Elliott Bay Seawall Project

Geology and Soils Discipline Report

FINAL

October 2012

Submitted to:

City of Seattle
Department of Transportation
700 5th Avenue, Suite 3900
Seattle WA 98124

Submitted by:
Tetra Tech, Inc.

Prepared by:
Shannon & Wilson, Inc.

Elliott Bay Seawall Project

GEOLOGY AND SOILS DISCIPLINE REPORT

Agreement No. T09-24

FINAL

OCTOBER 2012

This Discipline Report provides detailed background and analysis to support the City of Seattle's SEPA (Washington State Environmental Policy Act) Environmental Impact Statement for the Elliott Bay Seawall Project. This report also serves the same role to support the United States Army Corps of Engineer's NEPA (National Environmental Policy Act) environmental analysis for the Elliott Bay Seawall Project. Thus, both SEPA and NEPA references and considerations are included.

To conduct this project, SDOT contracted with:

Tetra Tech, Inc.

1420 5th Avenue, Suite 550
Seattle WA 98101

In association with:

Anchor QEA
BergerABAM
Coast & Harbor
EnviroIssues
Fehr & Peers
Floyd|Snider
GHD
JA Brennan
LPES
Magnusson Klemencic Associates
Mimi Sheridan
Nelson\Nygaard
Power Engineers
Risk Strategics
Shannon & Wilson
SWCA Environmental Consultants
Washington2 Advocates
William P. Ott Construction Consultants
ZGF Architects

City of Seattle

Geology and Soils Discipline Report

TABLE OF CONTENTS

Title **Page No.**

Executive Summary **ES-1**

CHAPTER 1. Project Description **1**
1.1 Project Background 1
1.2 Project Area Limits and Zones 2
1.3 Project Alternatives 3
1.4 No Action Alternative 3
1.5 Design Features Common to the Build Alternatives 4
1.5.1 Seawall 5
1.5.2 Habitat Improvements 5
1.5.3 Upland Improvements 6
1.6 Project Construction 7
1.6.1 Construction Schedule 7
1.6.2 Temporary Roadway and Construction Work Zone 7
1.6.3 Construction Methods 8
1.6.3.1 Soil Improvement 9
1.6.3.2 Braced Soldier Piles 9
1.6.4 Soil Dewatering and Spoils Disposal 9
1.6.5 Utility Protection and/or Relocation 10
1.7 Build Alternatives 11
1.7.1 Alternative A 11
1.7.1.1 Seawall 11
1.7.1.2 Roadway 11
1.7.1.3 Habitat Improvements 12
1.7.1.4 Upland Improvements 12
1.7.1.5 Construction and Schedule 12
1.7.2 Alternative B 15
1.7.2.1 Seawall 15
1.7.2.2 Roadway 15
1.7.2.3 Habitat Improvements 15
1.7.2.4 Upland Improvements 16
1.7.2.5 Construction and Schedule 16
1.7.3 Alternative C 19
1.7.3.1 Seawall 19
1.7.3.2 Roadway 19
1.7.3.3 Habitat Improvements 19
1.7.3.4 Upland Improvements 20
1.7.3.5 Construction and Schedule 20

CHAPTER 2. Methodology **35**
2.1 Study Area 35

2.2 Regulations and Guidelines 35
2.3 Sources of Data 35
2.4 Analysis of Existing Conditions 35
2.5 Analysis of Environmental Effects 36
2.6 Determining Mitigation Measures 36

CHAPTER 3. Coordination and Information Sources 37

CHAPTER 4. Affected Environment 39
4.1 Topographic and Geologic Setting 39
4.2 Tectonics and Seismicity 40
4.2.1 Shallow Crustal Zone 41
4.2.2 Deep Intraslab Zone in the Juan de Fuca Plate 42
4.2.3 Interplate Zone 42
4.3 Site Geology 43
4.3.1 Holocene Soil Deposits 43
4.3.2 Quaternary Soil Deposits 45
4.4 Existing Conditions 46
4.4.1 Existing Seawall 46
4.4.2 Subsurface Soil Conditions 47
4.4.2.1 Zone 1 – Pioneer Square/Washington Street Boat Landing 47
4.4.2.2 Zone 2 – Ferry Terminal 48
4.4.2.3 Zone 3 – Central Pier 50
4.4.2.4 Zone 4 – Park/Aquarium 51
4.4.2.5 Zone 5 – Bell Harbor 52
4.4.2.6 Zone 6 – North Pier 53
4.5 Geologic Hazards 54
4.5.1 Landslides 55
4.5.2 Erosion 55
4.5.3 Fault Rupture 55
4.5.4 Liquefaction 56
4.5.5 Ground Motion Amplification 56
4.5.6 Seiches and Tsunamis 57
4.6 Regional Groundwater Systems 57
4.6.1 Regional Groundwater Flow 57
4.6.2 Site Groundwater Conditions 58
4.6.3 Groundwater Recharge and Discharge 58
4.6.4 Current Aquifer Use and Institutional Use Prohibitions 59
4.6.4.1 Sole Source Aquifers 59
4.6.4.2 Wellhead Protection Areas 59

