,409,731	$ 2,819,462
8A	Inclusive of 60% of Ferry Building	$ 153,929	$ 923,575	$ 1,847,151
8B	40% of Ferry Building, Sinbads,	$ 24,391	$ 146,349	$ 292,697
9A	Pier 14 to Folsom Ftreet	$ 3,147	$ 18,883	$ 37,767
9B	Folsom to Harrison Street	$ 25,508	$ 153,047	$ 306,093
9	Pier 24 and a half to Bryant Street	$ 188,296	$ 1,129,779	$ 2,259,558
10	Pier s 30 and 32 inclusive	$ 147,411	$ 884,467	$ 1,768,933
11A	NA	NA	NA	NA
11	Brannan St , Brannon Street	NA	NA	NA
12	Parcel 3320, Piers 38 and 40	$ 147,309	$ 883,853	$ 1,767,706
13	South Beach Harbor and Parcels	$ 23,319	$ 139,915	$ 279,830
46	Ball Park	$ 405,176	$ 2,431,055	$ 4,862,109
	TOTAL	**$ 5,090,659**	**$ 30,543,956**	**$ 61,087,912**

By illustration of how conservative these numbers are, if the projected rental impact for Section 1 (Pier 39) is only $4.6 million for a year, the direct impact to Pier 39 for the same time frame is estimated by management to be more than $30 million. Similarly, two thirds of the Ferry Building is dedicated to office space with rents now approaching $90 per square foot on an annual basis. Regardless of the base rent to the Port provided by the master lease, if businesses were required to relocate for a lengthy period the gross impacts would be far greater.

Non-Measurable Impacts

There are additional impacts that are difficult to estimate predicated on the unique land uses and tourism activity that constitutes so much of the draw of San Francisco waterfront. From the research conducted in conjunction with this analysis only summary comments are possible. A comprehensive visitor intercept study was prepared by Destination Analysts (San Francisco) in 2014. In addition, San Francisco Travel collects data on an ongoing basis regarding the nature of the visitors to the City. Using aggregated data it is possible to make general observations regarding visitor volumes to many of the major destination experiences in the study area.

San Francisco Travel and Destination Analysts estimate that annual visitation to the City (2014) exceeded 18 million, including day visitors from the greater Bay Area, which the organization translates into150,000 visitors a day. Total visitor spending in that year exceeded $10.6 billion and generated in excess of $665 million in taxes and fee revenue to the City. The industry supports over 87,000 jobs.

For the first time the organization estimated the volume of cruise traffic either originating in San Francisco or passengers disembarking during a call at 260,000 for the year. A review of the cruise terminal schedule indicates over 80 scheduled calls for 2016.

Some salient facts of the visitor characteristics as they impact the study area follow:

- Vacation and other personal reasons constitute 35.8 percent and 19.8 percent, respectively, of the reasons for visiting the area. Special events and getaway weekends are cited next. Surprisingly, conventions and business travel were each cited at about 7 percent as the reason for traveling to the city.
- There is a very high repeat visitation pattern, with over 46 percent of visitors having been to the city five times or more. Not surprisingly, nearly 90 percent of that group consists of Bay Area residents on leisure day trips.
- Air and personal/rental cars are the most cited means of arrival and departure, but while in San Francisco, nearly 55 percent of visitors use public transit. Important to the current study is the fact that 16.7 percent use the cable cars and another 7.2 percent use the F-Line during their visit.
- Overall, 77.4 percent of visitors dine out in restaurants where they spend $40.50 per day. Another 54.4 percent shop in retail locations, where they spend nearly $30.00 per day.
- Fisherman's Wharf is visited by 44.7 percent of visitors, and the Embarcadero by 38.8 percent of the total.
- When asked where they shopped, 16.1 percent cited Fisherman's Wharf and another 10.1 percent cited the Embarcadero. Both destinations appeared to appeal more for dining, with 23.6 percent of visitors cited dining in Fisherman's Wharf and 16.8 percent someplace on the Embarcadero.

- When asked about specific attractions visited, Pier 39 was visited by 43.7 percent, the Ferry Building by 19.5 percent, and Ghirardelli Square by 19.4 percent. AT&T Park was visited by 15.3 percent, mostly by area residents, not destination visitors. The Exploratorium was visited by 10.2 percent.
- 77.3 percent of visitors are from the United States, with nearly 60 percent coming from within California. Among international visitors, the Golden Gate Bridge was cited as the 6th greatest known iconic U.S. destination among 38 nationally mentioned, and Fisherman's Wharf was ranked as 18th.

Comments Regarding Specific Destinations

Pier 39: As noted in the 2014 study, Pier 39 is the most visited destination in San Francisco, capturing 43.7 percent of the visitors, which translates into 7.9 million domestic and international visitors annually. Adding in resident visitors, the facility claims annual visitation exceeding 11 million people per year. Annual revenues are among one of the best areas of the city on a per square foot basis. Again, no estimates are available for monthly or seasonal variations. In addition to the sales per square foot for retail and food operations, they control the public marina and manage the Blue and Gold tours as part of their lease. No estimates are available for the economic contribution of these entities.

The Ferry Building: Based on the visitor survey, the Embarcadero captures over 7.1 million visitors a year, with an unspecified but reasonably high percentage of those visiting the Ferry Building, the most iconic destination along the waterfront besides Pier 39. In addition, the weekly Farmers' Market serves 15,000 to 25,000 patrons a week, for an estimated visitation of approximately 1.1 million people annually, which is inclusive of both residents and visitors. No estimates are available to distribute this visitation by season, and attempting to derive more specific estimates by examination of Franchise Tax Board documentation may be possible, but was outside the scope of this engagement.

Moreover, the Ferry Building is the hub for ferry service for both tourists and residents who contribute approximately 11,000 people a day to the traffic flows through and around the building. Obviously, all of this traffic is concentrated during normal business hours with only a few full service restaurants operating beyond the end of the normal ferry service operating hours.

Fisherman's Wharf: This area obviously constitutes a much larger area than merely the Port controlled properties. Any damage to the wharf areas would undoubtedly negatively impact the rest of the activity in the immediate area. As noted above, approximately 8.2 million visitors go to the Wharf annually, excluding resident patronage. It also claims to be one of the most visited destinations in the City with over 12 million annual visitors, 35 percent of whom are regional residents, which would appear to corroborate the 2014 visitor survey data. The Wharf is organized as a Community Benefit District and contains over 500 merchants, 13 hotels containing over 3,200 hotel rooms, and employing in excess of 7,400 people Any seismic activity along the sea wall should be expected to have a pro-rata or greater impact on Fisherman's' Wharf in general during the period of interruption.

AT&T Ball Park: This event center hosts on average 80 home baseball events per year to a capacity of approximately 42,000 people. 2013 paid attendance was 3.37 million generating in excess of $316 million in revenue, for an estimated $94 average per capita expenditure. In addition, there is a wide variety of additional scheduled events that includes musical concerts, the circus, automotive events, and conferences which attract typically smaller crowds. Ticket pricing can range from a low of $15 per event to over $4,000 for a season pass. There is a wide variety of dynamic pricing options that make calculation of either onsite population or individual event patronage particularly difficult. Given the location of the park and recent construction standards utilized, it is unlikely that seismic activity along this portion of the seawall will have much negative impact.

The Exploratorium: Recently relocated to its new location at Pier 15, the Exploratorium claims to attract over 550,000 annual paid visitors. Based on the visitor survey, the total visitation should be closer to 1.8 million. With a highly visible location located on public transit, it is reasonable to expect visitor volumes will increase substantially.

Public Area Utilization: During the course of this engagement, various spaces along the waterfront were observed at different times of the day, but we could find only one source that has attempted to quantify the pedestrian traffic flow along the waterfront. During the planning for the new Exploratorium location, pedestrian counts were commissioned in 2011 at Pier 39 and the Ferry Building, as well as the public pier (Pier 7). Counts were made at different times of the day on a typical midweek and weekend period (April) which attempted to document not only aggregate people visiting, but also their traffic pattern within the attraction and whether they were headed east or west along the waterfront.

A summary of this information for Pier 39 shows that the pedestrian flow did not deviate dramatically throughout the day, other than slight jumps at lunchtime and the early evening. The direction of movement also did not deviate dramatically as to whether it originated from the direction of the Ferry Building or from the direction of Fisherman’s Wharf. Of all the pedestrian traffic, Pier 39 appeared to capture approximately 25 percent of the total with average hourly traffic ranging from 80 to 100 people. The evening traffic was not recorded.

For the Ferry Building, the only deviation was a slightly higher percentage of total traffic flowing northwest toward Pier 39, but a higher overall capture of approximately 43 percent of total pedestrians. This may be impacted by the transit purposes of the terminal as well as greater preponderance of take home food outlets rather than tourism oriented retail. The average hourly traffic counts were similar, but the group size of the patrons was smaller than at Pier 39 with fewer children in evidence.

Summary of Impacts on Tourism

From all of the above data, a break along the seawall could be expected to have a significant impact on the tourism industry, independent of any other damage affecting the tourism environment, i.e. airport, bridges, etc. Should any portion, or all, of the seawall be seriously breached, closing access to the area for any period of time, visitation would essentially cease and with that interruption, the spending generated by visitors would disappear. It is reasonable to assume that total visitation to San Francisco would decline given that so many of the visitors to the City patronize the waterfront during a visit. Even if total visitation were to remain static, the spending to the various food and beverage and retail venues along the waterfront would be interrupted, and it is not clear that it would stay at the same levels, and merely be captured by other locations within the City.

As an example, if 75 percent of visitors spend approximately $40.50 daily dining out and nearly 55 percent spend $30 shopping, adding the average length of stay of 2.75 nights, the combined total spending on merely these two categories is in excess of $2.3 billion annually. Factoring for those who specified where they shopped and dined (Fisherman's Wharf and the Embarcadero), then conservatively $500 million is spent somewhere along the San Francisco seawall area annually. Thus, if the seawall were inaccessible for one year, this amount of spending might evaporate even if tourism levels were to remain the same. Alternatively, if the total visitation to the area eroded during that time, every 10 percent reduction in visitors would further erode this spending by $50 million.

6. Seawall Section Prioritization

6.1. Introduction

Seawall sections are assessed for their relative economic risks, cost of mitigation, and resulting relative importance for mitigation based on value engineering techniques. This was done by determining the economic risk of each seawall section, the least costs for short and long term geotechnical and structural mitigation, and assuming relative importance of the economic risk, costs of mitigation, and other non-economic factors that may be important to the Port and stakeholders. Once these items are defined, each item is assigned a rating relative to all seawall sections; most ratings are formulated based on the economic data determined for each seawall section. Ratings for non-economic factors are left to the discretion of the Port but ratings for non-economic factors are assumed here for illustrative purposes.

The result of this exercise is a prioritization of seawall section mitigations and associated minimum short and long term mitigation costs. The short term and long term prioritization is not necessarily the same.

6.2. Seawall Section Economic Risk

The economic risk for each seawall section is based on the present value of assets for each seawall section. Replacement costs for such assets have been determined from data provided by the Port and are divided by superstructure or substructure, and landside, bulkhead wharf and pier assets. This leads to six possible delineations of assets:

- Landside superstructure – includes all building assets landside of the seawall
- Landside substructure – includes all seawall structure
- Bulkhead wharf superstructure – includes all building assets supported by the bulkhead wharfs
- Bulkhead wharf substructure – includes all bulkhead wharf structure
- Finger pier superstructure – includes all building assets supported by the finger piers
- Finger pier substructure – includes all finger pier structure

Table 6-1 summarizes these asset values by asset delineation and seawall section.

Table 6-1: Port Asset Economic Values by Seawall Section and Delineation

	SUMMARY VALUES BY SECTION			SUMMARY VALUES BY SECTION			
	SUB-STRUC-TURE LANDSIDE	SUB-STRUC-TURE BHD	SUB-STRUC-TURE PIER	SUPER-STRUC-TURE LANDSIDE	SUPER-STRUC-TURE BHD	SUPER-STRUC-TURE PIER	SECTION TOTALS
FW	$0	$11,824,500	$89,217,250	$0	$40,637,000	$70,384,250	$101,041,750
B	$0	$0	$3,396,250	$4,973,000	$3,431,250	$777,500	$3,396,250
A	$0	$0	$16,305,000	$0	$0	$2,905,750	$16,305,000
1	$0	$0	$67,760,000	$33,653,750	$0	$0	$67,760,000
2	$0	$18,327,500	$171,664,750	$3,155,500	$1,300,000	$0	$189,992,250
3	$0	$62,336,250	$44,825,000	$5,053,750	$54,109,600	$22,278,150	$107,161,250
4	$0	$79,175,250	$105,806,750	$22,484,000	$12,931,175	$95,662,325	$184,982,000
5	$0	$42,690,000	$92,890,750	$17,595,000	$40,868,000	$81,097,000	$135,580,750
6	$0	$8,162,500	$49,687,500	$0	$3,941,400	$21,988,350	$57,850,000
7	$0	$7,254,500	$83,101,250	$0	$8,259,175	$23,003,325	$90,355,750
8a	$0	$61,108,500	$0	$0	$27,193,750	$0	$61,108,500
8b	$0	$0	$31,855,000	$0	$0	$0	$31,855,000
8	$0	$18,328,500	$8,207,500	$0	$5,546,500	$2,269,000	$26,536,000
9a	$0	$0	$2,501,250	$0	$0	$0	$2,501,250
9b	$0	$21,563,750	$0	$0	$7,633,000	$0	$21,563,750
9	$0	$9,248,750	$79,828,500	$0	$7,317,250	$47,228,500	$89,077,250
10	$0	$0	$143,647,000	$0	$309,000	$0	$143,647,000
11a	$0	$0	$0	$0	$0	$0	$0
11	$0	$0	$0	$0	$0	$0	$0
12	$0	$27,889,500	$73,466,250	$0	$27,552,000	$0	$101,355,750
13	$0	$0	$0	$0	$0	$0	$0
P46	$0	$0	$0	$0	$0	$0	$0
CB	$0	$0	$0	$0	$0	$0	$0
TOTALS	$0	$367,909,500	$1,064,160,000	$86,915,000	$241,029,100	$367,594,150	$1,432,069,500

The estimated 2016 total value of all Port assets is $ 1,432,069,500 based on economic data provided to us by the Port. This value represents the Port's present day economic risk along the Northern Seawall.

