MEMORANDUM

April 7, 2016

TO: MEMBERS, PORT COMMISSION
Hon. Willie Adams, President
Hon. Kimberly Brandon, Vice President
Hon. Leslie Katz
Hon. Eleni Kounalakis
Hon. Doreen Woo Ho

FROM: Elaine Forbes
Interim Executive Director

SUBJECT: Informational presentation on the Results of the Earthquake Vulnerability Study of the Northern Waterfront Seawall

DIRECTOR'S RECOMMENDATION: Informational Only; No Action Required

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Executive Summary

The City is engaged in an effort to prepare for a major earthquake and to create more resilient City infrastructure. As part of this effort, the Port is developing a plan to strengthen the Northern Waterfront Seawall ("Seawall") to maintain viability of Port's operations, increase protection of Port and City assets, and enhance life safety in the face of degradation, flooding, earthquakes, climate change, and security hazards. The Seawall was constructed over 100 years ago within the Bay and supports reclaimed land, or fill, and as a result is more vulnerable to seismic risk. Earthquake performance of reclaimed land is an issue for coastal communities worldwide. This staff report presents a summary of the initial findings of earthquake vulnerability and mitigation alternatives for the Northern Waterfront Seawall, which stretches from Fisherman's Wharf to Mission Creek. The Study is at an advanced draft stage, has been developed with input and review by Port staff, has been peer reviewed by an independent engineering team, and will be finalized in June 2016 after input from the Port Commission, public and key stakeholders. Results of the Study will be used to advance the Port and City's resiliency goals for the waterfront, and to work with Port tenants, City and public agencies to plan Seawall seismic improvements.

The primary study findings are:

- Most of the Seawall is built over Young Bay Mud, a weak, saturated, and highly compressible marine clay that tends to amplify earthquake shaking and is susceptible to earthquake induced lateral spreading and settlement.

- Fill that was used to create the land behind the Seawall is susceptible to liquefaction, a phenomenon where the soil loses strength and behaves similarly to a liquid. This has previously been predicted, however, the Study confirms the potential based on current knowledge.

- Large earthquakes will likely cause most of the Seawall to settle and move outward toward the Bay due to a combination of weakness in the underlying Bay Mud and increased pressure from the liquefiable fill. The amount of movement varies across the waterfront, but in general, up to a foot is predicted in moderate to large earthquakes and more than several feet is predicted in a major earthquake. Complete failure of the Seawall is unlikely.

- Seawall movement will significantly increase earthquake damage and disruption along the waterfront. Historic bulkhead wharf structures built of non-ductile concrete are particularly at risk to increased levels of damage. Piers are at risk to increased damage where they connect to the bulkhead wharves, and to disruption from utility damage and land access. The bulkhead wall may be compromised in some areas leading to erosion from tides and waves. Within The Embarcadero, lateral spreading and settlement associated with Seawall movement will increase damage to utilities, Embarcadero Promenade and roadway, and Muni light rail tracks.

- While the Seawall has survived over 100 years in an active earthquake zone, the infrastructure has not weathered a major earthquake. Most of the bulkhead buildings and piers in the Northern Waterfront were built after the Great 1906 Earthquake; therefore, it was not a test of performance in a major earthquake. The fact that the Ferry Building was in place and survived largely intact is encouraging, but is not representative of the expected behavior of most structures and the Seawall in a repeat of a major seismic event[1]. The 1989 Loma Prieta Earthquake, a damaging earthquake that helped to transform the waterfront, was only a minor test of the Seawall itself. If a similar size earthquake occurs 10 miles away on the San Andreas Fault, rather than 60 miles away, it would likely cause much higher levels of ground shaking, Seawall movement, and damage.

- The Study includes an economic analysis which indicates that $1.6B in Port assets are at risk from earthquake damage within the Seawall zone of influence, and that $2.1B of rents, business income, and wages are generated yearly in these Port assets. Besides direct and indirect impacts to the Port, the Northern Waterfront is a major contributor to the tourism industry, valued at over $11B per year, and of significant overall economic importance to the City and Bay Area. Recent disasters have shown that reducing recovery time is the key to managing the overall impact of a major disaster, both economic and to human suffering. The performance of key

[1] The Ferry Building area was constructed early and is unique. Being located in deep Bay Mud out in Yerba Buena Cove, the design consists of a massive pile supported concrete bulkhead wall integral with the arched concrete foundation of the Ferry Building, itself supported by over 6,000 timber piles which stop short of firm ground. A timber relieving platform is located landside to prevent the weight of fill from squeezing mud out under the wall.

Port water transportation and maritime facilities in the Northern Waterfront will be a significant player in any post-disaster recovery effort, so the accessibility and continued function of these facilities is a priority.

- It is feasible to stabilize the Seawall by improving the soils below and the fill behind, however construction is costly and disruptive. Stabilizing the Seawall will greatly improve the earthquake safety and performance of the Northern Waterfront including the existing wharves, piers, utilities, roadway, and light rail. The Study evaluated various concepts and developed rough order of magnitude costs that exceed several billion dollars. It is important to note that at this stage, these are very conceptual improvements and costs are subject to change.

- Seattle is facing earthquake safety concerns and deterioration of its Seawall and is in the process of replacing a key section stretching slightly less than one mile. The project is still in construction and costs are in the range of $500M per mile.

- Earthquake safety and performance of the Seawall should be improved, and sea level rise and climate change must factor into the decisions. Rising seas and climate change will necessitate intervention that may include major changes to the Northern Waterfront and the Seawall over the next 100 years. A damaging earthquake could occur at any time, and there is scientific consensus that one is nearly certain to occur within the next 30 years. Given this context, careful and informed decision-making is necessary to direct limited resources. This Study goes a long way to advance the earthquake safety and performance picture of the Seawall; however, much more study and outreach with stakeholders is needed to inform decision-making on the scope and approaches for improving the earthquake performance of the Seawall.

Port efforts on this Study have been underway for the last year, with ongoing coordination with the City's Chief Resiliency Officer and City Capital Planning Committee. Improvements to the Seawall are recognized as an important City infrastructure need that is included in the Citywide Resiliency Plan, Lifelines Council, and City capital planning efforts. Staff believes significant improvements should be made and that an 8 to 10 year effort is required for a project of this scale.

This report concludes with recommended next steps to further define and prioritize areas of the Seawall and adjoining land and structures that should be seismically improved.

Strategic Objective

This effort complies with the Port's Resiliency Strategy which is to *Lead the City's effort to address infrastructure and Seawall resiliency to earthquake, sea level rise and natural hazards*.

Study Team and Approach

In October 28, 2014[2], the Port hired GHD/GTC JV, a joint venture to lead a team of geotechnical and civil engineers, and cost estimating, economics and coastal engineering professionals to conduct a 3-part Earthquake Vulnerability Study of the Northern Waterfront Seawall ("Study"). Port staff provided a Port Commission briefing on the first part of the study, geotechnical conditions, in October 13, 2015[3] ; Part 2 produced a Vulnerability Assessment, and Part 3 presents a range of conceptual solutions. This staff report provides an overview and draft findings of the entire Study. The Port hired COWI and Langan, engineering firms with expertise in waterfront structures, to peer review the engineering vulnerability analysis and project solutions.

The Seawall and Seismic Risk

The Northern Waterfront Great Seawall ("Seawall") provides the foundation of the waterfront from Fisherman's Wharf in the north to Mission Creek in the south. Constructed between 1879 and 1916, the Seawall made possible the transformation of three miles of shallow tidelands into a world-class maritime waterfront that was key to the development and prosperity of San Francisco. Constructed hundreds of feet Bayward of the natural shoreline, the Seawall was built by dredging a trench through the mud, approximately100 feet wide and 30 feet deep, filling the trench with rock to create a pyramid shaped dike up to 40 feet tall, capped with a "bulkhead wall". The Seawall and bulkhead wall provide the foundation for pile-supported "bulkhead wharves" and buildings built on top of the created deck areas, notably the historic bulkhead buildings *(see Exhibit A, Typical Seawall Section)*.

Today the Seawall provides flood and wave protection to Downtown San Francisco, and stabilizes hundreds of acres of filled land (*see Exhibit B, Zone of Influence*). The Seawall itself is a contributing resource in the Embarcadero Historic District listed on the National Register of Historic Places, as are the historic bulkhead wharf structures supported by the Seawall, and adjoining historic finger piers. Within this area are significant Port and City assets including historic architecture of the finger piers and bulkhead buildings, Ferry Building, Agriculture Building, Embarcadero Promenade and roadway, Downtown Ferry Terminal, Pier 27 Cruise Terminal, BART Transbay Tube, MUNI light rail, and key utility infrastructure, including the City's combined sewer system.

The Study has revealed greater than expected risk to the Seawall, which sits atop weak native soils, typically Young Bay Mud, and buttresses fill used to create the land behind the Seawall, which is subject to liquefaction during an earthquake. The Study focused specifically on the performance of the Seawall under different earthquake conditions. When subject to moderate amounts of earthquake ground shaking, the weak soils below the Seawall begin to fail causing it to settle and move towards the Bay. This movement, called lateral spreading, is correlated to the size of the earthquake, particularly the duration

[2] http://www.sfport.com/ftp/meetingarchive/commission/38.106.4.220/modules/Item%2011A%20Seawall%20RFP%20Award-documentid=9010.pdf

[3] http://sfport.com/modules/showdocument.aspx?documentid=10533

of ground shaking, and can be on the order of several inches or less in a frequent earthquake, such as the 1989 Loma Prieta Earthquake[4], to several feet or more in a major earthquake with a long duration, such as a repeat of the 1906 Earthquake[5]. While not uniform throughout, lateral spreading is predicted to occur along the entire three miles and increases the expected damage to structures and infrastructure adjacent to the Seawall. *Exhibit C depicts the earthquake vulnerabilities of a typical section of the Seawall. Maps showing the lateral spreading predicted after a major earthquake are included in Exhibit D*. Bulkhead wharves which support bulkhead buildings, utilities, the Embarcadero Promenade and Roadway, and Muni rail lines are particularly at risk to increased damage due to Seawall movement.