CHAPTER 5. Construction Effects and Mitigation 61
5.1 No Action Alternative 61
5.2 Construction Effects 61
5.2.1 Common to All Build Alternatives 61
5.2.1.1 Erosion and Sediment Transport 61
5.2.1.2 Existing Pavement 62
5.2.1.3 Construction Vibrations 62
5.2.1.4 Fill Placement and Compaction 62

5.2.1.5 Temporary Excavation Support 62
5.2.1.6 Excavations and Dewatering 63
5.2.1.7 Dredging 63
5.2.1.8 Pile Installation 63
5.2.1.9 Ground Anchor Installation 64
5.2.1.10 Removal of Existing Structures 64
5.2.1.11 Spoils Disposal 64
5.2.1.12 Stockpiles 65
5.2.2 Alternative A 65
5.2.2.1 Soil Improvement 65
5.2.2.2 Spoils Disposal 66
5.2.2.3 Habitat Bench between Piers 54 and 55 67
5.2.3 Alternative B 67
5.2.3.1 Drilled Shafts 67
5.2.3.2 Spoils Disposal 68
5.2.3.3 Intertidal Habitat Bench near Washington Street Boat Landing 68
5.2.3.4 Habitat Area at the Seattle Aquarium 68
5.2.4 Alternative C 69
5.2.4.1 Soil Improvement 70
5.2.4.2 Spoils Disposal 70
5.2.4.3 Habitat Bench between Piers 54 and 55 70
5.2.4.4 Intertidal Habitat Bench near Washington Street Boat Landing 70
5.3 Indirect Effects 70
5.4 Mitigation Measures 70
5.4.1 Common to All Build Alternatives 71
5.4.1.1 Erosion and Sediment Transport 71
5.4.1.2 Existing Pavement 71
5.4.1.3 Construction Vibrations 72
5.4.1.4 Fill Placement and Compaction 72
5.4.1.5 Temporary Excavation Support 72
5.4.1.6 Excavations and Dewatering 72
5.4.1.7 Dredging 73
5.4.1.8 Pile Installation 73
5.4.1.9 Ground Anchor Installation 73
5.4.1.10 Removal of Existing Structures 74
5.4.1.11 Spoils Disposal 74
5.4.1.12 Stockpiles 74
5.4.2 Alternative A 74
5.4.2.1 Soil Improvement 74
5.4.2.2 Habitat Bench between Piers 54 and 55 75
5.4.3 Alternative B 75
5.4.3.1 Drilled Shafts 75
5.4.3.2 Intertidal Habitat Bench near Washington Street Boat Landing 76
5.4.3.3 Habitat Area at the Seattle Aquarium 76
5.4.4 Alternative C 76

CHAPTER 6. Operational Effects and Mitigation 77
6.1 No Action Alternative 77

6.2 Build Alternatives 77
6.2.1 Operational Effects 77
6.2.1.1 Utilities 78
6.2.1.2 Groundwater 78
6.2.1.3 Fills 78
6.2.1.4 Liquefaction-Induced Settlement 79
6.2.1.5 Soil Improvement 79
6.3 Indirect Effects 79
6.4 Mitigation Measures 79
6.4.1 Exploration and Design Approach 79
6.4.2 Utilities 80
6.4.3 Groundwater 80
6.4.4 Fills 80
6.4.5 Liquefaction-Induced Settlement 80
6.4.6 Soil Improvement 81

CHAPTER 7. References 83

LIST OF TABLES

No.	Title	Page No.
Table 1-1.	Comparison of Features of the Three Elliott Bay Seawall Project Build Alternatives	23
Table 4-1.	Geologic Units and General Descriptions – Holocene Deposits	44
Table 4-2.	Geologic Units and General Descriptions – Pre-Vashon Deposits	45