Risk ratings by seawall section for subsequent value engineering are linearly distributed between the maximum and minimum economic risk shown on the above table. The minimum risk (i.e., $0) receives a 5 rating (the most favorable with respect to risk); the maximum risk receives a zero rating with all other risks inversely distributed relative to the section totals shown.

6.3. Seawall Section Mitigation Costs

Estimated rough order of magnitude construction costs were developed for various geotechnical and structural mitigation alternatives. The applicability of these alternatives to each seawall section, either as short or long term mitigation, was determined and, where applicable, the resultant ROM costs were applied for each section. The primary objective of a long term mitigation technique is to reduce or eliminate soil lateral sliding tendency using geotechnical mitigation methods. Mitigation addressing life safety and structural collapse deficiencies would be termed short term. Long term mitigation would also address sea level rise by raising the wharf deck or bulkhead grade elevation.

The minimum mitigation cost for each seawall section for both short term and long term mitigation scenarios was assumed as the estimated mitigation cost for the purposes of seawall section ranking and prioritization. ***Table 6-2*** summarizes these minimum mitigation costs by seawall section.

Table 6-2: Short and Long Term Mitigation Costs by Seawall Section

	ESTIMATED ROM MITIGATION CONSTRUCTION COSTS (2016 $/FT)			
	SHORT TERM		LONG TERM	
Section	MIN	MAX	MIN	MAX
FW	$51,230	$86,360	$61,560	$95,680
B	$51,230	$86,360	$61,560	$95,680
A	$54,795	$91,711	$63,547	$142,086
1	$49,125	$81,183	$62,187	$89,631
2	$51,575	$87,560	$62,372	$97,343
3	$67,850	$98,650	$71,892	$108,433
4	$61,350	$95,230	$73,892	$105,013
5	$58,895	$94,850	$73,842	$104,633
6	$59,870	$108,438	$94,494	$120,666
7	$42,785	$71,836	$63,301	$100,883
8a	$10,077	$10,077	$149,469	$149,469
8b	$9,200	$9,200	$125,093	$125,093
8	$128,563	$197,567	$160,383	$230,177
9a	$7,334	$10,867	$93,364	$93,364
9b	$60,178	$104,746	$72,464	$119,124
9	$64,804	$107,279	$77,441	$116,017
10	$66,520	$113,520	$47,736	$123,840
11a	$14,412	$14,412	$183,784	$183,784
11	$10,850	$10,850	$90,147	$90,147
12	$53,363	$90,967	$38,837	$101,462
13	$7,193	$9,807	$38,641	$38,641
P46	$11,388	$12,687	$11,388	$12,687
CB	$11,388	$12,687	$11,388	$12,687

The estimated minimum 2016 ROM construction cost for all short and long term mitigation costs is $ 863.9 million and $ 1.284 billion, respectively. This value represents the Port's present day short and long term mitigation costs along the Northern Seawall.

Mitigation cost ratings by seawall section for subsequent value engineering are linearly distributed between the maximum and minimum short and long term mitigation costs shown on the above table. The minimum section mitigation cost receives a 5 rating (the most favorable with respect to mitigation cost); the maximum section mitigation cost receives a zero rating with all other risks linearly distributed relative to the section totals shown.

6.4. Seawall Section Ranking

The seawall sections are ranked relative to each other using value engineering principles. Basically, value engineering compares alternatives with each other on a quantitative basis by assigning relative parameter ratings and parameter weights on a rational basis for parameters that are important to the various stakeholders involved with a project. This study assumes parameters, weights, ratings and stakeholders for the purposes of demonstration and determining the seawall section ranking. However, any one or more of these items may be adjusted as the Port sees fit.

Parameters

The assumed parameters for this study are based primarily on economics with an additional open parameter that reflects social and/or political influences deemed important to the ranking process.

The primary economic parameters are economic risk and minimum mitigation costs. The associated mitigation alternatives are:

- Do nothing.
- Perform short term mitigation.
- Perform long term mitigation.

A third parameter, titled "Other Issues" may include any non-economic parameter deemed important to the ranking process. This study assumes that specific seawall sections will have additional considerations, economic or otherwise, that are deemed worthy of additional consideration. This study assumes that the Ferry Building, Fisherman's Wharf, Pier 39, the cruise terminal at Pier 27, the Exploratorium at Piers 15-17, and the other publicly or privately occupied space at Piers 9, 1 to 3, 26-28 and 38 are relatively more important due to tourism, commerce and life safety issues. The new Pier 43.5 and Brannan Street Wharf are deemed less important because they are of newer construction designed to present day design codes. Section P46 and China Basin are also deemed less important because there is little significant Port infrastructure located at these seawall sections.

Parameter Weighting Factors

Parameter weighting factors are assigned for each major parameter. These weighting factors may be of any value but should be assigned on a quantitative basis relative to each other. For example, if economic risk is deemed to be twice as important as the cost of mitigation, the economic risk weight should be double that of the cost of mitigation. For a base case for this study, it is assumed that economic risk is the primary concern, so this is given a weighting factor of 60 percent of the total of all primary weighting factors. The mitigation costs and the specific section location are each assigned a weighting factor of 20 percent of the total. The Port or other stakeholders may take issue with these relative weighting factors and this is to be expected. The weighting factors may be varied to assess the sensitivity on resulting priorities. Thus, this study also looks at three additional cases assuming that economic risk, mitigation cost or "other issues" is 100% important with the exclusion of all other considerations.

Additional weighting factors are applied for each alternative parameter, e.g., do nothing, short term mitigation and long term mitigation. There is no prioritization for doing nothing, so this alternative is always assigned a weighting factor of zero. The short and long term alternatives are assigned a weighting factor of 1 or 0 depending on the desired result of the prioritization (namely, short or long term prioritization). The short and long term weighting factors vary in this study to produce recommended priorities for both short and long term mitigations.

For the other issues category, there is only one item presently in this group, assigned a weighting factor of 1. Other items could be added with an appropriate adjustment of relative weighting factors.

Section Ratings by Parameter

Ratings are assigned for each parameter item by seawall section. These ratings range from zero to five with zero being highly unfavorable to five being highly favorable. For economic considerations, these ratings are assigned by formula so that the ratings are proportional to the economic risk or cost involved.

For economic risk, the maximum risk on a per foot basis is assigned a rating of 5.0 because this would be a seawall section that would deserve the highest priority, all other things being equal. Lower risk ratings are based on the economic risk relative to this maximum, linearly distributed between zero and 5. If a seawall section were to have zero economic risk, it would be assigned a rating of zero as it would deserve no prioritization, all other things being equal.

For mitigation cost, the maximum cost on a per foot basis is assigned a rating of zero because this would be a seawall section that would deserve the lowest priority, all other things being equal. Lower mitigation cost ratings are based on the cost relative to this maximum, linearly distributed between zero and 5.0. If a seawall section was to have zero mitigation cost (which should be impossible), it would be assigned a rating of 5.0 as it would deserve the highest prioritization, all other things being equal.

For the other issues, we assign a rating of 2.5 to seawall sections with no discernible or average relative importance either way. We assign a rating of 5.0 to seawall sections that are deemed relatively important with respect to life safety and emergency facilities, such as the Ferry Plaza, new cruise terminal at Pier 27, the fire house at Pier 24, and the Port offices at Pier 1. We assign a rating of 3.5 to seawall sections that are deemed relatively important to tourism and commercial operations for the City, such as Fisherman's Wharf, Pier 39 and the Exploratorium at Piers 15-17. We assign a rating of zero to seawall sections that are deemed relatively unimportant with respect to consequences of failure or have been recently reconstructed, such as the seawall near Pier 14, Piers 30-32, Brannan Street Wharf, Section P46 and along China Basin. Pier 43.5 encompasses about half of the seawall Section B length, so this rating is averaged to 1.25.

The ratings are quantitative and independent of weighting factors. Once a rating is assigned based on some rational means, it should not be changed. The assigned rating factors are shown on the ranking matrices shown on ***Table 6-3*** and ***Table 6-4.***

Seawall Section Ranking

Overall seawall section ranking is determined by calculating the weighted average of item ratings for each seawall section. The relative weighted averages among seawall sections, ranging from zero to 5, establish the relative ranking.

Table 6-3 and ***Table 6-4*** present these ratings and weighting factors by seawall section and mitigation alternative or other issues for both short and long term mitigation assuming the weighting factors and ratings discussed above.

Table 6-3: Seawall Section Priorities for Short Term Mitigation (Base Case Assumptions)

Project: POSF-Se POSF-Seawall Vulnerability Study - Northern Seawall
Description: Ranking Ranking Matrix

SEAWALL SECTION AND RATINGS

		FW	B	A	1	2	3	4	5	6	7	8a	8b	8	9a	9b	9	10	11a	11	12	13	P46	CB
	Piers	FW	P45-P43	P41	P39	P35-P33	P31-P29	P27-P23	P19-P15	P9-P7	P3-P1	Fry Plz	Fry Plz	P2	P14	P24	P26-P28	P30-P32	BSW	BSW	P38-P40	--	--	--
	Length (feet)	1,997	1,000	561	1,158	1,000	1,000	1,000	1,000	800	1,307	392	450	300	934	788	816	750	170	353	910	830	371	926
	Bhd Wharf	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO	NO
	Bhd Wharf Area (SF)	59,910	31,418	33,660	50,952	47,115	38,272	46,000	43,956	35,767	53,398	58,800	67,500	35,000	0	3,600	22,032	20,250	0	0	14,298	0	0	0
	Finger Pier	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO	NO
	Adj Roadway	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	NO
RANKING PARAMETER	Parameter Weighting Factor																							
ECONOMIC RISK (5=MAX RISK $/FT, 0=NO RISK)	0.60																							
DO NOTHING	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SHORT TERM MITIGATION	1.00	0.49	0.32	0.57	0.56	0.92	1.21	1.90	1.72	1.52	0.51	2.94	1.00	3.61	0.20	0.61	4.38	5.00	1.09	0.53	3.16	0.22	0.75	0.30
LONG TERM MITIGATION	0.00	0.69	0.34	0.52	0.70	0.71	2.48	3.99	2.91	1.58	1.30	5.00	0.93	3.64	0.14	0.58	4.13	3.60	0.78	0.38	2.67	0.16	0.54	0.22
MITIGATION COSTS (5=NO COST, 0=MAX COST $/FT)	0.20																							
DO NOTHING	0.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
SHORT TERM MITIGATION	1.00	4.60	4.60	4.57	4.62	4.60	4.47	4.52	4.54	4.53	4.67	4.92	4.93	4.00	4.94	4.53	4.50	4.48	4.89	4.92	4.58	4.94	4.91	4.91
LONG TERM MITIGATION	0.00	4.67	4.67	4.65	4.66	4.66	4.61	4.60	4.60	4.49	4.66	4.19	4.32	4.13	4.49	4.61	4.58	4.74	4.00	4.51	4.79	4.79	4.94	4.94
OTHER ISSUES (5=MOST IMPORTANT, 0=NO IMPORTANCE)	0.20																							
SEAWALL SECTION LOCATION	1.00	3.50	1.25	2.50	3.50	2.50	2.50	5.00	3.50	3.50	5.00	5.00	5.00	2.50	0.00	5.00	2.50	0.00	0.00	0.00	2.50	0.00	0.00	0.00
OTHER	0.00																							
OTHER	0.00																							
	RATING	1.92	1.36	1.76	1.96	1.97	2.12	3.04	2.64	2.52	2.24	3.75	2.58	3.47	1.11	2.27	4.03	3.90	1.63	1.30	3.31	1.12	1.43	1.16
	RANK	15	19	16	14	13	12	6	7	9	11	3	8	4	23	10	1	2	17	20	5	22	18	21
															--LAST CHOICE--		--FIRST CHOICE--							

Table 6-4: Seawall Section Priorities for Long Term Mitigation (Base Case Assumptions)

GHD GTC

Project: POSF-Se POSF-Seawall Vulnerability Study - Northern Seawall

Description: Ranking Ranking Matrix

		SEAWALL SECTION AND RATINGS																						
		FW	B	A	1	2	3	4	5	6	7	8a	8b	8	9a	9b	9	10	11a	11	12	13	P46	CB
	Piers	FW	P45-P43	P41	P39	P35-P33	P31-P29	P27-P23	P19-P15	P9-P7	P3-P1	Fry Plz	Fry Plz	P2	P14	P24	P26-P28	P30-P32	BSW	BSW	P38-P40	--	--	--
	Length (feet)	1,997	1,000	561	1,158	1,000	1,000	1,000	1,000	800	1,307	392	450	300	934	788	816	750	170	353	910	830	371	926
	Bhd Wharf	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO	NO
	Bhd Wharf Area (SF)	59,910	31,418	33,660	50,952	47,115	38,272	46,000	43,956	35,767	53,398	58,800	67,500	35,000	0	3,600	22,032	20,250	0	0	14,298	0	0	0
	Finger Pier	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	NO	YES	YES	NO	NO	YES	NO	NO	NO
	Adj Roadway	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	NO	NO
RANKING PARAMETER	Parameter Weighting Factor																							
ECONOMIC RISK (5=MAX RISK $/FT, 0=NO RISK)	0.60																							
DO NOTHING	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SHORT TERM MITIGATION	0.00	0.49	0.32	0.57	0.56	0.92	1.21	1.90	1.72	1.52	0.51	2.94	1.00	3.61	0.20	0.61	4.38	5.00	1.09	0.53	3.16	0.22	0.75	0.30
LONG TERM MITIGATION	1.00	0.69	0.34	0.52	0.70	0.71	2.48	3.99	2.91	1.58	1.30	5.00	0.93	3.64	0.14	0.58	4.13	3.60	0.78	0.38	2.67	0.16	0.54	0.22
MITIGATION COSTS (5=NO COST, 0=MAX COST $/FT)	0.20																							
DO NOTHING	0.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
SHORT TERM MITIGATION	0.00	4.60	4.60	4.57	4.62	4.60	4.47	4.52	4.54	4.53	4.67	4.92	4.93	4.00	4.94	4.53	4.50	4.48	4.89	4.92	4.58	4.94	4.91	4.91
LONG TERM MITIGATION	1.00	4.67	4.67	4.65	4.66	4.66	4.61	4.60	4.60	4.49	4.66	4.19	4.32	4.13	4.49	4.61	4.58	4.74	4.00	4.51	4.79	4.79	4.94	4.94
OTHER ISSUES (5=MOST IMPORTANT, 0=NO IMPORTANCE)	0.20																							
SEAWALL SECTION LOCATION	1.00	3.50	1.25	2.50	3.50	2.50	2.50	5.00	3.50	3.50	5.00	5.00	5.00	2.50	0.00	5.00	2.50	0.00	0.00	0.00	2.50	0.00	0.00	0.00
OTHER	0.00																							
OTHER	0.00																							
	RATING	2.05	1.39	1.75	2.05	1.86	2.91	4.31	3.37	2.55	2.71	4.84	2.42	3.51	0.98	2.27	3.90	3.11	1.27	1.13	3.06	1.05	1.31	1.12
	RANK	14	17	16	13	15	8	2	5	10	9	1	11	4	23	12	3	6	19	20	7	22	18	21
												--FIRST CHOICE--			--LAST CHOICE--									

6.5. Seawall Section Prioritization

A base case prioritization scenario was assessed as a best-estimate for a mix of economic risk, mitigation cost and other issues parameters. In our opinion, this mix best accommodates all of the stakeholder significant items that are important to and are affected by mitigation of the Northern Seawall.