The United States Geological Survey (USGS) 2014 Working Group on California Earthquake Probabilities concluded that there is a 72 percent probability of a strong earthquake (M≥6.7) occurring in the San Francisco Bay Region in a thirty year period between 2014 and 2043 (WGCEP, 2015). Additionally the 2014 WGCEP has concluded that within the next 30 years the probability of a strong earthquake (M≥6.7) occurring on regional faults is as follows: 21% for the N. San Andreas Fault Zone, 31% for the Hayward-Rodgers Creek Fault Zone, and 7% for the Calaveras Fault.

There are several principle factors that are predicted to inform the level of damage arising from an earthquake:

- its moment magnitude (the measure of its strength on the Richter scale);
- the distance of its epicenter to the Port;
- the duration of ground shaking;
- the character of soils supporting the Seawall and adjoining Port structures and the character of liquefiable fill material behind the Seawall;
- the age, construction and weathering of piles, beams and slabs supporting Port structures.

The study indicates that the economic value of Port structures in the Northern Waterfront is $1.6B and that $2.13B per year is generated in rent, revenue and employment within those structures. A repeat of the 1906 Earthquake is predicted to cause as much $1B in damage and $1.3B per year in disruption costs. Besides those costs, the Study indicates that damage will impact disaster recovery of the City and Region by impacting ferry service, maritime berthing, utility service, transportation, and the tourism industry which is valued at over $11B per year.

[4] The epicenter of the 1989 M6.8 Loma Prieta Earthquake was approximately 60 miles away from the Seawall; levels of groundshaking measured nearby are similar to levels expected in a smaller earthquake located nearby, and are considered to have a 50% in 30 year probability of exceedance. Evidence of small movement of the Seawall was noted during this event.

[5] Seismologists estimate the 1906 Earthquake was a M7.8 with fault rupture of 296 miles and an epicenter several miles offshore of San Francisco. The return period for a similar event is estimated at 200 to 250 years, or a 20% in 50 years probability of exceedance.

Mitigation Alternatives

The Study Team developed a range of engineering options to mitigate the earthquake vulnerabilities associated with the Seawall. Options were developed to limit lateral spreading and settlement of the waterfront, reduce the potential for liquefaction along The Embarcadero, and to improve performance and safety of the bulkhead wall and wharf structures. Utility improvements were not specifically analyzed, but the study contemplates performance and options to improve performance. The purpose is to develop measures that are technically feasible from an engineering and construction standpoint and to identify basic advantages/disadvantages including performance, cost, constructability, disruption, environmental issues, preservation, and adaptability to sea level rise and climate change. Options include ground improvement techniques to strengthen the soil below the Seawall *(Exhibit E1)*, strengthen the soil landward of the Seawall including the liquefiable fill (*Exhibits E2 & E4*), options to buttress the Seawall by constructing new soil-structures on the Bayward side *(Exhibit E3)*, and structural retrofits/replacement of bulkhead wall and wharves (*Exhibits E5 & E7*). The various options are not applicable to all sections, but taken together, form an overall menu that can be further considered during development of a resilience strategy and detailed project design.

The most promising mitigation options include:

Jet Grouting to Strengthen the Weak Soils Under the Seawall (Exhibit E1): Strengthening the Young Bay Mud under the rock dike stabilizes the Seawall, greatly reducing lateral spreading and settlement of the waterfront and subsequently improving the performance and safety of the bulkhead, wharves and piers. It improves the performance of The Embarcadero, but localized damage to the roadway or Promenade from liquefaction is still expected. It also provides a strong foundation for the Seawall that can be built upon for adaptation to sea level rise.

The difficulty with strengthening the soil under the rock dike is that, (a) Young Bay Mud is one of the more difficult soils to strengthen, (b) the project would need to penetrate through the rock dike, (c) there are historic wharves and buildings above it in many locations, and (d) to be most effective, the project would need to strengthen at least 2/3 of the width including some areas that are within the Bay. Of all the techniques available today, Jet Grouting appears best suited to overcome most of these challenges.

Jet Grouting is a soil strengthening technique that uses small diameter drilling equipment to create large diameter soil-cement columns in place, including in Young Bay Mud. The specialized drill bit includes jet nozzles connected to a high capacity pump that cut the soil and mix it with cement using a high pressure spinning action. The benefits of Jet Grouting are that the equipment can penetrate the rock dike to reach the soil below, that it can be used at an inclined angle, and that a range of equipment sizes are available. Jet Grouting is expensive and the expense grows significantly when production rates are slowed by all of the challenges at the Port. It also creates spoils through the drill hole which need to be collected and removed, an environmental concern in the water. It does appear feasible that with a combination of inclined drilling, small equipment, and spoils collection, that Jet

Grouting can be accomplished where there are bulkhead buildings and wharves. Costs for Jet Grouting are estimated to range from $20,000 to $120,000 per linear foot.

<u>*Bulkhead Wall and Wharf Retrofits and Replacement*</u>: Performance of bulkhead walls and wharves can be improved using various structural retrofits. Options for the bulkhead walls include tiebacks *(Exhibit E-5*), reinforced concrete overlays, and buttressing with revetment (*Exhibit E-6*). Retrofits for bulkhead wharves include jacketing piles, strengthening deck/pile connections with pins, strengthening beams with reinforced concrete overlays, and adding piles where accessible *(Exhibit E-7*). These types of retrofits are recommended because bulkhead wall and wharves are still vulnerable to damage from earthquake ground shaking even if the Seawall is stabilized using Jet Grouting. Without stabilizing the Seawall, these retrofits can improve life safety, but will do little to mitigate damage of the piles underground due to lateral spreading. Structural retrofits and ground improvement do not need to occur at the same time, allowing a phased approach, but ground improvement costs increase somewhat if retrofits occur first. Costs for structural retrofits are estimated to range from $5,000 to $30,000 per linear foot (based on standard 60 ft. widths).

Besides retrofits, replacing bulkhead wharves is an option, especially where wharves are in an advanced stage of deterioration. New bulkhead wharves can be designed to meet current code without stabilizing the Seawall by using high strength and ductile piling, such as steel pipe piling, in combination with higher strength decks that can better withstand earthquake ground shaking. This approach was used at the Brannan Street Wharf and is being contemplated for the new Downtown Ferry Terminal where the structure is being designed to meet essential facility performance criteria. The increased structure demands from lateral spreading and settlement of the Seawall generally increase structure costs by 20% to 50% based on site conditions and performance criteria. It must also be noted that lateral spreading and settlement may impact the utilities and access to these structures. Stabilizing the Seawall with Jet Grouting is possible after constructing new bulkhead wharves, but it does complicate construction and add to expense. Costs for new bulkhead wharves range from $30,000 to $60,000 per linear foot (based on standard 60ft widths).

<u>*Improvement of Liquefiable Fill Landside of the Seawall (Exhibit E2)*</u>: Improving the liquefiable fill within The Embarcadero will reduce the earthquake pressure on the Seawall and lessen the amount of Seawall movement somewhat. The primary benefit, however, is to minimize damage to utilities, roadway, and light rail tracks, especially when combined with Jet Grouting to stabilize the Seawall. Improvement techniques include stone columns, densification, chemical grouting, and soil mixing. All of these techniques are disruptive and would require closure of The Embarcadero roadway and Promenade for affected construction areas. Costs range from $10,000 to $40,000 per linear foot (based on 160ft width of Embarcadero).

It is noted here, that if The Embarcadero were to be raised as part of a sea level rise strategy, that strengthening of the underlying Bay Mud would be needed to prevent settlement. In this area, Deep Soil Mixing (DSM) appears the most cost effective method. DSM creates in situ soil cement columns, similar to Jet Grouting, but using large track mounted mixing paddles. It is less expensive than Jet Grouting, but highly disruptive and costs increase greatly if production rates are low, such as may be the case if portions of The Embarcadero were kept open for traffic, pedestrians, bike, and the light rail during the construction period. Where obstructions existing, such as a high density of utilities or buries structures, Jet Grouting is a better alternative. DSM can also improve the fill and should be done at the same time rather than phased. Costs for this are still in development.

Potential Mitigation Program and Overall Cost

At this stage of investigation, it appears that costs to significantly improve the resiliency of the entire three miles of the Seawall and waterfront are on the order of $2-$3 billion. This includes what the Team considers as the most promising mitigation options to fully improve earthquake resilience of the northern waterfront:

- ground improvement of the Seawall foundation using jet grouting techniques
- a combination of structural retrofits and replacement of bulkhead wall and wharf structures
- mitigation of liquefaction in The Embarcadero using stone columns
- select utility replacement and relocation

With consideration of sea level rise, it is estimated that costs could reach $5 billion to fully incorporate adaptation measures needed for the next 100 years. While this Study considers these other waterfront resilience needs, there is an urgency to advance Seawall seismic strengthening efforts given that a major earthquake could occur at any time and is very likely to occur within the next 30 years.

Staff recommend that a program be developed with the goal of completing significant earthquake safety and performance improvements of the Seawall within the next 8 to 10 years. The next phase of study will examine in further detail criteria by which segments of the Seawall and key Port assets should be improved for better earthquake performance, in addition to improvement strategies and associated cost so policymakers and the public can make informed decisions about where to spend public funds.