LIST OF FIGURES

No.	Title	Page No.
Figure 1-1.	Elliott Bay Seawall Project Area	1
Figure 1-2.	Elliott Bay Seawall Zone Designations	2
Figure 1-3.	Conceptual Rendering of Proposed Habitat Improvements	6
Figure 1-4.	Construction Work Zone and Temporary Roadway	8
Figure 1-5.	Representative Cross Section Showing Typical Existing Utility Locations within Project Limits	10
Figure 1-6.	Alternative A, Stage 1	13
Figure 1-7.	Alternative A, Stage 2	13
Figure 1-8.	Alternative A, Stage 3	14
Figure 1-9.	Alternative A, Stage 4	14
Figure 1-10.	Alternative B, Stage 1	17
Figure 1-11.	Alternative B, Stage 2	17
Figure 1-12.	Alternative B, Stage 3	18
Figure 1-13.	Alternative B, Stage 4	18
Figure 1-14.	Alternative C, Stage 1	21
Figure 1-15.	Alternative C, Stage 2	21
Figure 1-16.	Alternative C, Stage 3	22
Figure 1-17.	Alternative C, Stage 4	22
Figure 1-18.	Alternative A: Central Seawall Plan	27
Figure 1-19.	Alternative A: North Seawall Plan	28
Figure 1-20.	Alternative B: Central Seawall Plan, Option 1	29
Figure 1-21.	Alternative B: Central Seawall Plan, Option 2	30
Figure 1-22.	Alternative B: North Seawall Plan	31
Figure 1-23.	Alternative C: Central Seawall Plan	32
Figure 1-24.	Alternative C: North Seawall Plan	33
Figure 4-1.	Location of Cascadia Subduction Zone	40
Figure 4-2.	Schematic of Subduction of the Juan de Fuca Plate under the North American Plate	40
Figure 4-3.	Locations of Earthquake Source Zones	41

Figure 4-4. Map of Study Area and Project Zones 46
Figure 4-5. Generalized Subsurface Conditions in Zone 1 – Pioneer Square/S. Washington Street Boat Landing 48
Figure 4-6. Generalized Subsurface Conditions in Zone 2 – Ferry Terminal 49
Figure 4-7. Generalized Subsurface Conditions in Zone 3 – Central Pier 50
Figure 4-8. Generalized Subsurface Conditions in Zone 4 – Park/Aquarium 51
Figure 4-9. Generalized Subsurface Conditions in Zone 5 – Bell Harbor 53
Figure 4-10. Generalized Subsurface Conditions in Zone 6 – North Pier 54

ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

AWV	Alaskan Way Viaduct
AWVSRP	Alaskan Way Viaduct and Seawall Replacement Program
bgs	below the ground surface
BMP	Best Management Practice
BNSF	BNSF Railway
BSP	braced soldier pile
City	City of Seattle
EBSP	Elliott Bay Seawall Project
Ecology	Washington State Department of Ecology
EIS	Environmental Impact Statement
GEDR	Geotechnical and Environmental Data Report
I-90	Interstate 90
km	kilometer
LPS	light-penetrating surface
NAVD	North American Vertical Datum
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
SDOT	Seattle Department of Transportation
SEPA	State Environmental Policy Act
USACE	United States Army Corps of Engineers
VWP	vibrating wire piezometer
WAC	Washington Administrative Code
WSDOT	Washington State Department of Transportation

This page intentionally left blank.

EXECUTIVE SUMMARY

This Geology and Soils Discipline Report describes the geologic conditions present along the alignment of the Elliott Bay Seawall Project (EBSP) and the anticipated construction and operational effects of the EBSP on the geology and soils environment. The EBSP would consist primarily of rebuilding the existing Elliott Bay Seawall and creating habitat improvements. This Discipline Report addresses the No Action Alternative, Build Alternative A (minimum wall pull-back), Build Alternative B (maximum wall pull-back), and Build Alternative C. Alternatives A and C use a soil improvement structural option and Alternative B uses a braced soldier pile structural option, but either structure may be substituted in any of the build alternatives, as conditions require. The build alternatives include various habitat improvements such as placement of fill for shallow-water habitat in Elliott Bay.

The seawall is located along the west side of downtown Seattle, a highly developed area that includes buildings, utilities, roadways, railroads, and numerous other surface and subsurface features. The geology encountered along the seawall generally consists of glacially overridden deposits overlain by various thicknesses of recent native soils (deposited through geologic processes) and fill (deposited by humans). Along most of the EBSP, the glacially overridden deposits are located within about 60 feet of the ground surface. Groundwater is encountered about seven to 15 feet below the ground surface, depending on location along the seawall.

The seawall has experienced degradation and damage from marine boring organisms and erosion and piping of soils from behind the wall via groundwater flow, coastal storms and wave action. Sinkholes have developed behind the wall and repairs have been made frequently over the years. In its current state, the seawall continues to be subject to the potential for erosion and wall damage from coastal storms and wave action.