The sensitivity of the prioritization to each parameter was also evaluated by assessing prioritization scenarios for each parameter individually.

Base Case Ranking

Table 6-3 and ***Table 6-4*** show the relative ranking of seawall sections assuming the base case assumptions discussed above. The tables indicate the relative ranking, or prioritization, for undertaking the short and/or long term mitigation work. These results are presented ***on Figure 6-1*** and ***Figure 6-2,*** respectively, with the highest priority on the left, lowest on the right, with associated ROM mitigation costs for each seawall section. Under this scenario, the recommended first and last priorities for short term mitigation are seawall sections 9 (Pier 26-28) and 9a (Pier 14), respectively. The recommended first and last priorities for long term mitigation are seawall sections 8a (Ferry Plaza) and 9a (Pier 14), respectively. These are summarized on ***Table 6-5.***

Each table of results, by itself, suggests a recommended priority of seawall sections to be mitigated regardless of funding available for mitigating a specific seawall section. When a specific seawall section is up for mitigation but sufficient funding does not exist, the Port would be at liberty to either fund and mitigate such a section in phases, or delay the mitigation of that seawall section until adequate funding is obtained. Likewise, the tables cover both short and long term mitigation priorities and the priorities for short and long term mitigation are not necessarily the same. This will require a future assessment of long term mitigation in light of short term strategies that have already been implemented.

Ranking Assuming Economic Risk Only

By revising the weighting factors so that economic risk is the only consideration in the ranking procedure, the ranking and priorities change for short and long term mitigation, as shown on ***Figure 6-3*** and ***Figure 6-4,*** respectively. In case of a tie, the mitigation costs become the deciding factor. Under this scenario, the recommended first and last priorities for short term mitigation are seawall sections 10 (Piers 30-32) and 9a (Pier 14), respectively. The recommended first and last priorities for long term mitigation are seawall sections 8a (Ferry Plaza) and 9a (Pier 14), respectively. These are summarized on ***Table 6-5.***

Ranking Assuming Mitigation Cost Only

By revising the weighting factors so that mitigation costs are the only consideration in the ranking procedure, the ranking and priorities change for short and long term mitigation, as shown on ***Figure 6-5*** and ***Figure 6-6,*** respectively. In case of a tie, the economic risks become the deciding factor. Under this scenario, the recommended first and last priorities for short term mitigation are seawall sections 13 (former Piers 42 and 44) and 8 (Pier 2 and Agriculture Building), respectively. The recommended first and last priorities for long term mitigation are seawall sections P46 (former Pier 46) and 11a (Brannan Street Wharf), respectively. These are summarized on ***Table 6-5.***

Ranking Assuming Other Issues Only

By revising the weighting factors so that other issues are the only consideration in the ranking procedure, the ranking and priorities change to the same priorities for short and long term mitigation, as shown on ***Figure 6-7***. In case of a tie, the economic risks and mitigation costs become the deciding factor. Under this scenario, the recommended first priority for both short and long term mitigation is seawall sections 4 (Pier 27 cruise terminal) and the ranking results are identical for both short and long term mitigation, since these economic parameters are not considered in the rankings. These are summarized on ***Table 6-5.***

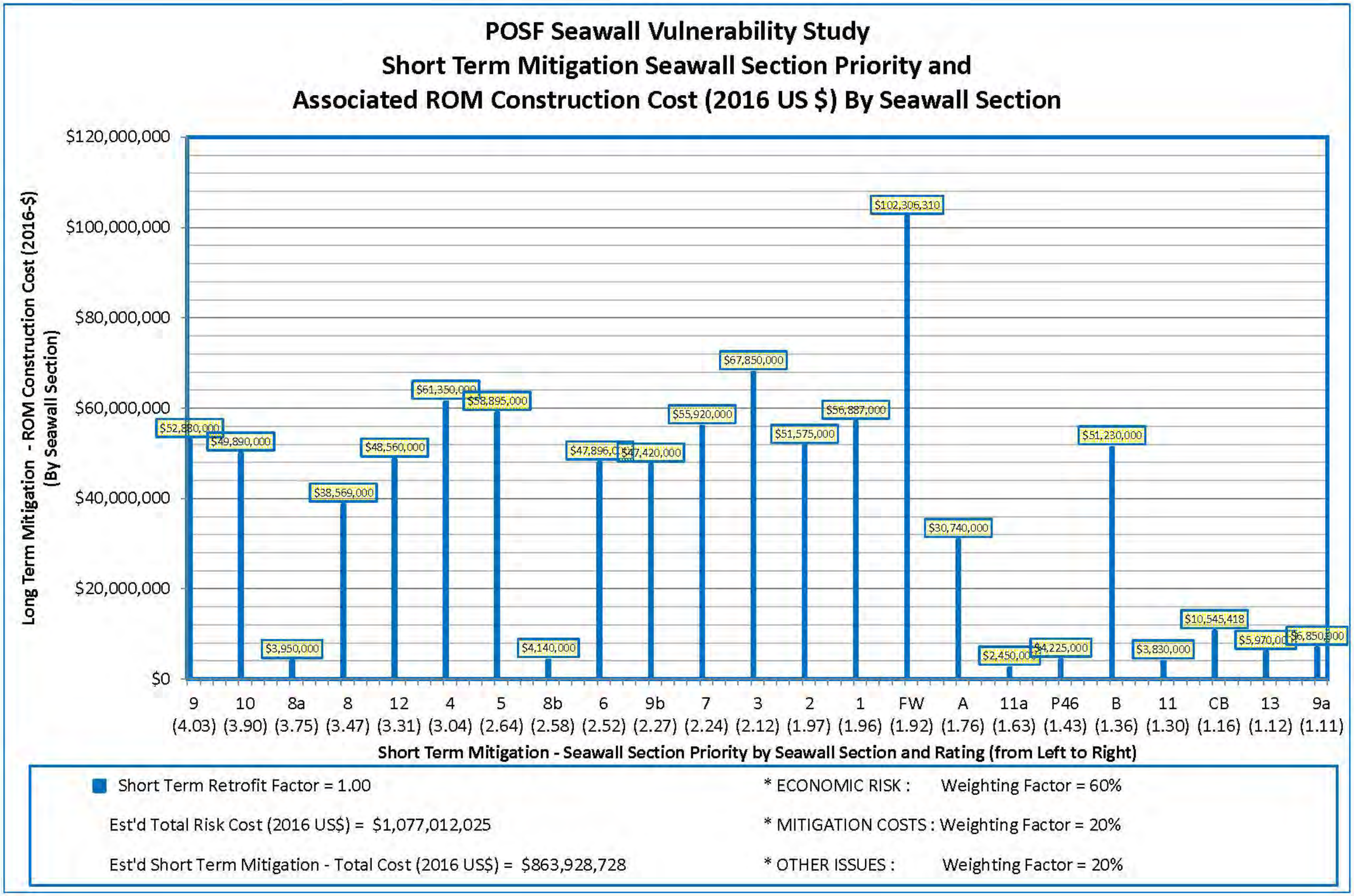

Figure 6-1: Seawall Section Priorities – Base Case Assumptions – Short Term Mitigations

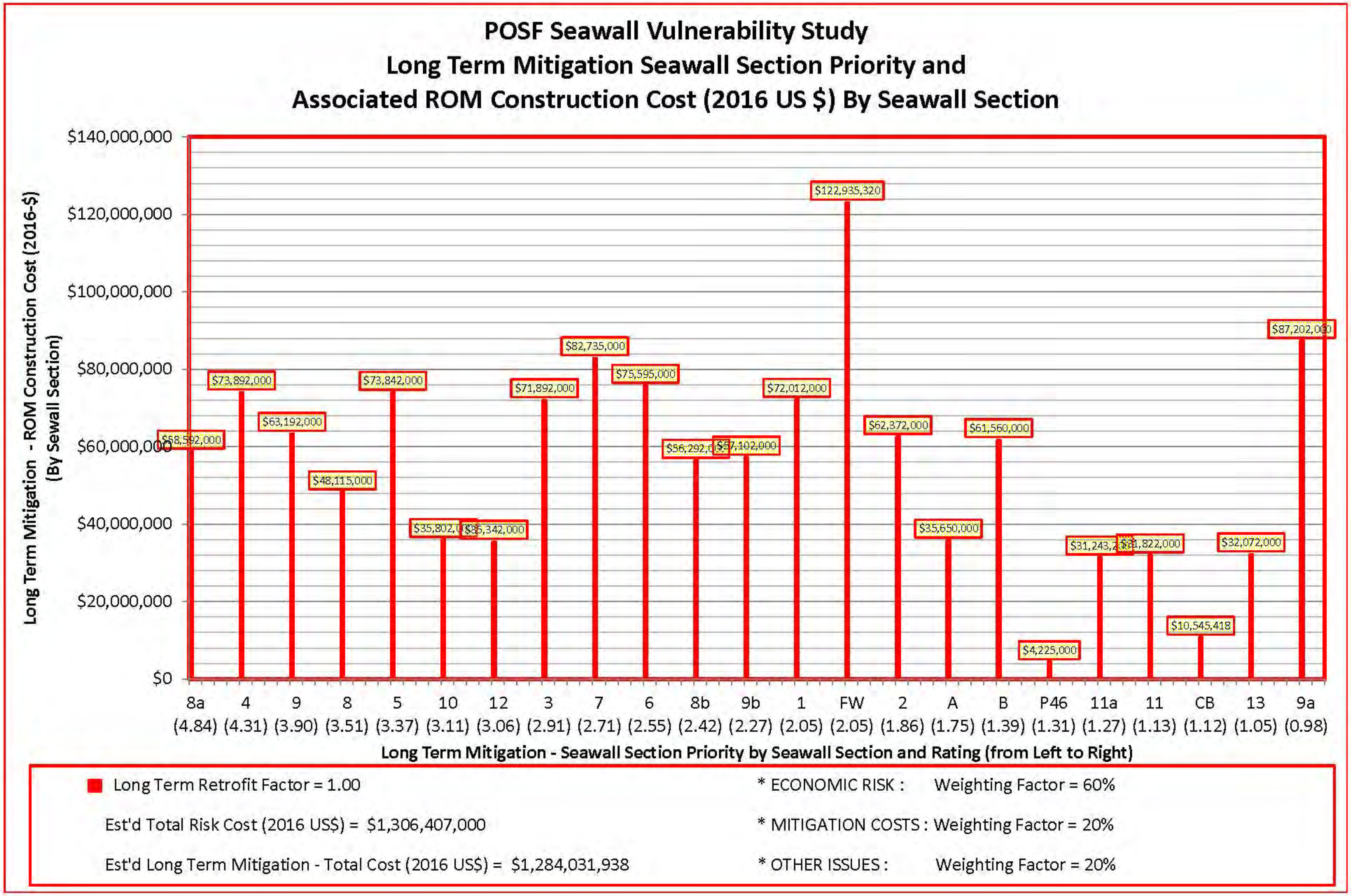

Figure 6-2: Seawall Section Priorities – Base Case Assumptions – Long Term Mitigations

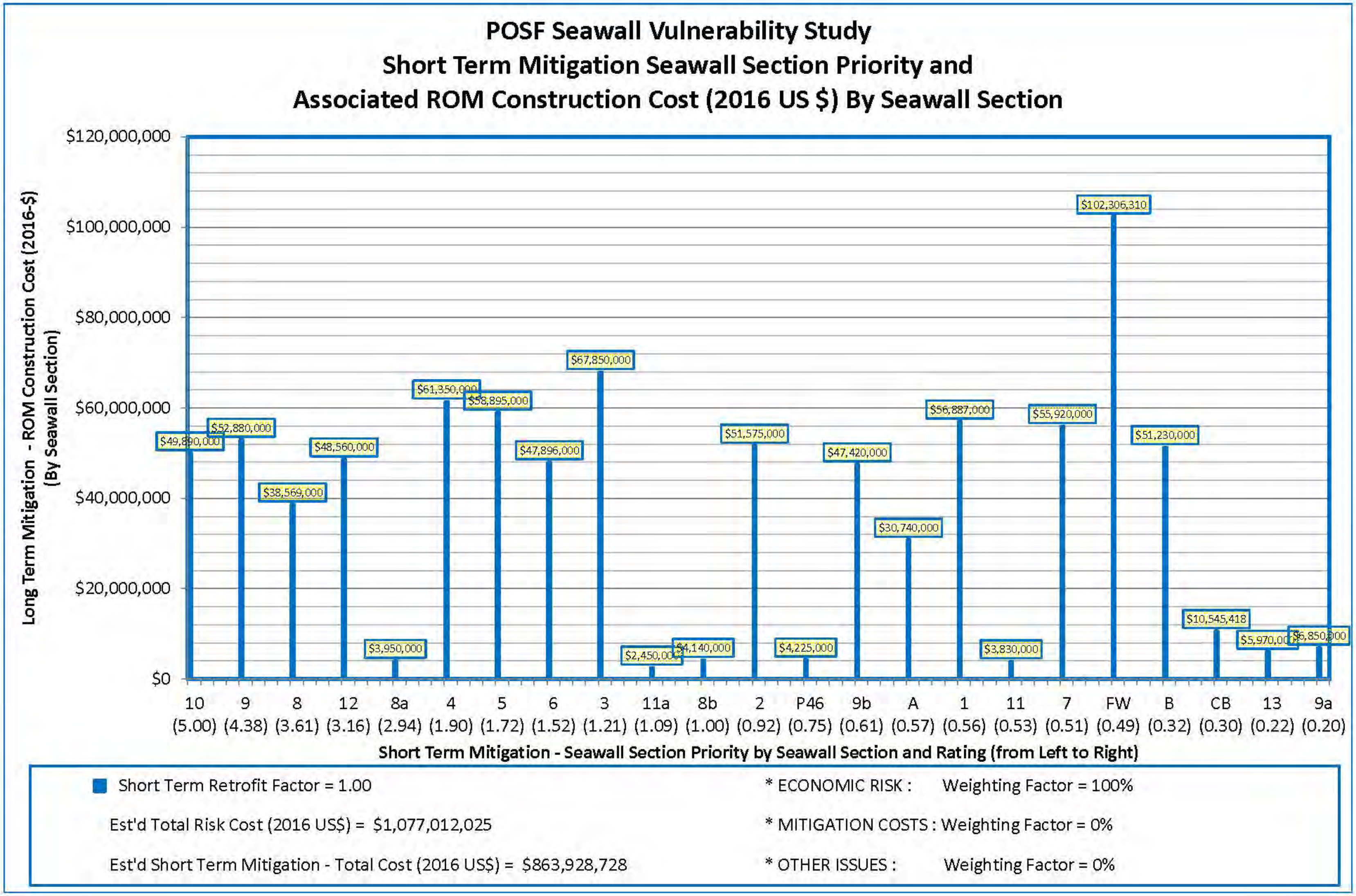

Figure 6-3: Seawall Section Priorities – 100% Risk Cost Assumption – Short Term Mitigations