An early implementation strategy that should be considered first includes ground improvements and bulkhead wall/wharf retrofits at key areas of the Seawall necessary for disaster recovery efforts, bulkhead wall/wharf replacement where key assets must perform and ground improvement is not practical, structural retrofits to improve life safety, and flood protection improvements to low lying areas just south of the Ferry Building. A conceptual budget of $500M is suggested, but further study and a robust stakeholder engagement process is needed develop the program.

In advance of this Study, the Port has been working with the City, including the City’s Chief Resiliency Officer and Capital Planning Committee, to collaborate on this important City infrastructure need, and to include the Seawall in City resilience planning and funding efforts. In 2014, the City of San Francisco Lifelines Council[6] released a report outlining a plan for improving earthquake resilience and included the Seawall as a vital piece of infrastructure. Mayor Edwin Lee also has championed this priority and directed the Port Seawall project to be entered into a recent competition where the project was selected to be part of a cohort of experts focusing on innovative financing for infrastructure.[7] The Port has already committed $1.5 million and has a requested $10M be included in the FY 2016-17 budget, $8M City and $2M Port, to develop the program, advance technical studies and engineering feasibility, engage stakeholders and the public in decision making, seek funding, and begin environmental review. Currently, there are no funding sources designated, and the City will have to work further to develop a financing plan for the construction of Seawall earthquake improvements.

Next Steps

The Study is a draft and will be completed by June of this year. The goal is to incorporate comments from the Port Commission, Port staff, key stakeholders, the Waterfront Land Use Plan Working Group, and the Peer Review Team into the Study and to create an executive summary document.

The Study results point to the need to make substantial investments to improve earthquake safety and performance of the Seawall. Because earthquakes are unpredictable and scientific consensus indicates that a major earthquake is very likely to occur sometime within the next 30 years, staff recommend making major improvements as soon as practical. To do this, staff recommends developing a robust program to advanced detailed study of vulnerabilities and risks, identify and engage stakeholders in decision-making and prioritizing program efforts, developing funding strategies and actively seeking assistance, advancing the design of mitigation concepts, seeking environmental clearance, and constructing improvements without delay. With a concerted effort and support from the Port Commission and the City, it is possible make significant improvements in the next 8 to 10 years. Where difficulty may arise is in the response to sea level rise, a game changing issue with evolving science that suggests action will be required over the next 20 to 50 years. Ideally, any major investments that are made for earthquake improvements to the Seawall are fully aligned with and adaptable to the overall strategy for sea level rise and climate change efforts along the Waterfront. While daunting, it is a challenge that we can certainly meet.

Specific next steps include:

- Complete the Earthquake Vulnerability Study by June of this year.

- Inform the Waterfront Land Use Plan Update process by presenting the findings at the next working meeting on April 13, 2016.

[6] http://sfgov.org/lifelines/sites/default/files/FileCenter/Documents/12025-LifelineCouncil%20Interdependency%20Study_FINAL.pdf

[7] City Accelerator Cohort on Infrastructure Financing, sponsored by Living Cities and the Citi Foundation

- Inform Port tenants of the Study findings and conduct outreach efforts.

- Continue to work closely with the City's Chief Resiliency Officer to include the Seawall in both the Citywide Resiliency Plan and the Lifelines Council efforts.

  Continue to work with the City's Capital Planning Committee to include $10M of funding in the FY 2016-17 budget for advancing a major Seawall Resiliency Project ($2M Port and $8M City), and to include the Project in the FY2018-2028 10 year Capital Plan Update. This funding will allow Port Engineering to further define and prioritize sections of the Seawall and adjoining land and structures that should be improved to mitigate seismic risk, protect key infrastructure and improve life safety.

- Continue to support the United States Army Corps of Engineers as they complete a Federal Interest Determination in response to the Port's request for assistance to improve flood protection of the Northern Waterfront and all of Port Jurisdiction.

- Together with the City, participate in the Living Cities Infrastructure Financing Cohort to discover new and innovative methods to finance Seawall Improvements.

Port staff looks forward to addressing the questions and direction from the Port Commission and the public. Port staff recommends that next steps focus on work with Port tenants with long-term leases, affected City departments and community partners to determine specific measures to develop seismic improvements and associated requirements. This work will inform the efforts to further define and establish a funding strategy for the Seawall. Port staff plans to complete and finalize this Study in June 2016 and report back to the Port Commission this summer with a status report.

Prepared by: Steven Reel, Project Manager

For: Eunejune Kim, Chief Harbor Engineer

EXHIBITS:

Exhibit A	Typical Seawall Section
Exhibit B	Seawall Zone of Influence
Exhibit C	Typical Earthquake Vulnerabilities
Exhibit D-1 & 2	Lateral Spreading Map
Exhibit E-1	Soil Strengthening Alternative-Jet Grout Under Rock Dike – Inclined
Exhibit E-2	Soil Strengthening Alternative-Liquefaction Remediation
Exhibit E-3	Soil Strengthening Alternative-Anchored Sheetpile & Deep Soil Mixing
Exhibit E-4	Soil Strengthening Alternative-Jet Grouting & Deep Soil Mixing Landside
Exhibit E-5	Bulkhead Wall Retrofit-Tiebacks and Micropiles
Exhibit E-6	Bulkhead Wall Retrofit-Revetment Bayside
Exhibit E-7	Bulkhead Wall Retrofit-Summary of Retrofits
Exhibit E-8	Combined Mitigation Alternative-Jet Grouting & Deep Soil Mixing and Bulkhead Wall & Wharf
Exhibit E-9	Long-Term Strategy Option-Bayward Seawall & Raising Embarcadero