The geologic hazard with the greatest potential to affect the seawall is liquefaction and related lateral spreading of the seawall resulting from a seismic event. Liquefaction occurs during ground shaking and results in a reduction of the shear strength of the soil (a quicksand-like condition). Liquefaction can result in ground movement (lateral spreading) towards Elliott Bay. Liquefaction and lateral spreading could cause the existing seawall to settle, tilt, move laterally or collapse. Liquefaction and lateral spreading will be considered in the design of the EBSP.

Construction of the EBSP will include excavations, shoring walls, pile and shaft installation, soil improvement, and fill placement. Most of the major construction effects identified for the build alternatives relate to potential ground movement from excavations and dewatering. These ground movements could damage existing utilities, buildings, and other structures. Improper construction techniques could lead to excessive settlement, vibration, or movement of adjacent buildings, pavements, utilities, and other structures. Mitigation measures identified herein and in the final design will be implemented by experienced construction staff who will construct the project in accordance with the plans and specifications using Best Management Practices specified by the City of Seattle.

The geology- and soils-related operational effects of the build alternatives are similar. Most of the identified effects are due to non-habitat related project features. Groundwater may mound up against the new seawall because it acts as a barrier to groundwater flow toward Elliott Bay. Because the new

seawall would extend deeper and be more impermeable than the existing seawall, the additional groundwater mounding may result in a higher groundwater table along the waterfront. However, the anticipated height of the mounded groundwater is within the current groundwater fluctuations due to the tides. Differential post-construction settlement could occur due to subsurface stiffness variations between soil improvement areas (Alternatives A and C) and areas that are not improved. Site-specific mitigation measures identified during the design process would be used to address potential effects to adjacent facilities. The identified effects can be mitigated by proper construction methods.

CHAPTER 1. PROJECT DESCRIPTION

1.1 PROJECT BACKGROUND

The City of Seattle Department of Transportation (SDOT) is proposing to construct the Elliott Bay Seawall Project (EBSP), which will replace the existing seawall along the shoreline of downtown Seattle. Extending from S. Washington Street to Broad Street, the seawall supports and protects the adjacent upland areas, which contain residences, commercial businesses and restaurants, parks and public facilities, transportation infrastructure (including sidewalks, streets, and a rail line), and a large number of utilities (Figure 1-1). The harbor area in Elliott Bay is used by ferries, cruise ships, and commercial vessels, as well as for recreation. Overall, the waterfront is an important center of commerce and recreation for the entire city and region.

Figure 1-1. Elliott Bay Seawall Project Area

The existing seawall includes three types of structures, all constructed between 1911 and 1936 and ranging in size from approximately 15 to 60 feet wide. Over time, these structures have deteriorated as a result of various natural and physical processes. The seawall's poor condition makes it vulnerable to significant damage during a major storm or seismic event. Therefore, the EBSP is a critical public safety project. The completed seawall will provide protection from coastal storm damages, seismic damages, and shoreline erosion, and will thereby contribute to the preservation of Seattle's downtown, the local economy, and the region's economic competitiveness and quality of life. Seawall replacement will also provide the foundation and structural support for the downtown Seattle waterfront, including improvements planned as part of Waterfront Seattle.

The project's purpose is to reduce the risks of coastal storm and seismic damages and to protect public safety, critical infrastructure, and associated economic activities along Seattle's central waterfront. Additionally, the project will improve the degraded ecosystem functions and processes of the Elliott Bay nearshore in the vicinity of the existing seawall.

Construction of a new seawall would have both beneficial and adverse effects on environmental resources. This discipline report will examine the effects of the project on geology and soils as part of the project's overall environmental documentation.

1.2 PROJECT AREA LIMITS AND ZONES

The project area for the EBSP extends from S. Washington Street to Broad Street, from the eastern edge of pavement below State Route (SR) 99 to the waters of Elliott Bay. The project has been divided into six zones. Zones 1 through 4 constitute the Central Seawall Study Area. The two remaining zones, Zones 5 and 6, make up the North Seawall Study Area. A delineation of the zones is provided in Figure 1-2 and concept plans are included at the end of this chapter.