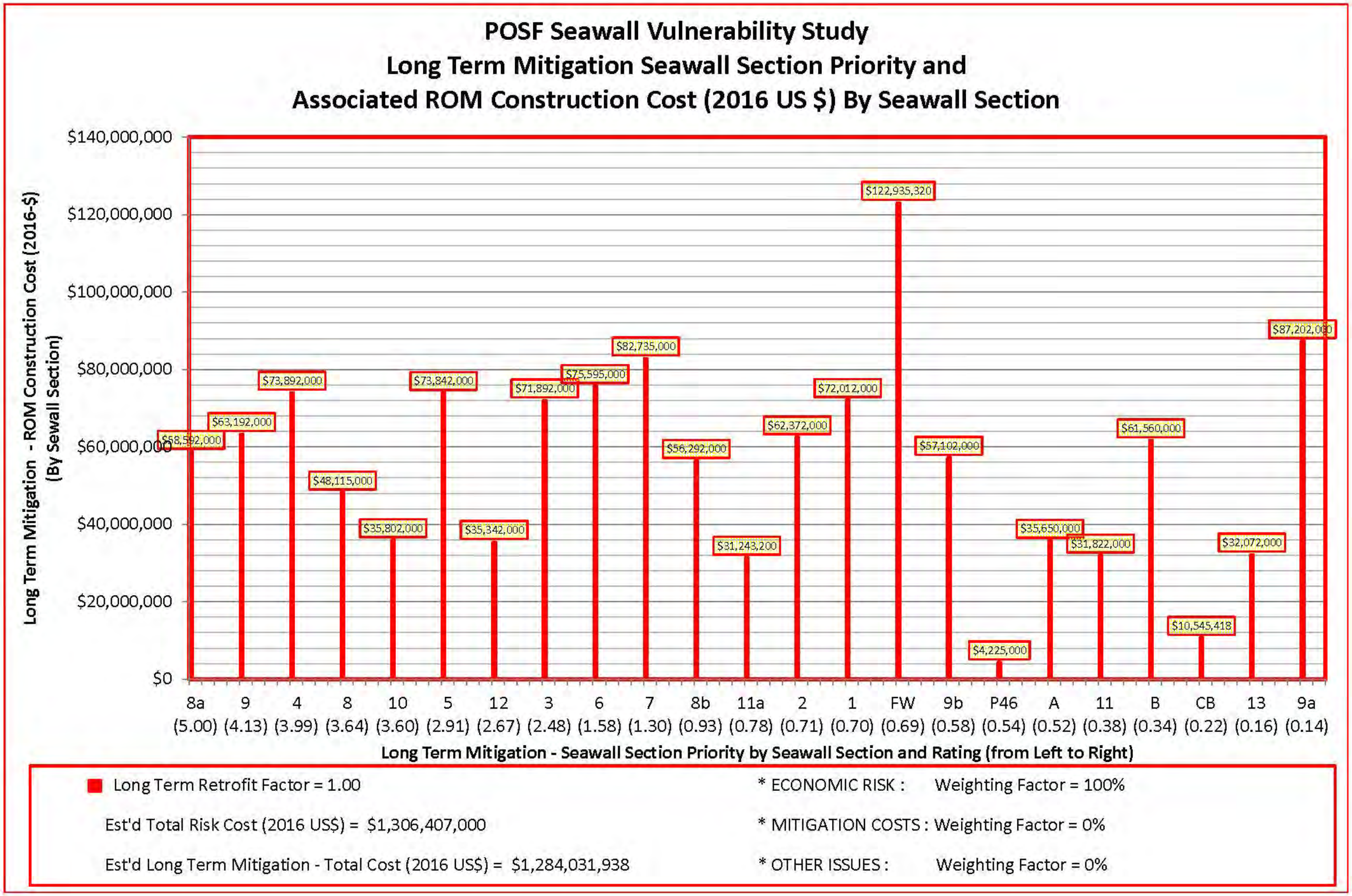

Figure 6-4: Seawall Section Priorities – 100% Risk Cost Assumption – Long Term Mitigations

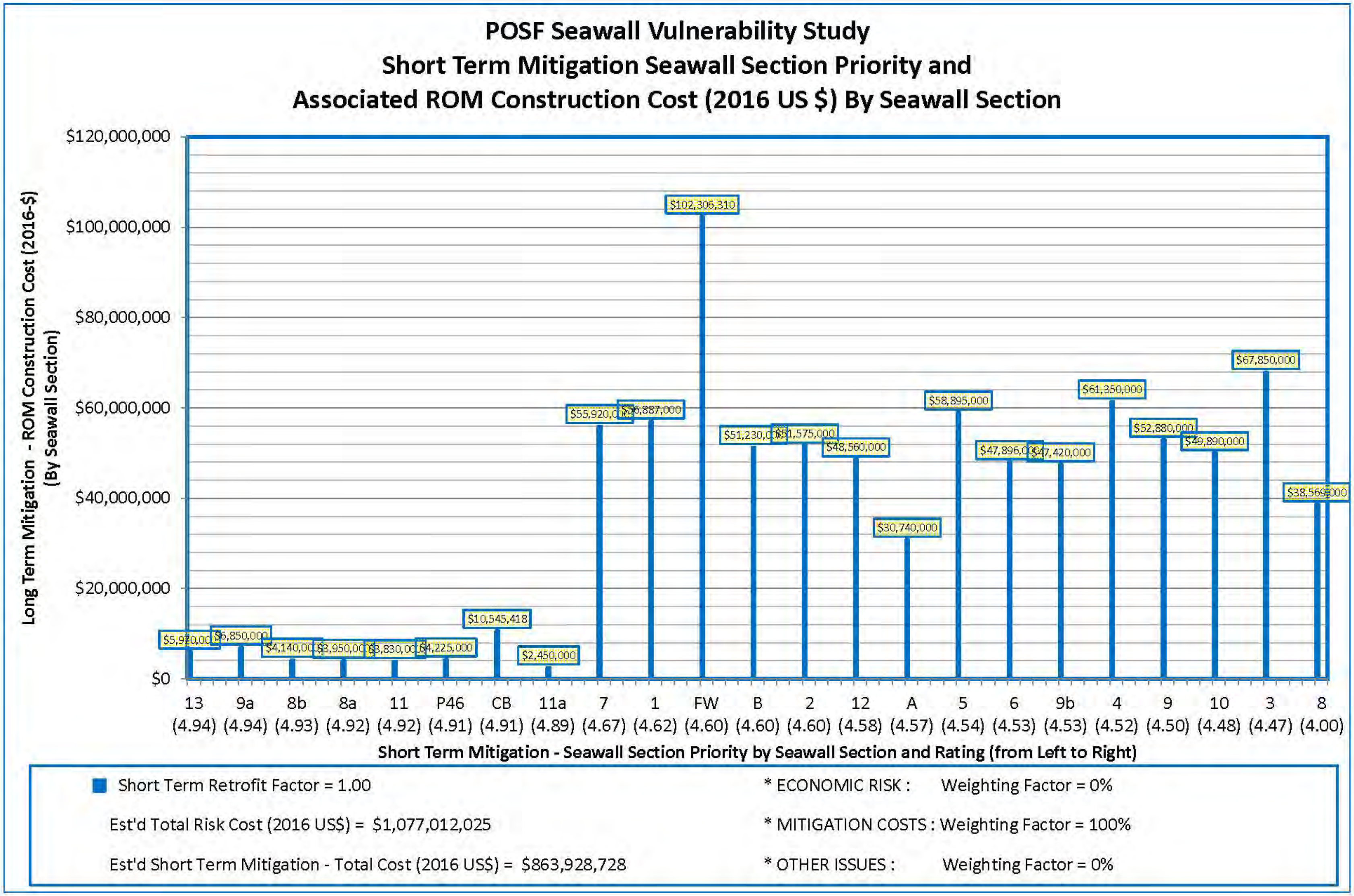

Figure 6-5: Seawall Section Priorities – 100% Mitigation Cost Assumption – Short Term Mitigations

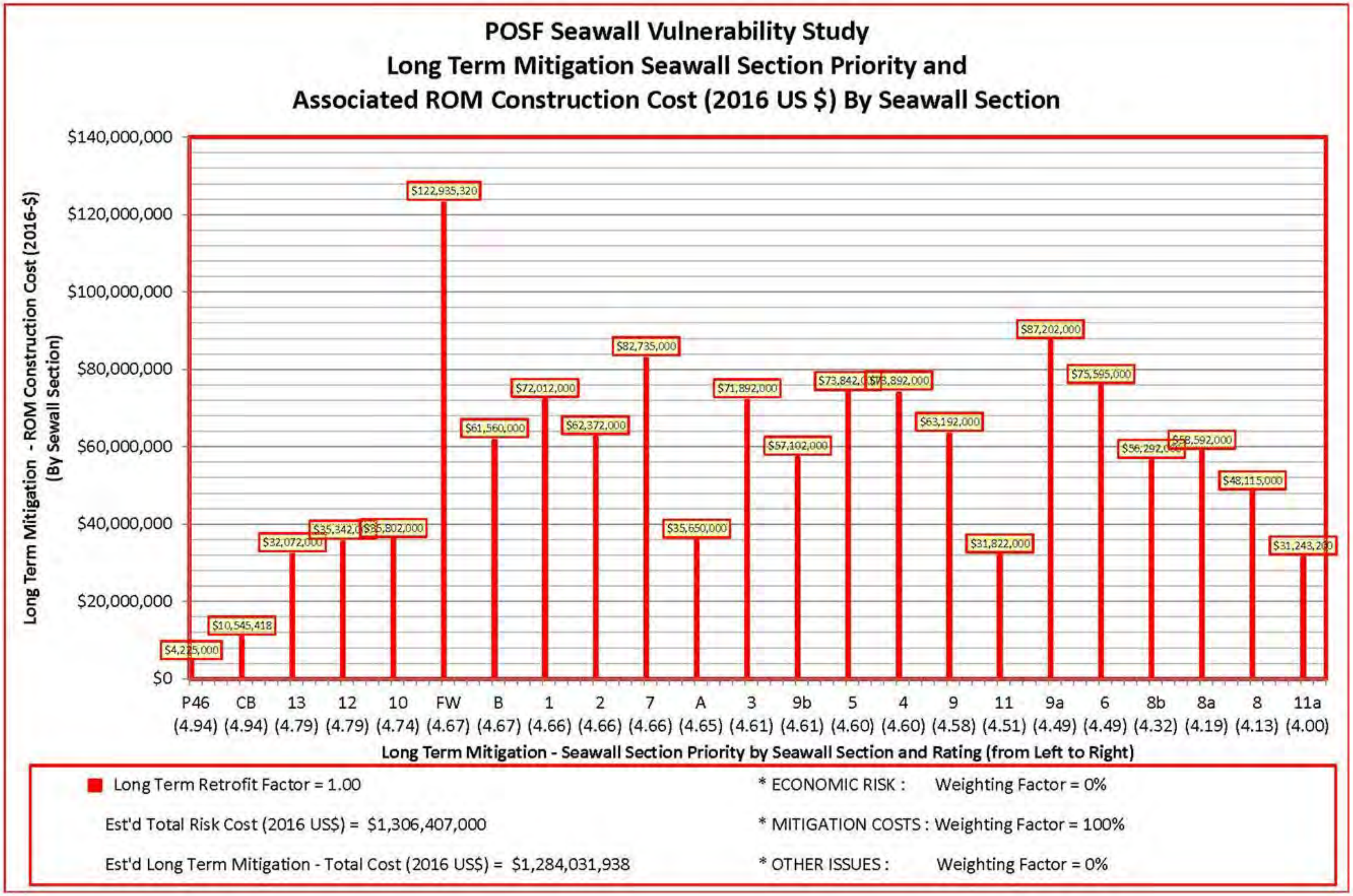

Figure 6-6: Seawall Section Priorities – 100% Mitigation Cost Assumption – Long Term Mitigations