Exhibit A: Typical Seawall Section

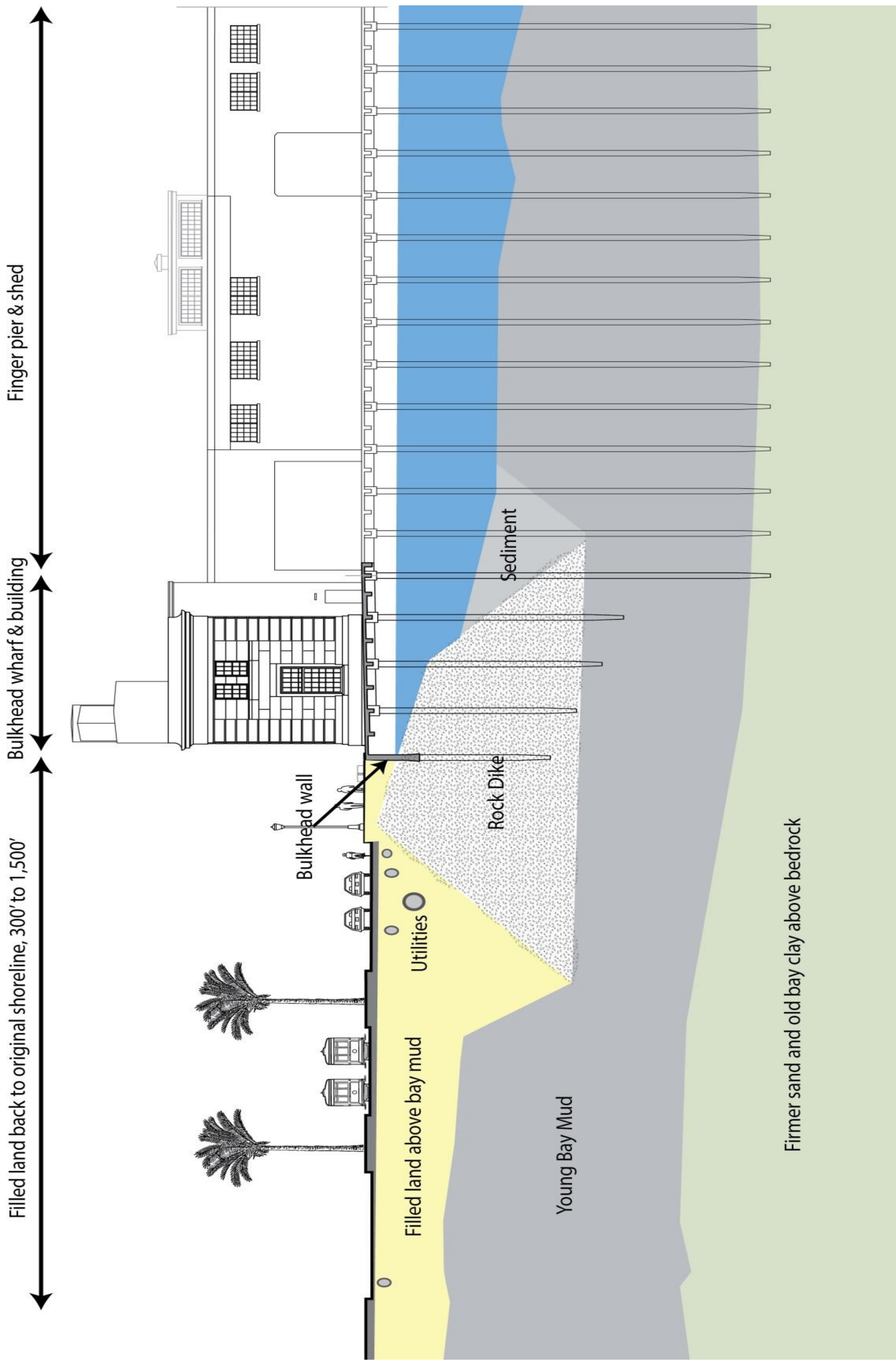

Exhibit A: Typical Seawall Section

Exhibit B: Seawall Zone of Influence

Exhibit C: Typical Earthquake Vulnerabilities

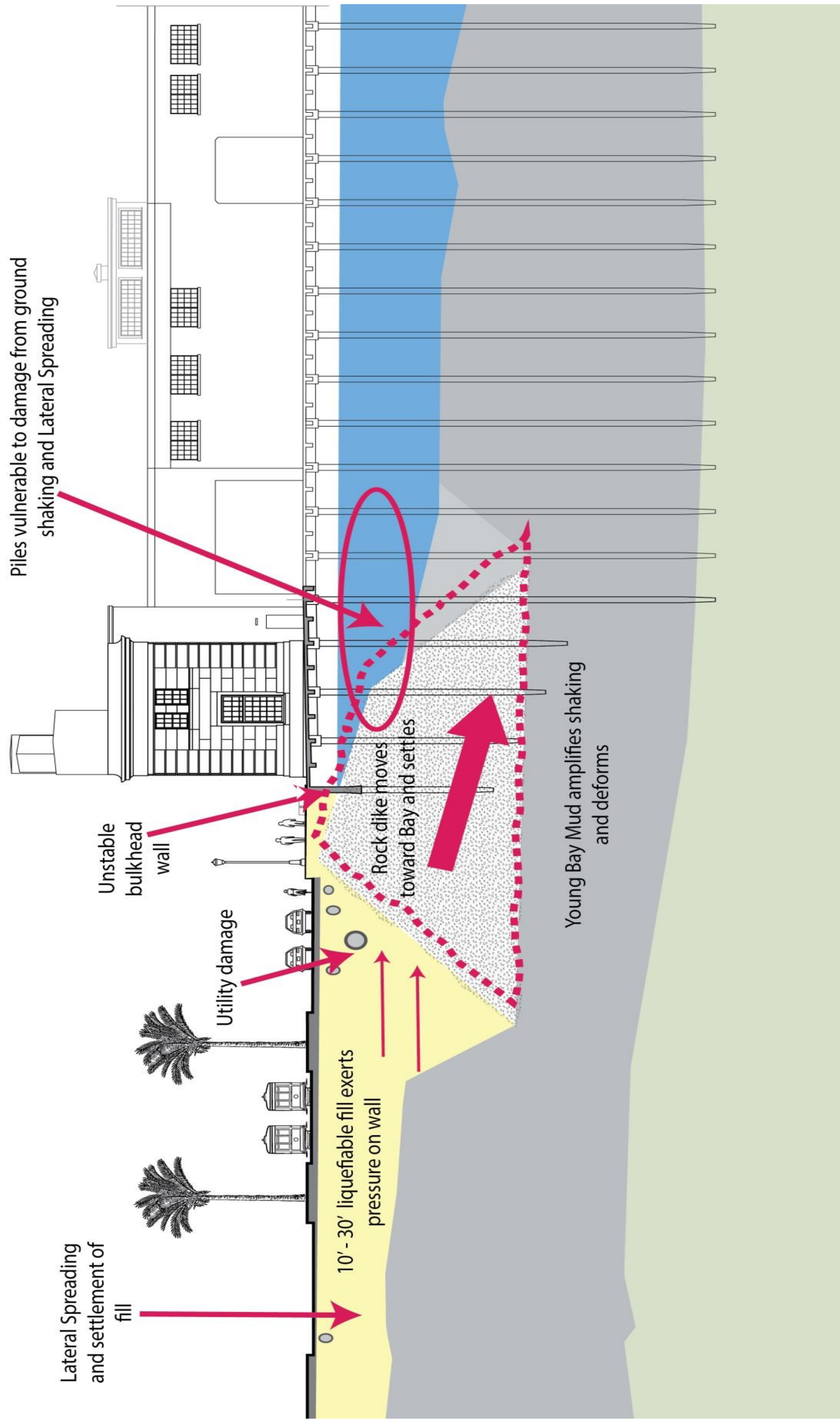

Exhibit C: Typical Seawall Earthquake Vulnerabilities

Exhibit D-1: Lateral Spreading Map, 1 of 2

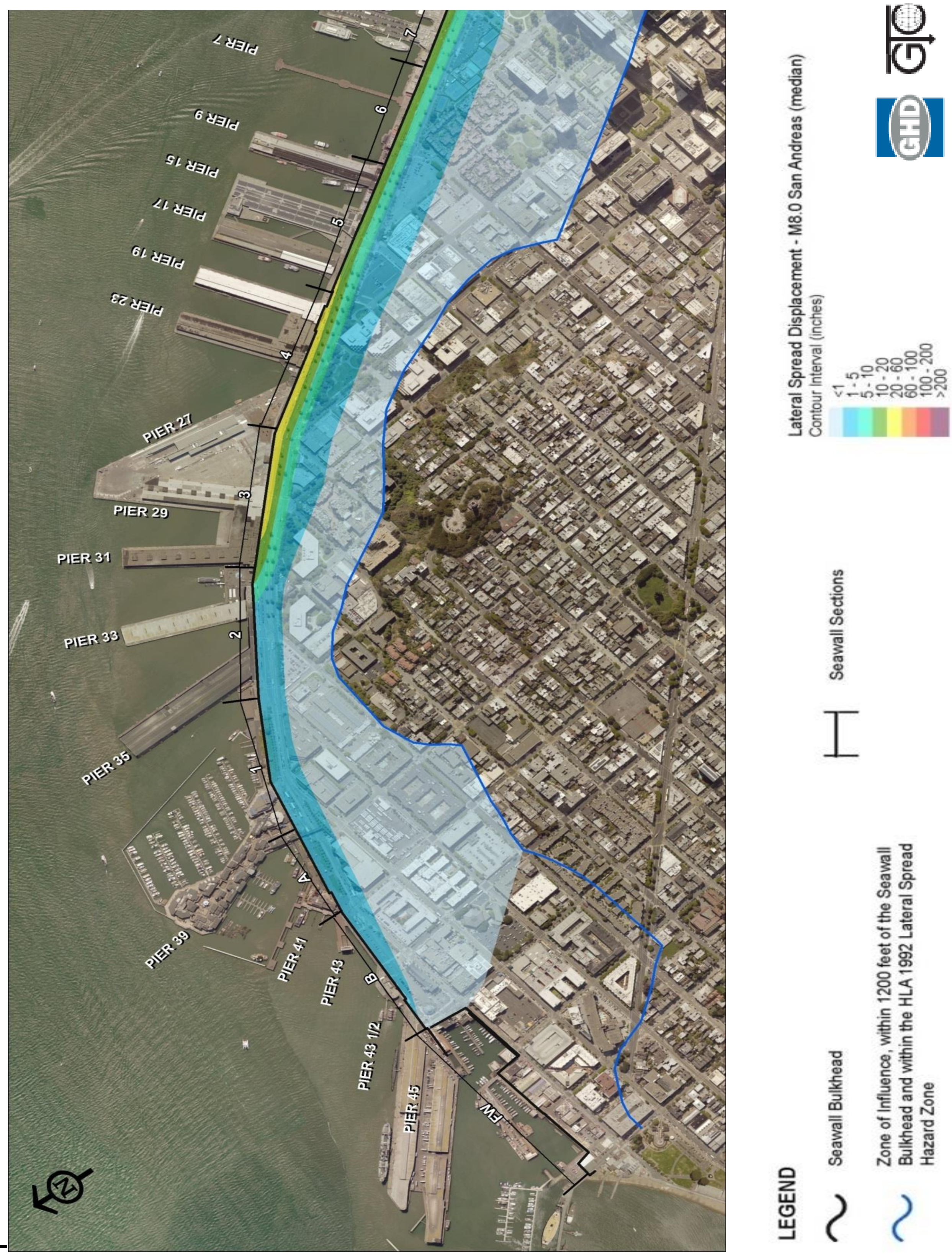

Exhibit D-2: Lateral Spreading Map, 2 of 2

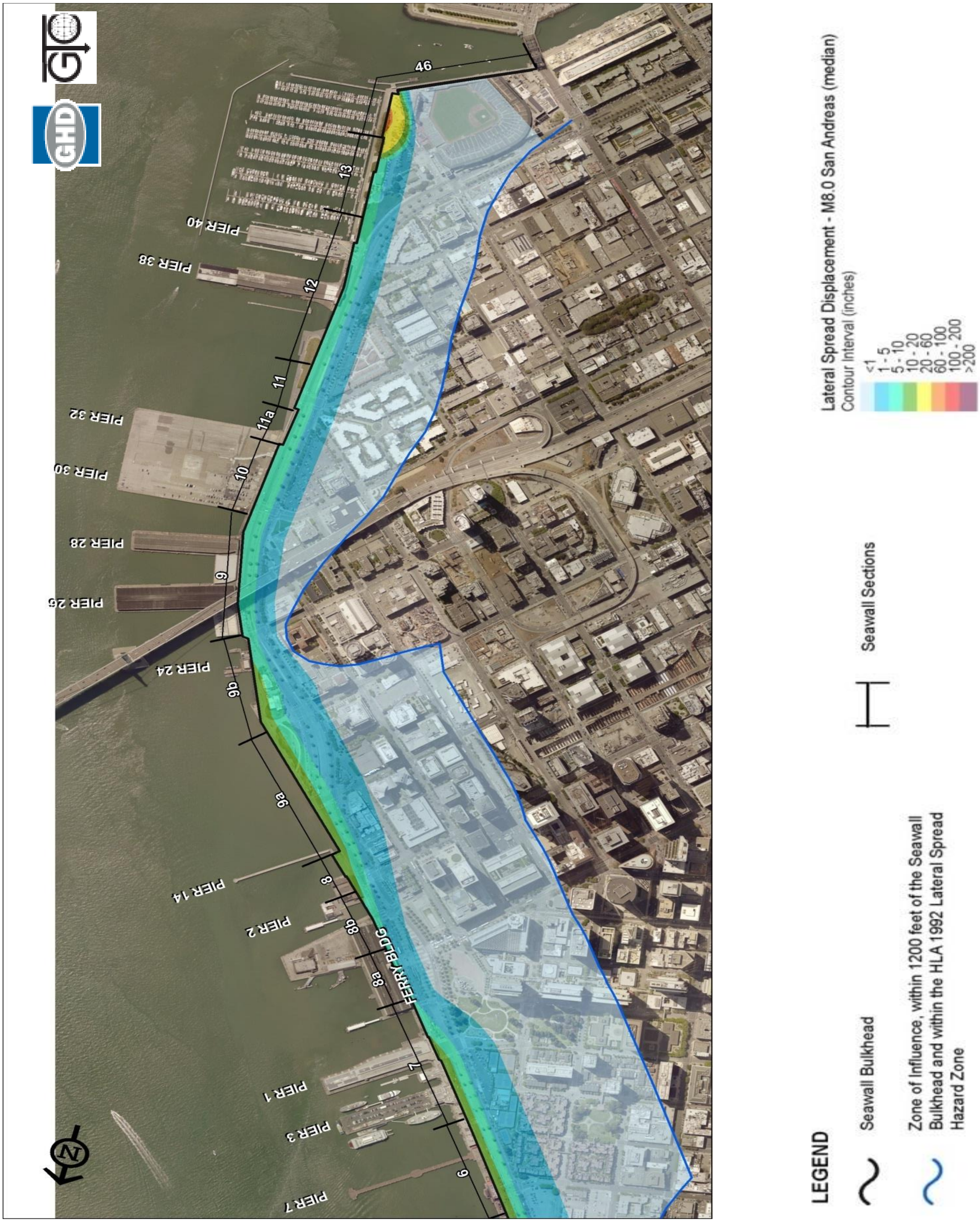