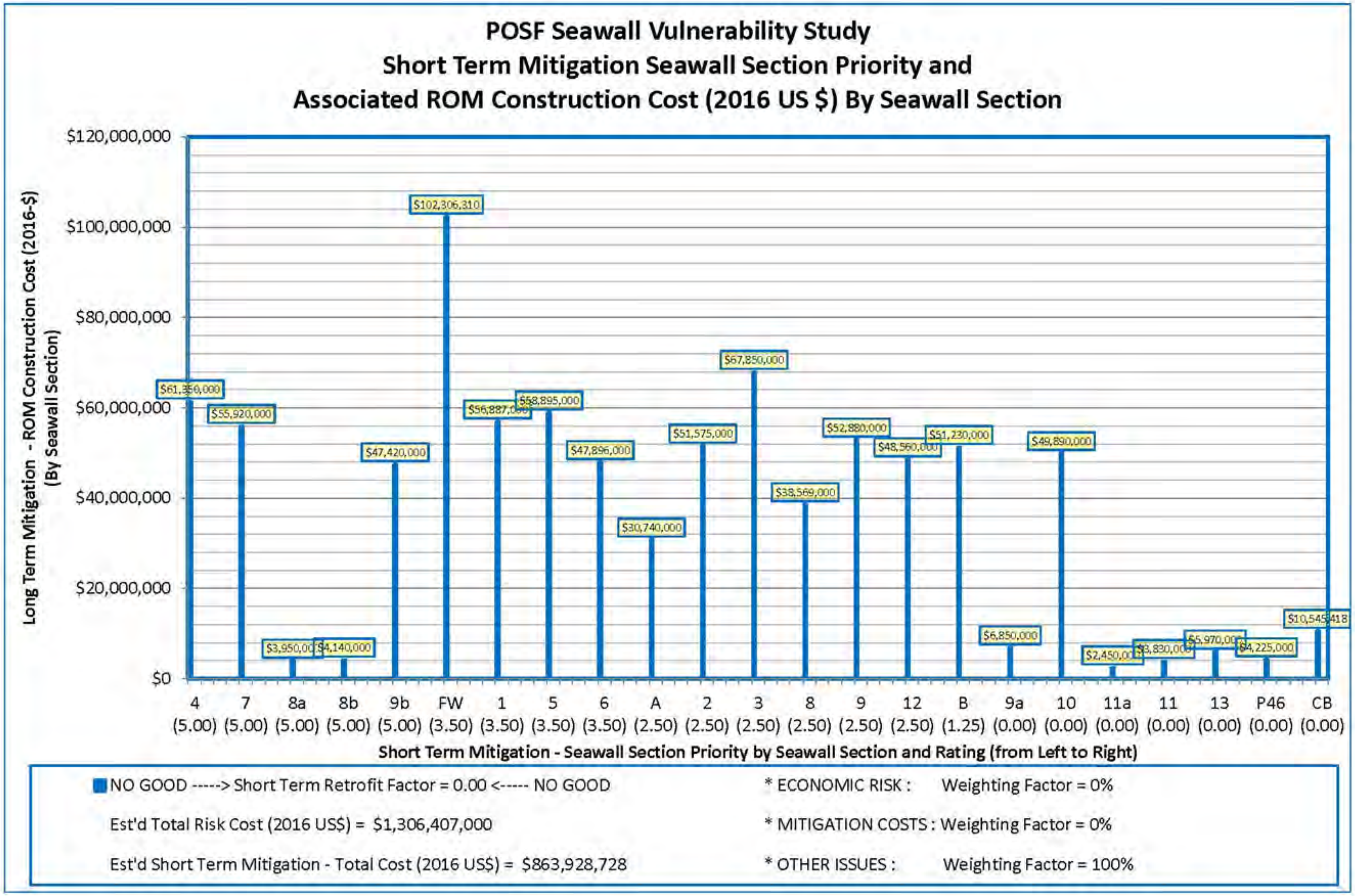

Figure 6-7: Seawall Section Priorities – 100% Other Issues Assumption – Short and Long Term Mitigations

Table 6-5: Section Seawall Ranking versus Weighting Factors

Item	Seawall Section Ranking vs. Weighting Factors						
Ranking Condition	Base Case		100% Risk Cost		100% Mitigation Cost		100% Other Issues
Mitigation Term	Short	Long	Short	Long	Short	Long	Short & Long
Section Risk Weighting Factor	60%		100%		0%		0%
Section Mitigation Weighting Factor	20%		0%		100%		0%
Other Issues Weighting Factor	20%		0%		0%		100%
First Priority (w/ Pier Location)	9 (P26-28)	8a (Fry Plz)	10 (P30-32)	8a (Fry Plz)	13 (P42-44)	P46 (P46)	4 (P27 CT)
Second Priority (w/ Pier Location)	10 (P30-32)	4 (P27 CT)	9 (P26-28)	9 (P26-28)	9a (P14)	CB (Ch Bsn)	7 (P1-P3)
Third Priority (w/ Pier Location)	8a (Fry Plz)	9 (P26-28)	8 (Ag Bldg)	4 (P27 CT)	8b (Fry Plz)	13 (P42-44)	8a (Fry Plz)
Fourth Priority (w/ Pier Location)	8 (Ag Bldg)	8 (Ag Bldg)	12 (P38-40)	8 (Ag Bldg)	8a (Fry Plz)	12 (P38-40)	8b (Fry Plz)
Fifth Priority (w/ Pier Location)	12 (P38-40)	5 (P15-19)	8a (Fry Plz)	10 (P30-32)	11 (BSW)	10 (P30-32)	9b (P24 Fire House)
Last Priority (w/ Pier Location)	9a (P14)	9a (P14)	9a (P14)	9a (P14)	8 (P2)	11a (BSW)	CB (Ch Bsn)

The above table demonstrates that the prioritization results are sensitive to the relative weighting factors used, especially if there is a desired bias towards one rating factor over the other. This demonstrates the need to establish weighting factors that account for relevant stakeholder input so that priorities are appropriately set with stakeholders in mind.

The base case weighting factors assumed for this study are the JV's recommended weighting factors but the Port may suggest other weighting factors for consideration.

7. Conclusions and Recommendations

7.1. Conclusions

Primary Seawall Vulnerabilities

The Northern Seawall Earthquake Vulnerability study has shown that development of the San Francisco waterfront on reclaimed land over past 100 plus years is associated with a risk of large deformations and/or damage to the seawall during and after a significant seismic event. Liquefaction of placed fill materials behind the seawall, varying from 10 to 30 feet thick, may cause additional vertical settlement due to permanent ground deformation following a seismic event. In addition, the soft clay layer (commonly known as Young Bay Mud), is a low strength material and is susceptible to lateral spreading during and after seismic events.

This study concluded that, due to the presence of this soft clay layer, the rock dike may move toward the Bay, producing damage to the seawall bulkhead wall, bulkhead wharf and piles supporting these structures. The bulkhead wharf and seawall bulkhead wall piles are relatively brittle (non-ductile) and will fail in shear, usually at their top connections to the supported structure or where the piles pass through the weak soil sliding layer.

Finally, significant soil movement will also cause cracking and settlement of the upland fill areas supporting the promenade, Embarcadero roadway and Muni Metro light rail. The seawall and adjacent bulkhead wharf and building structures, along with critical utilities and related infrastructure, are also located in the seawall zone of influence.

The primary seawall vulnerabilities consist of the following:

- Movement of the rock dike toward the Bay and vertical settlement
- Damage and failure of the bulkhead wall from ground shaking
- Damage and collapse of the bulkhead wall/wharf structures from both ground shaking and movement of the rock dike

Ancillary damage expected to occur with seismic events along the waterfront includes:

- Lateral spreading of the land within the seawall's zone of influence
- Increased vertical settlement of the land within the zone of influence
- Breaks to utility lines
- Cracking of pavement

7.2. Associated Hazards Summary

The JV team identified the following hazards during the course of the Northern Seawall vulnerability study:

Flooding and Sea Level Rise – current predictions for sea level rise relative to present day levels are 12 inches by 2050 and 36 inches by 2100. With its present configuration, the existing Northern Seawall structure will not preclude flooding of the adjacent uplands. This flooding can be mitigated by rehabilitating the existing seawall and/or adjacent infrastructure to accommodate expected sea level rise.

Utility Systems - below grade utility lines (electrical, water, sewer, storm drain and telecommunications) running along the Embarcadero, with laterals crossing or penetrating the seawall and out to finger piers may be damaged during a seismic event. Many utility lines have rigid joints and connections that do not accommodate out-of-plane movement or expansion/compression. Vertical support may also be lost if the Embarcadero and promenade suffer ground displacement of underlying fill or the bulkhead wharves and finger piers are damaged.

Embarcadero Roadway - liquefaction of cohesionless, non-uniform fill materials may cause vertical displacement and cracking in the roadway. Lateral spreading may also cause cracks. Fill is thickest behind the seawall bulkhead so greater displacement can be expected in this area. Reviewing permanent ground deformation (PGD) plots for varying ground motion levels, we can anticipate moderate to significant damage to roadway following large seismic event. Post-earthquake repairs to the pavement will be needed to allow traffic to safely use the roadway.

Muni Metro Light Rail - similar to the Embarcadero, damage can be expected to the rails for the Muni light rail and F-line along the Embarcadero. Settlement and possible distortion of the rails should be expected. Post-earthquake work will be required to filled in depressed areas and straighten, shim and level rails prior to reuse.

Essential Facility Access - access and entry to Pier 1, Pier 9 and entry to the Ferry Building and ferry terminals also could be cutoff by seawall failure and other damage due to permanent ground displacement. This may impact ferry service and potential evacuation needs, as well as the functioning of the emergency water transport. Additionally, public and private assets along the waterfront are at risk of direct building damage or indirect losses due to potential ground failure and seawall damage, utility outages and prolonged closures.

Water Transportation – San Francisco Bay Ferry system (WETA), barges, and the harbor pilots located at Pier 9. There may be increased needs for ferry and barge-related operations post-earthquake. It is also crucial to keep the harbor (bar) pilots in operation as they will provide commercial maritime navigation services for San Francisco Bay. The ferries must remain operational to allow emergency evacuation from San Francisco to other areas within the region.

7.3. Immediate Life Safety Items

The primary objective should be to safeguard the public, focusing on the bulkhead wharves, bulkhead buildings and promenade sections located over bulkhead walls. At a minimum, performance of these structures should be improved such that although there may be significant damage, occupants are able to safely leave the buildings. The structures should not collapse during or following a large earthquake.

The following life safety items are listed below in their order of concern:

- *Soil lateral sliding* – movement of underlying weak soil layers due to seismic shaking with accompanying significant permanent lateral displacements, most likely towards the bay. The lateral displacements associated with moderate earthquakes are deemed to be detrimental to the piled structures along the northern seawall and the magnitude of lateral displacement will increase with shaking intensity. These lateral displacements are expected to also cause settlements along the seawall, the combined displacement resulting in displacement induced structural damage to the supporting piles and parts or all of the seawall, bulkhead wharfs, finger piers and structures located landside of the seawall with associated risk of life safety damage.

- *Seawall to bulkhead wharf connections* – these typically consist of concrete or concrete encased steel wide flange beams seated into the seawall bulkhead structure. Details of these connections at each seawall section are typically unknown and the actual pull-out strength is not known. Based on demolition activities of the bulkhead wharf at Brannan Street Wharf in 2012, these connections demonstrated little or no load capacity. If this is the actual case, the failure of these connections with associated failure of the bulkhead wharf deck along the seawall is very likely during significant seismic shaking and perhaps during less significant earthquake events as well, with potential risk of life safety damage and the immediate inability to access the bulkhead wharf and finger pier structures and inhabitants beyond.
- *Bulkhead wharf pile head to deck connections* - these connections typically are the first to exhibit structural damage during a significant earthquake. While this is by design by present-day design codes, these existing pile head to deck connections on the bulkhead wharf structures are particularly susceptible as the provided displacement capacity is determined to be low by present day design standards. The difference between life safety and collapse displacement capacities for these connections also appears to be relatively small with little capacity difference between the two associated seismic events. However, there is a variation between seawall sections in the ability of bulkhead wharf structures to resist the imposed displacement demands. Some bulkhead wharf sections are expected to survive a life safety seismic event while some others are expected to suffer significant damage.

Seismic Vulnerability of Finger Piers

Another area where seismic damage can be expected to occur is at the transition between the finger pier and bulkhead wharf. This damage is caused by having a relatively stiff structure (bulkhead wharf) behaving very different than a more flexible structure (finger pier). A seismic joint can be installed at the interface between these two structures to mitigate damage.

The finger pier structures will need to be reviewed after removing the stiffer, shorter piles near the rock dike and bulkhead wharf. Removal of these pier sections will be necessary for construction of the replacement bulkhead wharf and new bulkhead alternatives. Review of the piers will also be needed in the case of strengthening the existing bulkhead wharf. The impact to the pier structure may be significant change to the structural response, increasing the structural period and lateral displacements (displacement demand.) In addition, liquefaction of cohesionless material may also increase effective length of the piles and produce down drag loading on the pier piles.

7.4. Conceptual Mitigation Alternatives

This study developed a number of mitigation alternatives that address some or all of the existing vulnerabilities presented above. These mitigation alternatives consist of geotechnical or structural mitigation techniques alone or in combination. The study concluded that a combination of techniques may be needed to adequately address all significant impacts identified in this study.

The mitigation alternatives fall into following four general types:

- Ground Improvement for Mitigation of Seismic Vulnerability
- Bulkhead Wall and Wharf Structural Retrofits for Mitigation of Seismic Vulnerability

- Bulkhead Wall and Wharf Structural Replacement for Mitigation of Seismic and Sea Level Rise Vulnerability
- Utility Relocation and/or Replacement for Mitigation of Seismic and Sea Level Rise Vulnerability

Geotechnical Solutions

Geotechnical mitigation techniques consist of some form of modification and strengthening of the underlying soil strata. These techniques take the form of jet grouting, deep soil mixing or compaction grouting. The geotechnical mitigation techniques are summarized as follows:

- Jet grouting
- Deep soil mixing
- Compaction grouting

Structural Solutions

Structural mitigation techniques consist of rehabilitation of the existing structure, either by strengthening, supplementing critical structure components and/or replacement of the structure. Supplementing critical structure components involves providing alternative load paths to critical load-resisting components. The bulkhead wharf strengthening techniques include:

- Strengthening of bulkhead wharf pile to deck and wharf deck beam to seawall connections.
- Increasing the vertical load carrying capacity of wharf deck beams.
- Replacement includes partial or total demolition of the existing structure and construction of new structure.

Economic Impacts Study Summary

The study included review of economic impacts to the Port of San Francisco following a seismic event. Service and access restoration intervals of zero, six months and one year were used for assessing maximum possible economic risk over time. Total economic value is tabulated for each seawall section on ***Table 5-1.*** The total economic risk for the entire Northern Seawall is $1.61 billion capital cost plus $2.13 billion per year in variable costs.

Seawall Section Prioritization for Mitigation

A prioritization scenario was assessed using a mix of economic risk, mitigation cost and other issues as parameters. Under this scenario, the recommended first and last priorities for short term mitigation are seawall sections 9 (Pier 26-28) and 9a (Pier 14), respectively. The recommended first and last priorities for long term mitigation are seawall sections 8a (Ferry Plaza) and 9a (Pier 14), respectively

Using other parameter assuming that emergency services and port operations are the highest ranked priority, the recommended first priorities for both short and long term mitigation are seawall sections 4 (Pier 27 and Cruise Terminal) and section CB (China Basin), respectively.