Exhibit E-1: Soil Strengthening Alternative (G-1a) – Jet Grout Under Rock Dike - Inclined

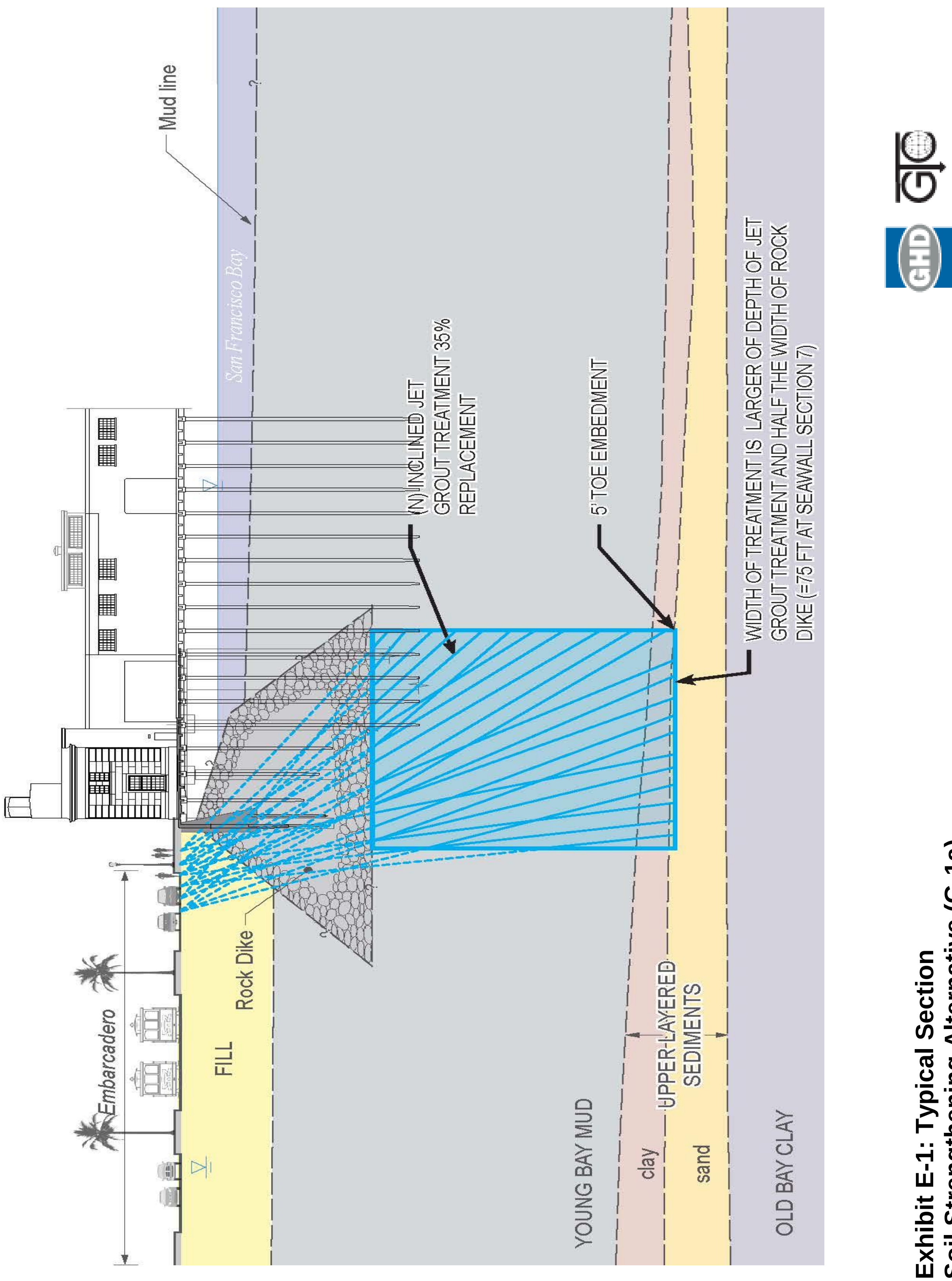

Exhibit E-1: Typical Section
Soil Strengthening Alternative (G-1a)
Jet Grout Under Rock Dike - Inclined

Exhibit E-2: Soil Strengthening Alternative (G-2) – Liquefaction Remediation

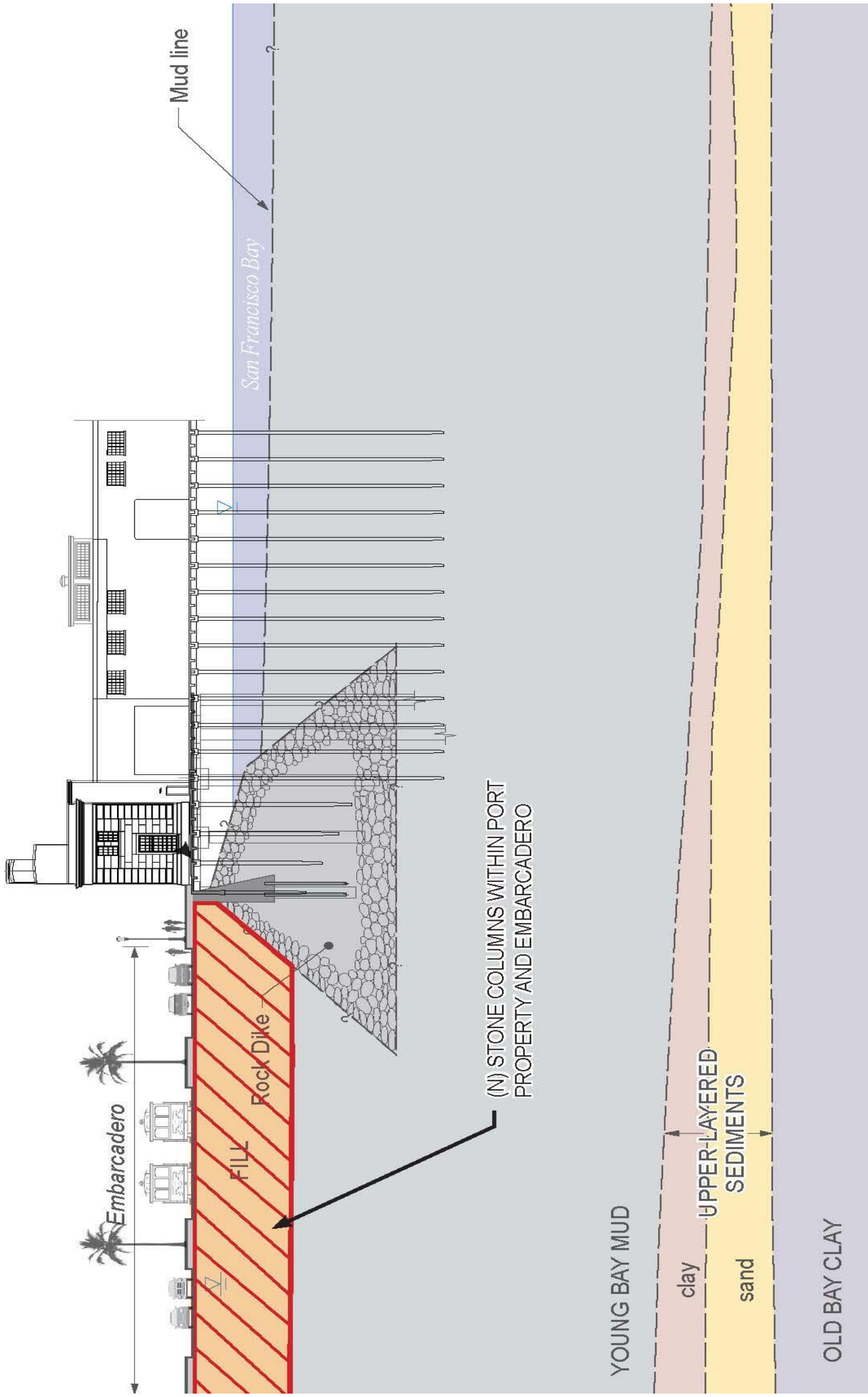

Exhibit E-2: Typical Section
Soil Strengthening Alternative (G-2)
Liquefaction Remediation of Fill

Exhibit E-3: Soil Strengthening Alternative (G-4) - Anchored Sheetpile and Deep Soil Mixing

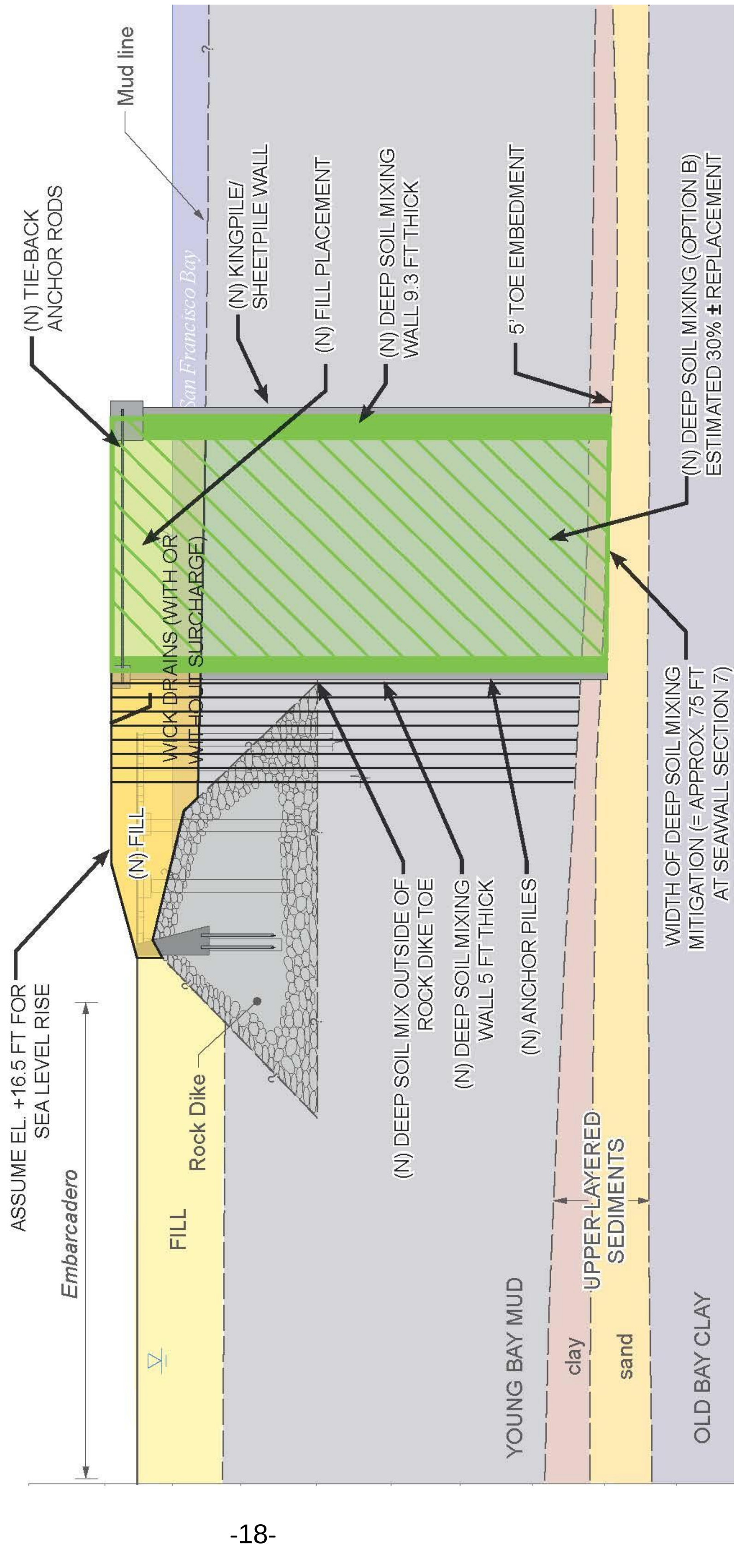

Exhibit E-3: Typical Section
Soil Strengthening Alternative (G-4)
Anchored Sheetpile and Deep Soil Mixing, Bayside, Option B

Exhibit E-4: Soil Strengthening Alternative (G-5) – Jet Grouting and Deep Soil Mixing, Landside

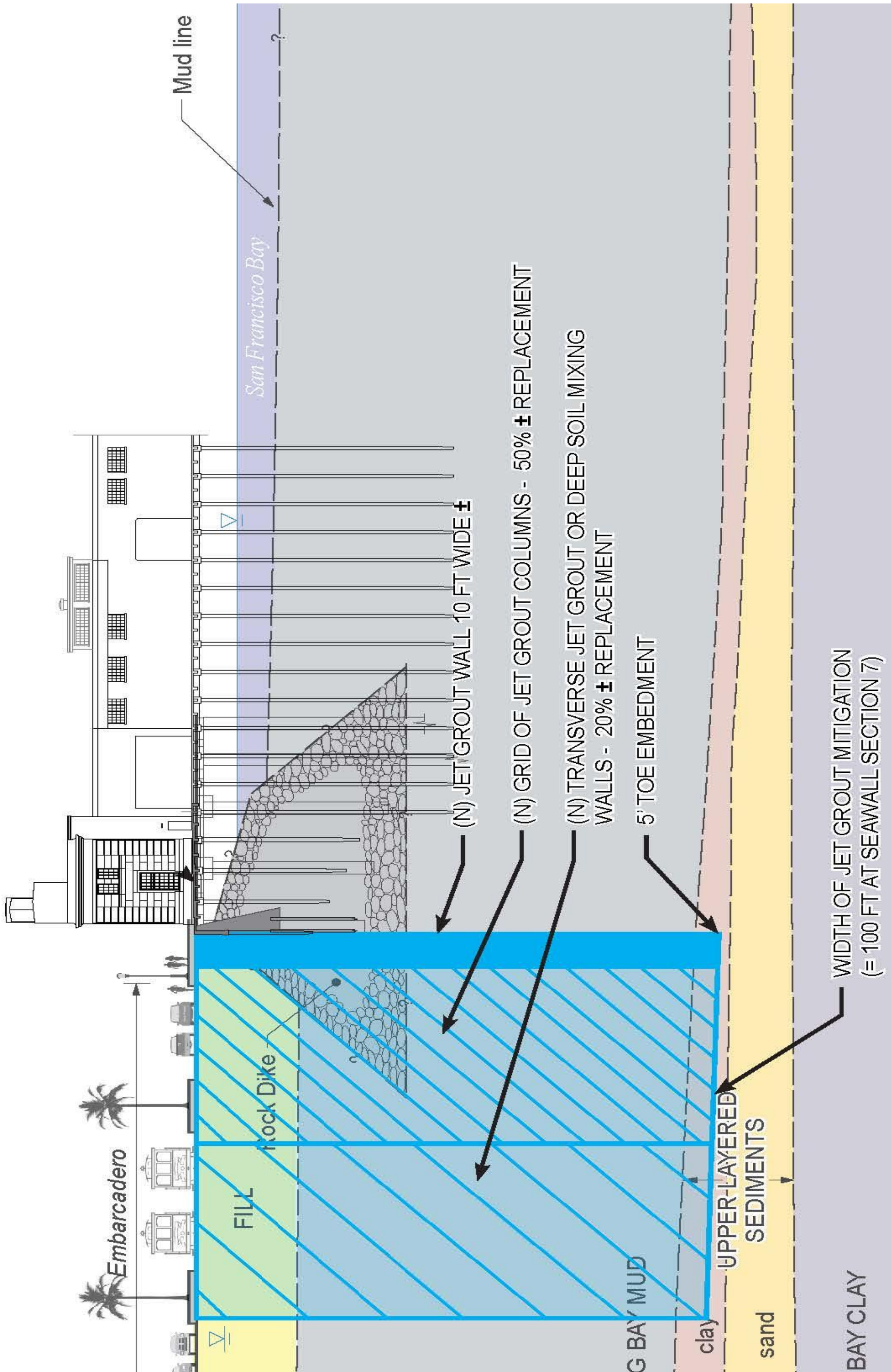

Exhibit E-4: Typical Section
Soil Strengthening Alternative (G-5)
Jet Grouting and Deep Soil Mixing, Landside