The Port may wish to emphasize essential facilities in their mitigation program rather than economic efficiency, especially with respect to short term mitigation work. If so, it is recommended that Seawall Sections 4 (Cruise Terminal), 7 (Port Offices), 8a and 8b (Ferry Building and Plaza), and 9a (Fire House) be considered as priorities.

7.5. Refining and Implementing Mitigation Strategies

The recommended seawall section priorities for mitigation, as determined by this study, should be used as a basis for further investigation and engineering studies. Short term mitigation work should take precedence over long term mitigation work unless funding is somehow obtained for the latter. Site specific investigation and detailed engineering design of mitigation alternatives applicable and specific to the high priority seawall sections should be performed in order to better define the vulnerability risks and costs of construction. The resulting data may be used in conjunction with this study to revise and enhance the results to refine mitigation costs and seawall section mitigation priorities.

Resiliency Considerations

Recovery and resiliency from earthquakes may include stockpiling of fill material and storage of movable transfer spans that can be implemented following an earthquake where significant damage is sustained. The transfer spans can be used to access bulkhead buildings from the Embarcadero in the case of a localized bulkhead wall failure or used to span areas with significant vertical or lateral ground deformation.

The Port and other San Francisco public agencies may consider maintaining an inventory list and continuously updating emergency resources consisting of temporary bypass piping, pipe, fittings, repair clamps, equipment and having specialized trained personnel available as-needed.

The Port will also have trained staff and consultants available to review the seawall bulkhead wall and bulkhead wharves immediately following an earthquake. Review of these structures should be done in addition to review of the bulkhead and pier shed buildings and other superstructures. Particular attention should be paid to the vulnerable bulkhead wall and wharf components highlighted in this report. Structures showing obvious distress will be red tagged as the Port did previously following the 1989 Loma Prieta earthquake. Small boats, operators, and safety equipment should be readily available as they will be needed for access under the bulkhead wharves. And, on-call contracts with contractors should be in place to ensure their immediate availability after a design-level seismic event.

Sea Level Rise Adaptability with Future Design

All waterfront and vulnerability mitigation projects undertaken by the Port or developers should consider higher water levels due to sea level rise unless very short term (10 to 20 years). Adaptability should be considered and placed into designs where applicable. For example, a concrete wharf deck can have embedded couplers in order to add reinforcing steel later for perimeter barrier or seawall extension.

Critical Lifeline Utilities

The critical utility system elements within the zone of influence require confirmation from the utility agencies that the systems can accommodate the predicted horizontal and vertical ground displacements. There is also confirmation needed with the utility agencies on their emergency plan of actions and mitigation measures.

7.6. Recommendations

Recommendations for Implementing Mitigation Strategies

The recommended seawall section priorities for mitigation, as presented by this study, should be used as a basis for further investigation and engineering studies. Short term mitigation work to address life safety deficiencies should take precedence over long term mitigation work unless funding is somehow obtained for the latter. Site specific investigation and detailed engineering design of mitigation alternatives applicable to high priority seawall sections should be performed in order to better define the vulnerability risks and costs of construction. Essential facility locations such as the Ferry Plaza and Ferry Terminal and Pier 9 should also be among the prioritized sections for mitigation. Access to Ferry Plaza through and adjacent to the Ferry Building and the ferry terminals following an earthquake is a concern; further study is needed for this section as record information for the Ferry Building substructure is not available.

The Port may also consider establishing an implementation program for the vulnerability mitigation projects. The program may include subsurface exploration (boring and sampling) for higher risk seawall sections to determine thickness and material properties of the rock dike and feasibility of pile installation. Detailed site-specific finite element modelling is also recommended using the preferred mitigation alternative to further refine the design and project elements. Existing structures would be included in the detailed analysis.

Recommended Short and Long Term Mitigations

The primary factor behind the significant vulnerability of the Northern Seawall to major earthquake events is the poor quality of the supporting soils and the distinct possibility of large lateral deformations of large volumes of soil strata located under the Northern Seawall.

Therefore, the primary objective of any long term mitigation technique is to reduce or eliminate this soil lateral sliding tendency using geotechnical mitigation methods. Where it is not possible to eliminate this effect, either due to cost or constructability given practical considerations, the mitigation technique would include structural mitigation techniques to arrive at a configuration that would provide acceptable short term performance from a life safety and structural collapse perspective. Long term mitigation would also address sea level rise by raising the wharf deck or bulkhead grade elevation.

This study identified and refined several such combined mitigation alternatives for the purposes of providing:

1 Mitigation alternatives that are applicable to and are likely to be used for at least one seawall section.

2 At least one short term and one long term mitigation alternative for each seawall section

3 A basis for developing rough order of magnitude (ROM) probable cost of construction for mitigation alternatives applicable to a given seawall section.

Appendix A

Report Peer Review Comment Log

Table 1-1: Mitigation Alternatives – Soil Strengthening Concepts

No.	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Estimated Construction Duration	Advantages	Disadvantages	Review Comments LTR Comment in Black COWI Comment in Red	GTC Response
	Near Term (Phase 1)							GENRAL: - Has there been any calculations/engineering evaluations performed in order to develop the options presented? - Is there a narrative (report, memo, letter, etc.) describing the goals objectives, methodology, areas where the different treatment are being considered? - Are all the alternatives being proposed for all the sections, or are some alternatives better suited for certain sections than others? - Is it anticipated that Phase 1 techniques will be used in addition to Phase 2 techniques, or is only one phase being considered? - Are some techniques anticipated to have more issues with subsurface obstructions/existing improvements) than others? - For each of this scheme please look at the feasibility, constructability, permitting and maintenance issues.	This conceptual level study is based on mitigation concepts used on past projects without the detailed engineering analysis that would be required for design-level evaluations of such mitigation techniques. Such a report is being prepared. Some alternatives are applicable to nearly all sections while others (e.g. compaction grouting) were developed for one section that has unique attributes. Applicability of alternatives are shown in tabular format in the Draft Phase 3 report. Both Phase 1 and Phase 2 techniques may be used, and the designation is a work in progress. Yes. For example, deep soil mixing is not easily accomplished with subsurface obstructions/existing improvements. On a conceptual level, these issues are being addressed for the various schemes.

G-2	Lessen vertical and lateral deformations of fill behind seawall	Mitigate liquefaction of fill below The Embarcadero	Stone Columns	• Demolish existing pavements within the Embarcadero promenade and roadway. • Relocate or protect subsurface utilities and other subterranean structures. • Clear obstructions with pre-drilling. • Install stone columns using the dry bottom feed process.	2' of seawall per rig shift (15 stone columns per rig shift)	• Lower cost mitigation once site is cleared. • Mitigates vertical settlement from liquefaction.	• May have limited applicability due to subsurface improvements. • Disruptive to The Embarcadero. • Limited improvement to lateral spread of seawall and resulting damage.	• What is the spacing of the columns? Considering the treatment of 2-feet of seawall with 15-columns, this appears to be a column every 9.3 feet on center, a relatively wide spacing. What was the basis for selecting this spacing and what is the anticipated performance? • With this mitigation technique there may be additional risks/disadvantages that should be considered/evaluated: 1) Significant vibrations during installation and the impacts of such vibrations on adjacent and nearby structures/utilities. 2) Heave of the adjacent ground 3) Settlement of the ground 4) Potentially liquefying the existing fill during installation.	• This was based on a 7' triangular spacing and was estimated based on discussions with Hayward Baker. Performance is anticipated to mitigate liquefaction of treated soils. • Agreed. This evaluation would need to be considered during design of such systems. May elect to perform other ground improvement techniques close to nearby structures/utilities.
G-6	Stabilize existing seawall at Seawall Section 46	Mitigate liquefaction of sand fill within rock dike section	Compaction Grouting	• Work zone from wharf deck. • Pre-drill holes through rock dike. • Inject low-viscosity grout into sand fill below rock dike to densify sand fill.	75 rig shifts for 236 ft. of seawall (250 cy of treated soil volume per rig shift)	• Potentially less construction impacts than other ground improvement methods. • Nearly eliminates lateral spreading and resulting damage for Seawall Section 46.	• Not applicable at other seawall sections.	• Constructability issues and/or considerations: 1) How will quality control be performed? This may be difficult since the treatment will be below the rock fill. 2) Have the issues with penetrating through the rock fill being addressed or considered? 3) What is the frequency of locations and performance required in terms densification? • Has the potential for heave of the ground surface or potential for long term settlement due to the additional weight of the treated soil been evaluated? • Are there any environmental considerations with this option such as a risk of grout entering the Bay? • Would this method be applicable to Sections 1 and 8b?	• 1) Agreed that improvement will be difficult to assess. Grout takes should be recorded to have a rough measure of the level of improvement. 2) Rock fill will need to be penetrated using a downhole hammer and casing. 3) Cost estimates are based on 7 ft. spacing. Will need to further assess during design. • At Seawall Section 46, the rock dike is underlain by stiff soils, so not a significant concern at this section. • With compaction grouting, not too much risk of grout entering the Bay because of its low viscosity. • Also applicable at the Ferry Plaza where sand fill is present (Sections 8a and 8b).

Notes:

1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

No.	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Estimated Construction Duration	Advantages	Disadvantages	Review Comments	GTC Response
	Long Term (Phase 2)								
G-1	Stabilize existing seawall	Mitigate lateral spreading	Jet Grout Buttress	• Identify work zone which may include Embarcadero promenade and roadway, wharf deck and overwater work. • For wharf deck and overwater work, create cofferdam to contain jet grout spoils. • Pre-drill holes through rock dike. • Install jet grout columns to improve young bay deposits underlying rock dike section and tie into rock dike.	150 cy of soilcrete volume per rig shift	• Nearly eliminates lateral spreading and resulting damage to piles, subsurface utilities, etc. that are subjected to large lateral displacements.	• Very expensive and disruptive. • Does not mitigate liquefaction potential of fill behind seawall and resulting vertical settlement.	• This system does not address sea-level rise. • What is the minimum shear strength that the improved soil will need to have? • What is the estimated production rate in terms of length of sea-wall/waterfront? • How will Quality Control be performed during construction? • Does the GTC team anticipate issues with penetrating through the rock fill and if so, how will those issues be addressed? • Has the potential for consolidation settlement due to the increased weight of the treated material been considered and/or evaluated?	• The area treated with jet grout can be built upon with additional fill. • This will need to be evaluated during design but target strengths of 300 psi of soilcrete in the young bay mud is anticipated. • This varies by seawall section because of varations in width and depth of treatment but can be calculated based on total volume of jet grout divided by soilcrete volume per rig shift. • Quality control is difficult to assess, but some ideas may be a test section that is excavated, use of computerized systems to evaluate grouted zones • Penetrating through the rock dike is difficult but possible and is accounted for in the cost estimates. • The Old Bay Clay would be subject to minor amounts of consolidation from added weight.

G-3	Create new seawall structure	Mitigate lateral spreading and raise grade for sea level rise	Deep Soil Mixing – Offshore (Option A)	• Construct a sheet pile / king pile wall bayside of the existing seawall. • Fill behind the wall to above water level (El. +10 ft.) to provide a working pad for DSM equipment. • Implement DSM through the sand fill and young bay mud, keying into underlying sediments. • Fill above DSM to desired grade.	500 cy of soilcrete volume per rig shift	• Nearly eliminates lateral spreading and resulting damage to piles, subsurface utilities, etc. that are subjected to large lateral displacements. • Raises grade to address sea level rise concerns. • Creates new land for development opportunities. • Less disruptive to activities landward of the seawall.	• Impacts to existing finger piers and other structures built outboard of the existing seawall. • Potential permitting issues with new bay fill. • Does not mitigate liquefaction potential of fill behind seawall and resulting vertical settlement.	• Has the potential for consolidation settlement due to the increased weight of the treated material and fill been evaluated? • These elements are typically unreinforced, has the minimum shear capacity/strength been determined? • What is the estimated production rate in terms of length along the sea-wall/waterfront?	• Additional measures to control consolidation-related settlement under the added weight of the fill will be added in the final mitigation concepts. • No, but these values will need to be determined during design. Target strengths of 100 psi of soilcrete in the young bay mud is anticipated without the need for reinforcing elements. • This varies by seawall section because of varations in width and depth of treatment but can be calculated based on total volume of DSM divided by soilcrete volume per rig shift.

No.	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Estimated Construction Duration	Advantages	Disadvantages	Review Comments	GTC Response
	Long Term (Phase 2)								
G-4	Create new seawall structure	Mitigate lateral spreading and raise grade for sea level rise	Deep Soil Mixing – Offshore (Option B)	• Construct a sheet pile / king pile wall bayside of the existing seawall. • Fill behind the wall to desired grade (El. +16.5 ft. assumed). • Implement DSM through the sand fill and young bay mud, keying into underlying sediments. • Install anchor piles in DSM columns on landward side of DSM treatment zone. • Tie sheet pile / king pile wall to anchor piles with tie beams.	500 cy of soilcrete volume per rig shift	• See No. G-3 for advantages. • Lessens DSM treatment zone width from Option A above.	• See No. G-3 for disadvantages.	• Has the potential for consolidation settlement due to the increased weight of the treated material and fill been evaluated? • These elements are typically unreinforced, has the minimum shear capacity/strength been determined? • Is there consideration for reinforcing these elements for providing appropriate shear capacity to the columns? • What is the anticipated production rate in terms of length along the sea-wall/waterfront?	• Additional measures to control consolidation-related settlement under the added weight of the fill will be added in the final mitigation concepts. • No, but these values will need to be determined during design. Target strengths of 100 psi of soilcrete in the young bay mud is anticipated. • We do not anticipate that the columns will be reinforced but this should be looked at during design level studies. • This varies by seawall section because of variations in width and depth of treatment but can be calculated based on total volume of DSM divided by soilcrete volume per rig shift.