Exhibit E-5: Bulkhead Wall Retrofit (S-1) – Tiebacks and Micropiles

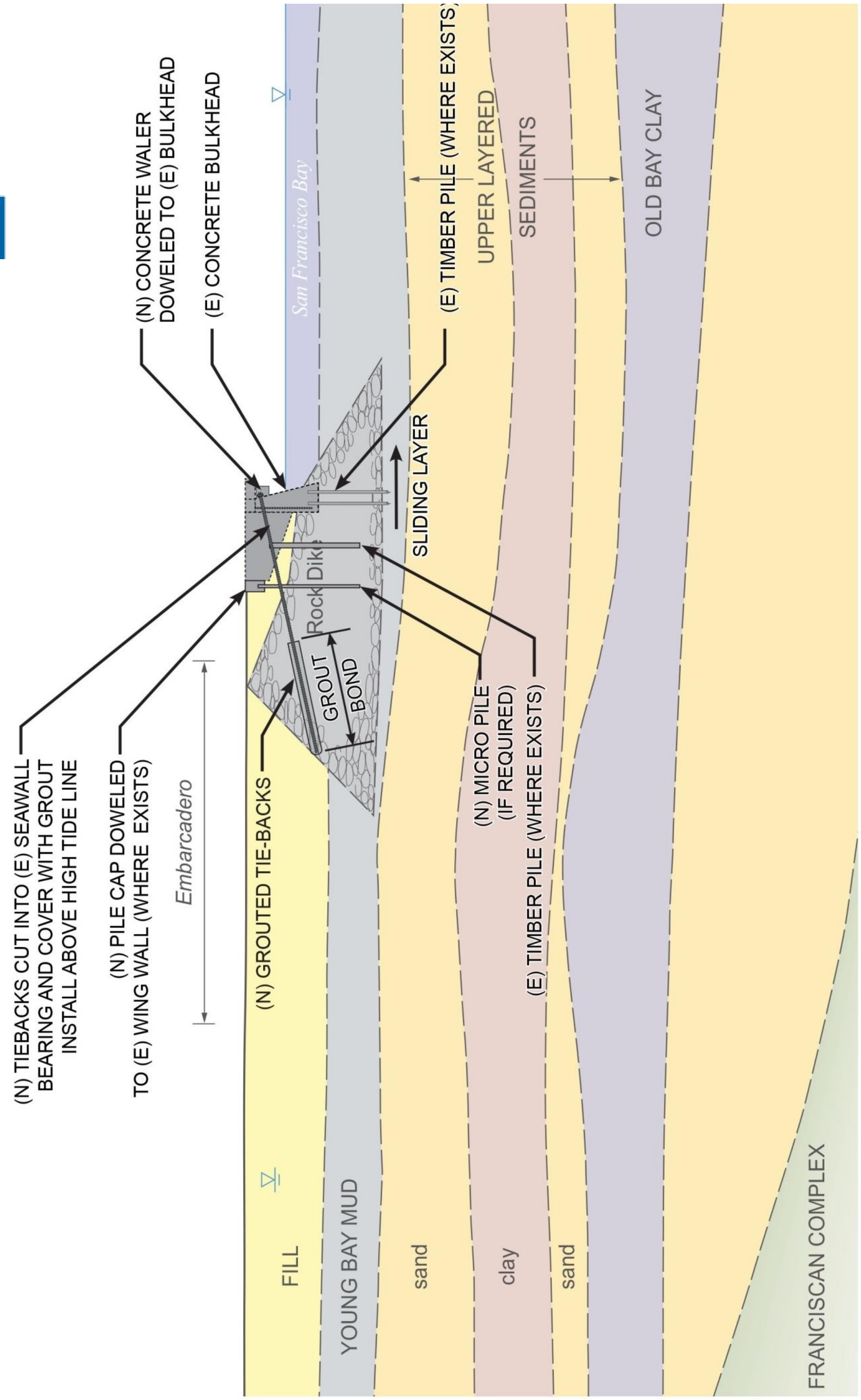

Exhibit E-6: Bulkhead Wall Retrofit (S-4) – Revetment Bayside

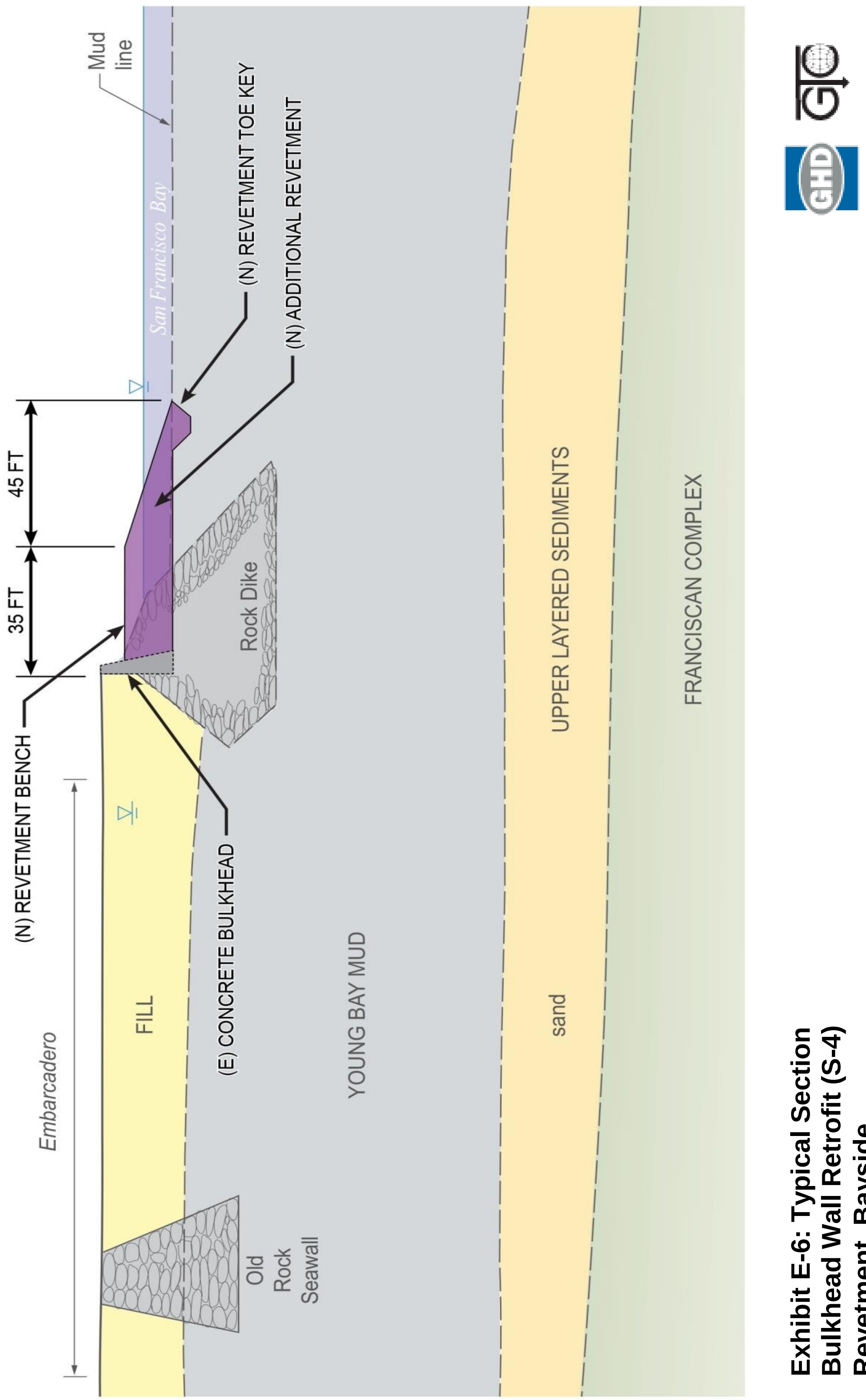

Exhibit E-7: Bulkhead Wall and Wharf Retrofit (S-11) – Summary of Retrofits

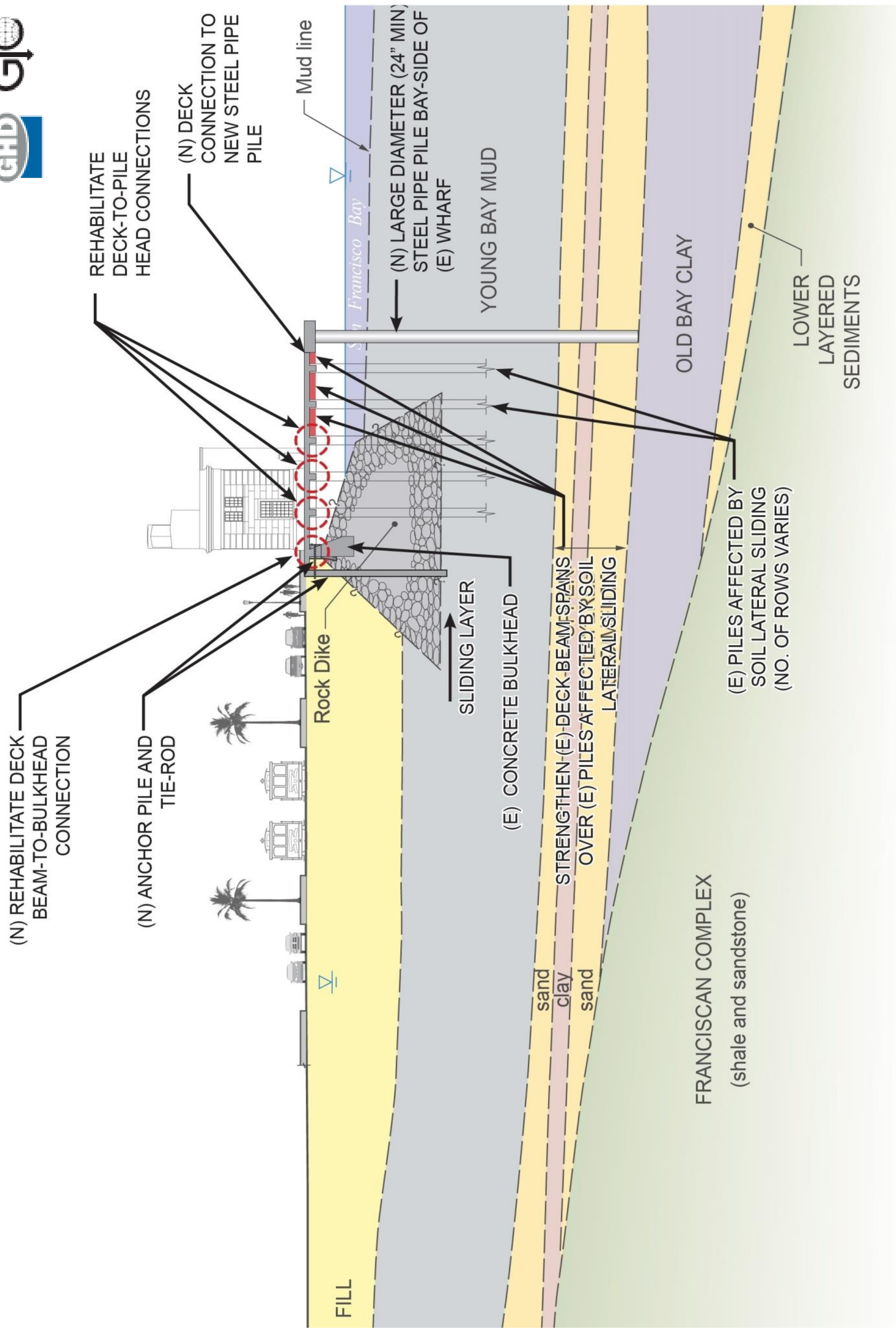

Exhibit E-7: Typical Section
Bulkhead Wall and Wharf Retrofit (S-11)
Summary of Retrofits

Exhibit E-8: Combined Mitigation Alternative (S-14) – Jet Grouting & Deep Soil Mixing and Bulkhead Wall & Wharf

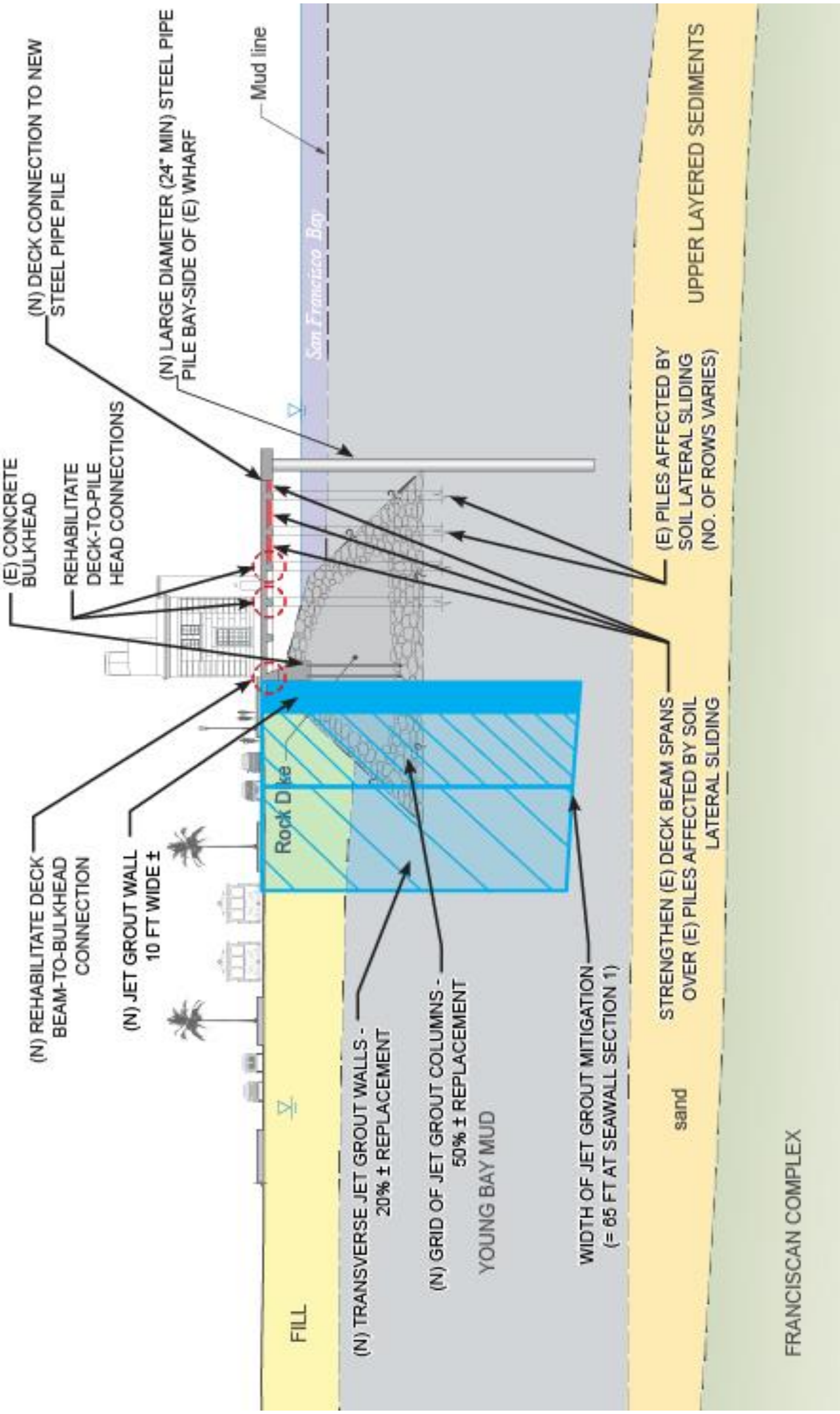

Exhibit E-8: Typical Section
Combined Mitigation Alternative (S-14) – Jet Grouting & Deep Soil Mixing and Bulkhead Wall & Wharf

Exhibit E-9: Long-Term Strategy Option (S-32)– Bayward Seawall & Raising Embarcadero

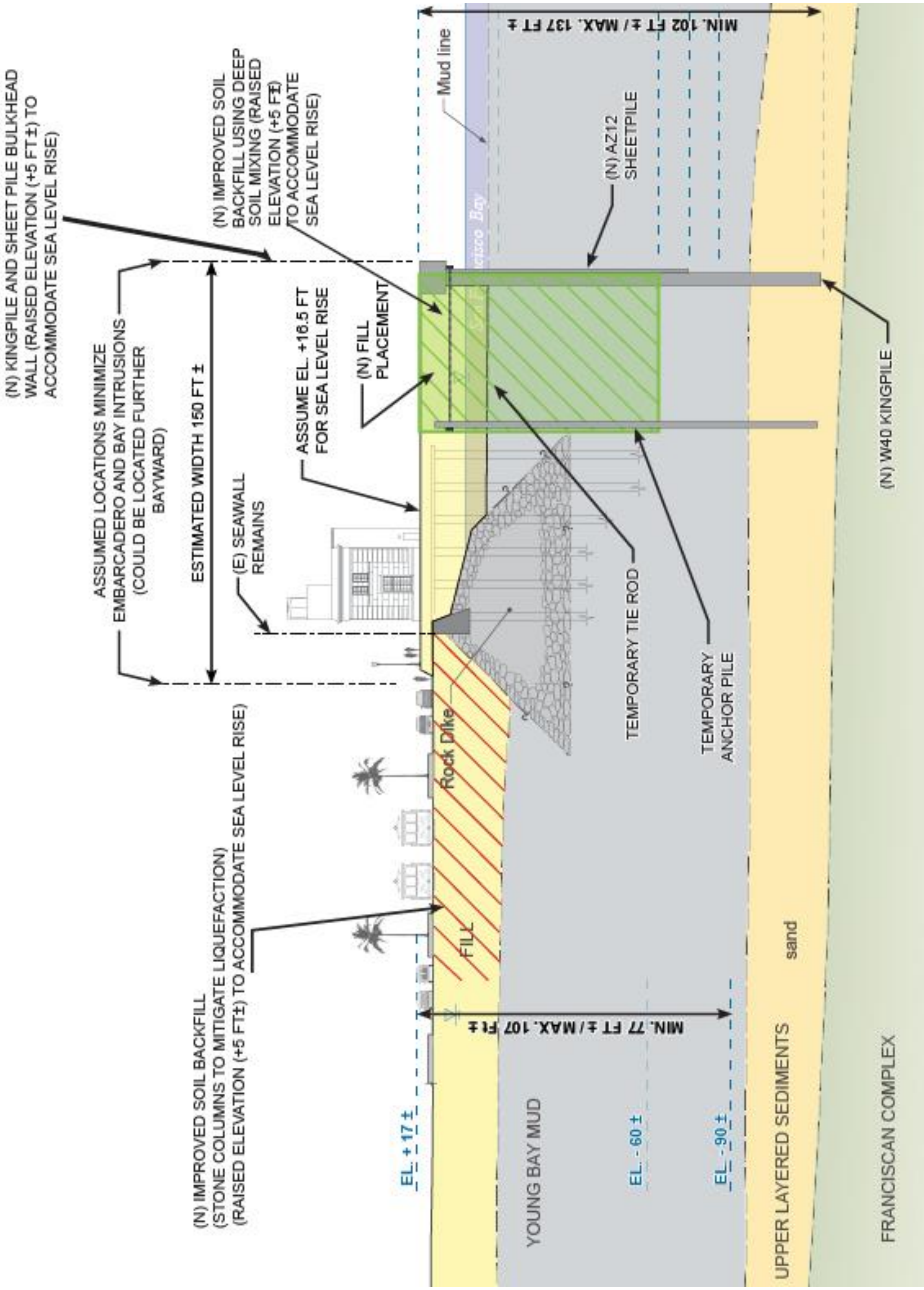

Exhibit E-9: Long-Term Strategy Option
Bayward Seawall & Raising Embarcadero (S-32)