G-5	Stabilize existing seawall	Mitigate lateral spreading	Jet Grout Mitigation – On Land	• Demolish existing pavements within the Embarcadero promenade and roadway. • Relocate or protect subsurface utilities and other subterranean structures. • Pre-drill holes through rock dike. • Install jet grout columns to improve young bay deposits and artificial fill within treatment zone.	150 cy of soilcrete volume per rig shift	• Nearly eliminates lateral spreading and resulting damage to piles, subsurface utilities, etc. that are subjected to large lateral displacements. • Mitigates liquefaction potential of fill behind seawall and resulting vertical settlement within treatment zone.	• Very expensive and disruptive.	• Has the potential for consolidation settlement due to the increased weight of the treated material and fill been evaluated? • These elements are typically unreinforced, has the minimum shear capacity/strength been determined? • What is the estimated production rate in terms of length of sea-wall/waterfront? • Are there areas where this option is not feasible due to site constraints or existing improvements? • This method only improves the area of the treatment. It does not improve anything on the bayside of the seawall, and as such there is still a potential for movement and damage of improvements on the bayside of the seawall.	• The Old Bay Clay would be subject to minor amounts of consolidation from added weight. • No, but these values will need to be determined during design. Target strengths of 100 psi of soilcrete in the young bay mud is anticipated. • This varies by seawall section because of varations in width and depth of treatment but can be calculated based on total volume of jet grout divided by soilcrete volume per rig shift. • There are likely going to be areas where jet grouting is not feasible although it is one of the more versatile tools for ground improvement. • Agreed, though the driving forces for slope instability are much reduced so the performance of the seawall is expected to improve considerably.

Table 1-2: Mitigation Alternatives Summary – Structural Concepts

No.	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Estimated Construction Duration	Advantages	Disadvantages	Review Comments LTR Comment in Black COWI Comment in Red	JV Response Geotech Responses in Black Structural Responses in Red
	Near Term (Phase 1)							**GENERAL:** - Are all the alternatives being proposed for all the sections, or are some alternatives better suited for certain sections than others? - Is it anticipated that Phase 1 techniques will be used in addition to Phase 2 techniques, or is only one phase being considered? - Are some techniques anticipated to have more issues with subsurface obstructions/ existing improvements) than others? - Are there well-defined Phase 1 (Near Term) and Phase 2 (Long Term) seismic performance-based criteria for the structural and/or geotechnical improvement? - For each of this scheme please look at the feasibility, constructability, permitting and maintenance issues.	1. **Some alternatives are better suited for certain sections than others.** 2. **Anticipate Phase 1 techniques to address short term life safety issues. Phase 2 techniques more appropriate for longer term LS and collapse limit states.** 3. **Yes.** 4. **Phase 1 addresses seismic inertial LS issues. Phase 2 addresses seismic soil lateral sliding and sea level rise issues.** 5. **OK.**
S-1	Improve life-safety by lessening lateral deformation of concrete bulkhead	Stabilize concrete bulkhead by adding lateral restraint	Seawall with Grouted Tie-Backs and Micropiles	• Demolition required at promenade and bulkhead wharf for access to drill and install grouted tie-back anchors from bayside of seawall • Micropiles installed where wingwalls present • CIP concrete wale constructed along face of seawall. • Promenade and bulkhead wharf are impacted.	5-6 months per 500 LF seawall section	• Provides short term seismic life safety performance for seawall structures	• Does not mitigate long term soil lateral sliding or bulkhead wharf seismic vulnerability • Does not accommodate sea level rise • Addresses seawall stability only • Partial demolition of bulkhead wharf may be required / disruption fairly significant • Utilities and other	• There may be difficulties and the need for specialized equipment to drill through the existing rock dikes. • Tiebacks will need to gain resistance in material not susceptible to creep or strength loss during a seismic event. • Tieback design details (unbonded, and bonded length) may vary significantly along the alignment due to variations in the subsurface conditions. • What is the maintenance requirement for these tiebacks? • Will these tiebacks prevent existing timber piles underneath seawall from failing under DE event?	• Agreed. • Agreed that the grout bond zone is ideally in stiffer soils. • Agreed. • Will need to provide adequate corrosion protection to the tieback system to obtain the necessary design life of the retrofit system. • Tie backs resists the lateral load demand, provide an alternative load path.

							subgrade infrastructure may present an obstruction		
S-2	Improve life-safety by lessening lateral deformation of concrete bulkhead	Stabilize concrete bulkhead by adding lateral restraint	Seawall with Cap Strut and Pile	• Demolition as required at promenade and bulkhead wharf for access to install steel pile • CIP pile caps and struts constructed at face of seawall • Promenade and bulkhead wharf are impacted.	4-6 months per 500 LF seawall section	• Provides short term seismic life safety performance for seawall structures • Partially mitigate soil lateral sliding if closely spaced steel pipe piles are used (multiple rows may be required)	• Does not accommodate sea level rise • Addresses seawall stability only • Partial demolition of bulkhead wharf and buildings is required	• It may be difficult to install micro-piles within the rock dike. It may be difficult to drill through the rock dike, and there may be significant grout loss in the rock dike. • It may be difficult to drive pipe piles through the rock dike. It may be necessary to remove and replace the rock dike in order to install the piles. • Have these issue been considered and how will they be addressed? • What is the typical spacing of these (N) 24" dia. pipe piles to partially mitigate soil lateral sliding? Do these piles need reinforced concrete core?	• Agreed, that rock dike adds complexity and cost to drilled elements. Can include permanent casing to control grout loss in rock dike. • Thick-walled pipe piles have historically been able to be driven through the rock dike. May need to spud through rock dike in some locations. • These isssues need to be addressed during the design phase of projects. • Provide pipe piles as a function of vertical load demand., check for global seismic capacity. 24" dia pipe pile should be able to withstand lateral sliding displacements, concrete core should not be needed (eg, BSW design).
~~S-3~~ S-4?	Improve life-safety by lessening lateral deformation of concrete bulkhead	Stabilize concrete bulkhead by increasing lateral resistance using larger revetment.	Added Revetment	• Minor amount of dredging is required using barge-mounted excavator • New revetment requires flatter slope on the revetment • Benched area provided at toe of revetment • Placement of rock performed using crane and rock barge • Water areas in front of seawall are impacted.	2 months per 500 LF seawall section	• Provides short term seismic life safety performance for seawall structures	• Not applicable where bulkhead wharf is present • Does not accommodate long term soil lateral sliding • Does not accommodate sea level rise • Addresses seawall stability only • Potential for long term settlement may require additional rock placement over time • Minor dredging required • Environmental permitting required due	• Should this be No. S-4? This alternative seems to be consistent with Figure S-4. • Has the potential for settlement of the existing seawall due to consolidation of the underlying Bay deposits been evaluated? • Is the (N) revetment bench considered bay-filling? Permitting and maintenance issues?	• Yes • Yes, this will need to be a design consideration and more revetment than needed may be needed to account for consolidation. • This alternative, as with any of them, requires BCDC and permitting agency approval.

							to in-water work		
~~S-4~~ S-3?	Improve life-safety by lessening lateral deformation of concrete bulkhead	Stabilize concrete bulkhead by adding lateral restraint	Seawall with Tie-back Anchor Piles	• Demolish existing infrastructure landward of the existing seawall as needed • Install new anchor piles • Trenching for tie-back rod placement • Piles installed using track crane • Install new tie-back anchors to anchor pile wall and connect to seawall • Promenade and Embarcadero roadway will be impacted	5-6 months per 500 LF seawall section	• Provides short term seismic life safety performance for seawall structures	• Does not accommodate long term soil lateral sliding • Does not accommodate sea level rise • Addresses seawall stability only • Significant impacts to promenade and Embarcadero roadway • Utilities and other subgrade infrastructure may present an obstruction	• Should this be No. S-3? This alternative seems to be consistent with Figure S-3. • What is the anticipated spacing of the tie-rods? • Construction and maintenance issues? • Elongation of (N) tie-back anchor rods on the effectiveness of laterally restraining seawalls? • What's typical size of (N) HP anchor pile or stiffness required? Need batter-pile anchoring bent?	• Yes • Should be evaluated during design phase of the project. • Construction issues – public disruption of streets and buildings. Maintenance, will need durable coatings and a long term, monitorable CP system. • Prestress the tie-backs. • TBD. Estimate HP16 or so, dependent on soil properties after remediation if any. Batter piles stiffen anchorage, needs consideration.

Notes:

1. Near Term (Phase 1) mitigation addresses life-safety seismic hazard and liquefaction within fill material behind seawall.
2. Long Term (Phase 2) mitigation addresses collapse prevention seismic hazard (soil lateral sliding), sea level rise and flooding.

3.

No.	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Estimated Construction Duration	Advantages	Disadvantages	Review Comments	JV Response Geotech Responses in Black Structural Responses in Red
	Near Term (Phase 1)								
S-11	Improve life-safety of bulkhead wharf and seawall structures	• Improve life-safety of bulkhead wharf structure • Stabilize concrete bulkhead by adding lateral restraint • Steel wharf pile is provided to survive the lateral sliding displacement and support the existing deck and buildings should adjacent existing piles fail under soil lateral sliding	Near Term Structural Rehabilitation of Bulkhead Wharf and Seawall with Grouted Tie-backs	• Demolish existing structure in front of and above existing seawall as needed • Install steel pipe piles bayside of bulkhead wharf to accommodate soil lateral sliding • Retrofit bulkhead wharf to seawall beam connections • Pile/wharf deck connections strengthened • Existing wharf piles are strengthened using jacket encapsulation where required • Retrofit existing deck beams to accommodate increased effective wharf deck spans when existing piles damaged by soil lateral sliding • Install new grouted tie-back anchors into competent landside soil strata and connect to seawall • Replace any demolished existing structure as required	14 to 16 months per 500 LF seawall section	• Provides short term seismic life safety performance • Bulkhead buildings may remain • Minimizes impact to Embarcadero roadway	• Does not accommodate sea level rise • Does not mitigate long term soil lateral sliding (kinematic loading) without installation of closely spaced steel pipe piles • Partial demo of existing wharf and supported buildings needed to install bay-side piles • See S-1 for additional disadvantages	• There may be difficulties and the need for specialized equipment to drill through the existing rock dikes. • Tiebacks will need to gain resistance in material not susceptible to creep or strength loss during a seismic event. • Tieback design details (unbonded, and bonded length) may vary significantly along the alignment due to variations in the subsurface conditions. • How is the issue of insufficient pile vertical capacity (after DE event) addressed by this mitigation scheme? • Permitting issue from possible increase of bay coverage? • Are (N) 24" diameter cantilever pipe piles large enough to resist combined seismic lateral loads from the pier and kinematic loads? Are batter piles needed?	• Agreed. • Agreed that the grout bond zone is ideally in stiffer soils. • Agreed. • Steel wharf piles to be designed to provide sufficient vertical capacity after design basis events. • This alternative, as with any of them, requires BCDC and permitting agency approval. • If N-24 not large enough, use larger piles as needed. Batter piles to be avoided.
S-12	Improve near term life-safety of bulkhead wharf and seawall structures	• Improve life-safety of bulkhead wharf structure • Stabilize concrete bulkhead by adding lateral restraint • Steel wharf pile is provided to survive the lateral sliding displacement and support the existing deck and buildings should adjacent existing piles fail under soil lateral sliding	Near Term Structural Rehabilitation of Bulkhead Wharf and Seawall with Anchor Pile Tie-backs	• Demolish existing structure in front of and above existing seawall as needed • Install steel pipe piles bayside of bulkhead wharf to accommodate soil lateral sliding. • Retrofit bulkhead wharf to seawall beam connections • Pile/wharf deck connections strengthened • Retrofit existing deck beams to accommodate deck effective increased spans for existing piles affected by soil lateral sliding • Install new H-piles and anchor pile wall landside of seawall and connect to seawall. Trenches for tie-back rods	14 to 16 months per 500 LF seawall section	• Provides short term seismic life safety performance • Bulkhead buildings may remain	• Does not accommodate sea level rise • Does not mitigate long term soil lateral sliding (kinematic loading) without installation of closely spaced steel pipe piles • Partial demo of existing wharf and supported buildings needed to install Bay-side piles • See S-4 for additional disadvantages	• What Is the anticipated spacing of the tie-rods? • Please see comments on S-3 for horizontal tie-backs and S-11.	• Should be evaluated during design phase of the project. • See responses on S-3.

No.	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Estimated Construction Duration	Advantages	Disadvantages	Review Comments	JV Response **Geotech Responses in Black** **Structural Responses in Red**
	Near Term (Phase 1)								
S-13	Improve near term life-safety of bulkhead wharf and seawall structures	• Improve life-safety of bulkhead wharf structure • Stabilize concrete bulkhead by adding lateral restraint • Steel wharf pile is provided to survive the lateral sliding displacement and support the existing deck and buildings should adjacent existing piles fail under soil lateral sliding	Near Term Structural Rehabilitation of Bulkhead Wharf and Seawall with Steel Pipe Piles and Cap	• Demolish existing structure in front of and above existing seawall as needed • Install steel pipe piles and cap bayside of bulkhead wharf to accommodate soil lateral sliding. • Retrofit bulkhead wharf to seawall beam connections • Pile/wharf deck connections strengthened • Retrofit existing deck beams to accommodate deck effective increased spans for existing piles affected by soil lateral sliding • Install new steel pipe piles and cap bayside of seawall and connect to seawall using strut.	14 to 16 months per 500 LF seawall section	• Provides short term seismic life safety performance • Bulkhead buildings may remain • New steel piles supporting providing lateral restraint to seawall can be closely spaced to mitigate soil lateral sliding	• Does not accommodate sea level rise • Does not accommodate long term soil lateral sliding (kinematic loading) without installation of closely spaced steel pipe piles • Partial demo of existing wharf and supported buildings needed to install bay-side piles • See S-2 for additional disadvantages	• There may be difficulties with driving piles through the existing rock dike. Which may require removal and replacement of the rock dike. • Please see comments on S-2 and S-11	• Thick-walled pipe piles have historically been able to be driven through the rock dike. May need to spud through rock dike in some locations. • Please see responses on S-2 and S-11.
S-14	Improve near term life-safety of bulkhead wharf and seawall structures. Addition of jet grouting per Mitigation Concept G-5 can mitigate soil lateral sliding.	See S-11 and G-5	See S-11 and G-5	See S-11 and G-5. Also, • Demolish existing pavements within the Embarcadero promenade and roadway • Relocate or protect subsurface utilities and other subterranean structures • Pre-drill holes through rock dike. • Install jet grout columns to improve young bay deposits and artificial fill within treatment zone	16 to 18 months per 500 LF seawall section	• See S-11 and G-5 • Addition of jet grouting per Mitigation Concept G-5 can mitigate soil lateral sliding • Landside and waterside work can be phased	See S-11 and G-5	See comments for S-11 and G-5.	See responses on S-11 and G-5.

S-15	Improve near term life-safety of bulkhead wharf and seawall structures. Addition of jet grouting per Mitigation G-5 can mitigate soil lateral sliding.	See S-12 and G-5	See S-12 and G-5	See S-12 and G-5. Also, • Demolish existing pavements within the Embarcadero promenade and roadway • Relocate or protect subsurface utilities and other subterranean structures • Pre-drill holes through rock dike. • Install jet grout columns to improve young bay deposits and artificial fill within treatment zone	16 to 18 months per 500 LF seawall section	• See S-12 and G-5 • Addition of jet grouting per Mitigation G-5 can mitigate soil lateral sliding • Landside and waterside work can be phased	See S-12 and G-5	See comments for S-12 and G-5.	See responses on S-12 and G-5.

No.	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Estimated Construction Duration	Advantages	Disadvantages	Review Comments	JV Response **Geotech Responses in Black** **Structural Responses in Red**
	Near Term (Phase 1)								
S-16	Improve near term life-safety of bulkhead wharf and seawall structures. Addition of jet grouting per Mitigation G-5 can mitigate soil lateral sliding.	See S-13 and G-5	See S-13 and G-5	See S-13 and G-5. Also, • Demolish existing pavements within the Embarcadero promenade and roadway • Relocate or protect subsurface utilities and other subterranean structures • Pre-drill holes through rock dike • Install jet grout columns to improve young bay deposits and artificial fill within treatment zone	16 to 18 months per 500 LF seawall section	• See S-13 and G-5 • Addition of jet grouting per Mitigation G-5 can mitigate soil lateral sliding • Landside and waterside work can be phased	See S-13 and G-5	See comments for S-13 and G-5.	See responses on S-13 and G-5.

No.	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Estimated Construction Duration	Advantages	Disadvantages	Review Comments	JV Response **Geotech Responses in Black** **Structural Responses in Red**
	Long Term (Phase 2)								
S-21	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures	• Stabilize concrete bulkhead to meet seismic demand by adding lateral restraint • Improve near term life safety of bulkhead wharf structure and mitigate soil lateral sliding by use of closely spaced stiff piles	Super Bulkhead Wharf with grouted tie-back anchors	• Demolish existing bulkhead wharf along section (work may be phased) • Demolish existing infrastructure as needed • Install new grouted tie-back anchors into competent landside soil strata and connect to seawall • Replace existing bulkhead wharf structure with new piled bulkhead wharf structure with closely spaced steel pipe piles (concrete piles used on outer rows). • Replace previously supported infrastructure with new construction in-kind • Permanent transfer span may be required for access to finger pier following construction	18 – 20 months per 500' seawall section	• Mitigates short term seismic life safety issues • Mitigates long term soil lateral sliding by providing closely spaced steel pipe piles • Accommodates sea level rise by providing higher wharf deck elevation • Minimizes impact to promenade and Embarcadero roadway	• Bulkhead buildings must be temporarily relocated or demolished • Partial demolition of adjacent finger pier is required for construction • See S-1 for additional disadvantages	• There may be difficulties and the need for specialized equipment to drill through the existing rock dikes and install piles through the existing rock dikes. • Tiebacks will need to gain resistance in material not susceptible to creep or strength loss during a seismic event. • Tieback design details (unbounded, and bonded length) may vary significantly along the alignment due to variations in the subsurface conditions. • Is it economically feasible to use large diameter (24" min) steel pipe piles to mitigate long term soil lateral sliding? What's the typical pile spacing? Will soil under the rock dike liquefy?	• Agreed. • Agreed that the grout bond zone is ideally in stiffer soils. • Agreed. • Economic feasibility is relative to other alternatives. Pile spacing a function of mitigation requirements, vertical and seismic inertial demand.
S-22	Address long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures	• Stabilize concrete bulkhead to meet seismic demand by adding lateral restraint • Improve near term life safety of bulkhead wharf structure and mitigate soil lateral sliding by use of closely spaced stiff piles	Super Bulkhead Wharf with tie-back anchor piles	• Demolish existing bulkhead wharf along section (work may be phased) • Demolish existing infrastructure as needed • Install anchor piles and tie-back anchor rods and connect to seawall • Replace existing bulkhead wharf structure with new piled bulkhead wharf	18 - 20 months per 500' seawall section	• Mitigates short term seismic life safety issues • Mitigates long term soil lateral sliding by providing closely spaced steel pipe piles • Accommodates sea level rise by providing higher wharf deck elevation	• Historic bulkhead buildings must be temporarily relocated or demolished • Partial demolition of adjacent finger pier is required for construction • Promenade and Embarcadero roadway are impacted by installation of tie-back and anchor	• There may be difficulties with driving piles through the existing rock dike. This may require removal and replacement of the rock dike. • What is the anticipated spacing of the tie-rods? • See comments on S-21	• Thick-walled pipe piles have historically been able to be driven through the rock dike. May need to spud through rock dike in some locations. • Should be evaluated during design phase of the project. • See responses on S-21.

				structure with closely spaced steel pipe piles (concrete piles used on outer rows). • Replace previously supported infrastructure with new construction in-kind • Permanent transfer span may be required for access to finger pier following construction			piles • See S-4 for additional disadvantages		

No.	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Estimated Construction Duration	Advantages	Disadvantages	Review Comments	JV Response Geotech Responses in Black Structural Responses in Red
	Long Term (Phase 2)								
S-23	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures	• Stabilize concrete bulkhead to meet seismic demand by adding lateral restraint • Improve near term life safety of bulkhead wharf structure and mitigate soil lateral sliding by use of closely spaced stiff piles	Super Bulkhead Wharf with pile and cap strut in front of seawall	• Demolish existing bulkhead wharf along section (work may be phased) • Demolish existing infrastructure as needed • Install pile cap and strut connection to bulkhead. • Replace existing bulkhead wharf structure with new piled bulkhead wharf structure with closely spaced steel pipe piles (concrete piles used on outer rows). • Replace previously supported infrastructure with new construction in-kind • Permanent transfer span may be required for access to finger pier	18 – 20 months per 500 LF seawall section	• Mitigates short term seismic life safety issues • Mitigates long term soil lateral sliding by providing closely spaced steel pipe piles • Accommodates sea level rise by providing higher wharf deck elevation • Minimizes impact to promenade and Embarcadero roadway	• Historic bulkhead buildings must be temporarily relocated or demolished • Partial demolition of adjacent finger pier is required for construction	• There may be difficulties with driving piles through the existing rock dike. This may require removal and replacement of the rock dike. • See comments on S-21	• Thick-walled pipe piles have historically been able to be driven through the rock dike. May need to spud through rock dike in some locations. • See responses on S-21.
S-24	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures Addition of jet grouting per Figure G-5 can mitigate soil lateral sliding and reduce displacement demand on wharf piles.	• Address long term performance of bulkhead wharf structure • Stabilize concrete bulkhead by adding lateral restraint • This mitigation concept uses waterside construction in the bulkhead wharf zone along with landside construction for jet grouting under the rock dike	Super Bulkhead Wharf with Soil Strengthening	See S-21 and G-5	18 – 22 months per 500 LF seawall section	• Mitigates short term seismic life safety issues • Mitigates long term soil lateral sliding by use of soil strengthening (jet grouting) • Jet grouting can be landside operation • Accommodates sea level rise by providing higher wharf deck elevation • Landside soil strengthening (jet grouting) and wharf	• Historic bulkhead buildings must be temporarily relocated or demolished • Partial demolition of adjacent finger pier is required for construction • Promenade and Embarcadero roadway are impacted by jet grouting operations (see G-5 description)	• See G-5 and S-21 Comments.	• See G-5 and S-21 responses.

						replacement can be conducted simultaneously • New wharf pile displacement demand greatly reduced by soil strengthening • Landside and waterside work may be phased • Large diameter steel wharf piles may be used to stabilize concrete bulkhead and eliminate grouted tie-back anchors			

No.	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Estimated Construction Duration	Advantages	Disadvantages	Review Comments	JV Response Geotech Responses in Black Structural Responses in Red
	Long Term (Phase 2)								
S-25	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures Addition of jet grouting per Figure G-5 can mitigate soil lateral sliding and reduce displacement demand on wharf piles.	• Address long term performance of bulkhead wharf structure • Stabilize concrete bulkhead by adding lateral restraint • This mitigation concept uses waterside construction in the bulkhead wharf zone along with landside construction for jet grouting under the rock dike	Super Bulkhead Wharf with Soil Strengthening	See S-22 and G-5	18 – 22 months per 500 LF seawall section	• Mitigates short term seismic life safety issues • Mitigates long term soil lateral sliding by use of soil strengthening (jet grouting) • Jet grouting can be landside operation • Accommodates sea level rise by providing higher wharf deck elevation • Landside soil strengthening (jet grouting) and wharf replacement can be conducted simultaneously • New wharf pile displacement demand greatly reduced by soil strengthening • Landside and waterside work may be phased • Large diameter steel wharf piles may be used to stabilize concrete bulkhead and eliminate grouted tie-back anchor piles	• Historic bulkhead buildings must be temporarily relocated or demolished • Partial demolition of adjacent finger pier is required for construction • Promenade and Embarcadero roadway are impacted by jet grouting operations (see G-5 description)	• See S-22 and G-5 Comments.	• See S-22 and G-5 responses.
S-26	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures	• Address long term performance of bulkhead wharf structure • Stabilize concrete bulkhead by adding lateral restraint	Super Bulkhead Wharf with Soil Strengthening	See S-23 and G-5	18 – 22 months per 500 LF seawall section	• Mitigates short term seismic life safety issues • Mitigates long term soil lateral sliding by use of soil strengthening (jet	• Historic bulkhead buildings must be temporarily relocated or demolished • Partial demolition of adjacent finger pier	• See S-23 and G-5 Comments.	• See S-23 and G-5 responses

	Addition of jet grouting per Figure G-5 can mitigate soil lateral sliding and reduce displacement demand on wharf piles.	• This mitigation concept uses waterside construction in the bulkhead wharf zone along with landside construction for jet grouting under the rock dike				grouting) • Jet grouting can be landside operation • Accommodates sea level rise by providing higher wharf deck elevation • Landside soil strengthening (jet grouting) and wharf replacement can be conducted simultaneously • New wharf pile displacement demand greatly reduced by soil strengthening • Landside and waterside work may be phased • Large diameter steel wharf piles may be used to stabilize concrete bulkhead	is required for construction • Promenade and Embarcadero roadway are impacted by jet grouting operations (see G-5 description)		

No.	Performance Objective	Purpose	Description	Construction Sequence and Impacted Area	Estimated Construction Duration	Advantages	Disadvantages	Review Comments	JV Response **Geotech Responses in Black** **Structural Responses in Red**
	Long Term (Phase 2)								
S-31	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures	• Soil strengthening is performed to reduce extent of lateral sliding and reduce the active soil pressures on the new bulkhead combi-wall • Concept uses waterside construction in the bulkhead wharf zone along with landside construction for installation of stone columns for mitigation of ground displacement due to liquefaction	Improved Earth Structure with grouted tie-back anchors	• Demolish existing infrastructure supported by bulkhead wharfs • Demolish existing bulkhead wharf in its entirety or, alternatively, abandon structure in place as appropriate • Bay-side of existing bulkhead wharf, install king pile combi-sheet pile wall of a height to accommodate sea level rise • Install fill and improve soil landside of the combi-wall using deep soil mixing. • Install grouted tie-back anchors • New improved wharf is assumed to be 150 feet wide on average • Replace previously supported infrastructure with new construction in-kind • Permanent transfer span may be required for access to finger pier	18 - 20 months per 500 LF seawall section	• Mitigates both short and long term vulnerability • Provide increased waterfront commercial/retail area and allows for greater public access • Width of DSM buttress (increased Bay fill) can be reduced by using anchor piles and tie-beams (see G-4) • King pile bulkhead lateral restraint using permanent ground anchors or, anchor piles/tie-rods is dependent on height of wall and thickness of soft clay layer at different sections	• Bulkhead buildings must be temporarily relocated or demolished • Partial demolition of adjacent finger pier is required for construction • Significant environmental permitting due to Bay fill • DSM spoils will need to be reused as fill or hauled offsite • See G-3, G-4 and S-1 for additional disadvantages	• See G-3, G-4, and S-1 comments. • There may be significant differential settlement along the length of the tie-rod anchor that may stress the anchor. • Difficult to get permit over Bay Fill? • Maintenance requirement for permanent ground anchor?	• See G-3, G-4 and S-1 responses. • Agreed that this should be evaluated and mitigated during the design phase of the project. • This alternative, as with any of them, requires BCDC and permitting agency approval. • Durable coatings and long lasting, monitorable CP system.
S-32	Addresses long term performance (collapse prevention) and sea level rise of bulkhead wharf and seawall structures	• Soil strengthening is performed to reduce extent of lateral sliding and reduce the active soil pressures on the new bulkhead combi-wall • Concept uses waterside construction in the	Improved Earth Structure with tie-back anchor piles	• Demolish existing infrastructure supported by bulkhead wharfs • Demolish existing bulkhead wharf in its entirety or, alternatively, abandon structure in place as appropriate	18 - 20 months per 500 LF seawall section	• Mitigates both short and long term vulnerability • Provides increased waterfront commercial/retail area and allows for greater public access • Width of DSM buttress (increased	• Bulkhead buildings must be temporarily relocated or demolished • Partial demolition of adjacent finger pier is required for construction • Significant environmental	• See G-3, G-4, and S-1 comments. • There may be significant differential settlement along the length of the tie-back anchor that may stress the anchor. • See comments on S-31	• See G-3, G-4, and S-1 responses. • Agreed that this should be evaluated and mitigated during the design phase of the project. • See responses on S-31.

		bulkhead wharf zone along with landside construction for installation of stone columns for mitigation of ground displacement due to liquefaction		• Landside of existing bulkhead wharf, install king pile combi-sheet pile wall of a height to accommodate sea level rise • Improve soil backfill landside of the combi-wall using deep soil mixing • Install anchor piles and tie-back rods • New improved wharf is assumed to be 150 feet wide on average • Replace previously supported infrastructure with new construction in-kind • Permanent transfer span may be required for access to finger pier		Bay fill) can be reduced by using anchor piles and tie-beams (see G-4) • King pile bulkhead lateral restraint using permanent ground anchors or, anchor piles/tie-rods is dependent on height of wall and thickness of soft clay layer at different sections	permitting due to Bay fill • DSM spoils will need to be reused as fill or hauled offsite • Promenade and Embarcadero roadway are impacted by installation of anchor piles and tie-rods at sections where required • See G-3, G-4 and S-1 for additional disadvantages		

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