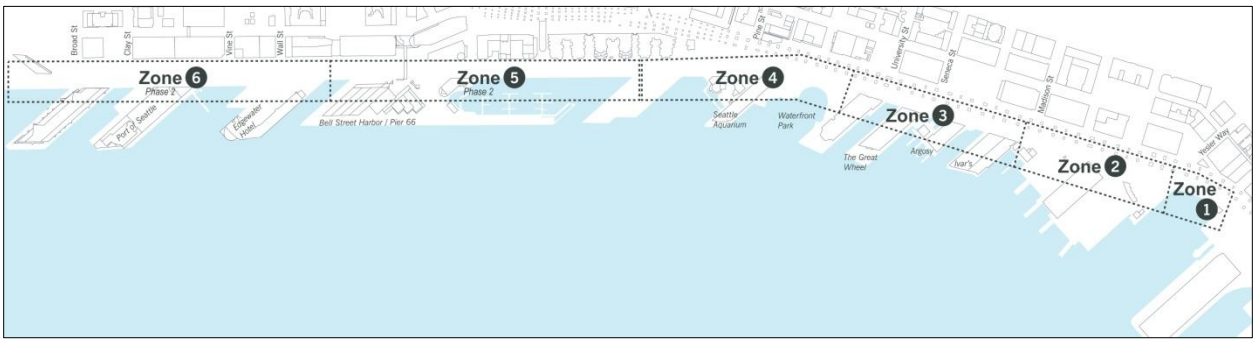


Figure 1-2. Elliott Bay Seawall Zone Designations

Central Seawall Study Area (S. Washington Street to Virginia Street):

- Zone 1, the Pioneer Square/Washington Street Boat Landing Zone, runs from S. Washington Street to Yesler Way.
- Zone 2, the Ferry Terminal Zone, stretches from Yesler Way to Madison Street, and includes the Colman Dock ferry terminal and Fire Station No. 5.
- Zone 3, the Central Pier Zone, includes the historic waterfront piers (Piers 54 to 57) and runs from Madison Street to just north of University Street.
- Zone 4, the Park/Aquarium Zone, includes Waterfront Park, the Seattle Aquarium, and Piers 62/63. This zone runs from north of University Street to approximately Virginia Street.

North Seawall Study Area (Virginia Street to Broad Street):

- Zone 5, the Bell Harbor Zone, runs from Virginia Street to Battery Street. This zone includes the Bell Harbor Conference Center, Cruise Ship Terminal, and Marina.
- Zone 6, the North Pier Zone, stretches from Battery Street to Broad Street, and includes the Edgewater Hotel, Port of Seattle Offices, and Pier 70.

1.3 PROJECT ALTERNATIVES

The EBSP Environmental Impact Statement (EIS) evaluates a No Action Alternative and three build alternatives for the project. As required by the National Environmental Policy Act (NEPA) and the Washington State Environmental Policy Act (SEPA), the build alternatives represent different ways of accomplishing the project purpose. Evaluating alternatives allows SDOT decision-makers, with input from the public, agencies, and tribes, to consider environmental impacts in conjunction with other decision factors such as cost, schedule, and feasibility.

The build alternatives for the EBSP are:

- **Alternative A**, which would reconstruct the seawall as close to its existing alignment as possible. Jet grouting, a subsurface soil improvement, would be used to form the seawall's structural support. Habitat improvements would include the addition of shoreline enhancements, installation of a continuous habitat bench, and intermittent light-penetrating surfaces (LPS) at piers.
- **Alternative B**, which would move the seawall up to 75 feet landward of its current location. Braced soldier piles (BSP) would be used to build an underground wall structure. Moving the seawall inland would allow the construction of expanded habitat enhancements and mostly continuous LPS, in addition to the habitat improvements and continuous habitat bench described for Alternative A.
- **Alternative C**, which would move the seawall up to 15 feet landward of its current location. This alternative would use subsurface soil improvements (likely including both jet grouting and deep soil mixing) to provide structural support. Alternative C would provide a continuous habitat bench and continuous LPS, in addition to shoreline enhancements similar to Alternative B.

These three build alternatives encompass a range of design ideas to establish "bookends" for the project, thus capturing a suite of potential options, impacts, and effects. Features of the alternatives could be blended in future design phases to reflect public, agency, and stakeholder input.

The following section (Section 1.4) describes the No Action Alternative. Section 1.5 discusses the features that are common to the three build alternatives and Section 1.6 provides an overview of project construction. Section 1.7 provides additional detail on specific features that differ among the build alternatives.

1.4 NO ACTION ALTERNATIVE

NEPA, SEPA, and the City of Seattle's (City's) implementing regulations (Seattle Municipal Code [SMC] 25.05) require that a No Action Alternative is evaluated in addition to the build alternatives in the EIS. The No Action Alterative provides a baseline against which the potential effects of the build alternatives can be compared.

The No Action Alternative is projected over the next 50 years. Given the age and condition of the seawall, continued deterioration and some level of failure will likely occur within the 50-year timeframe. Because the existing seawall is vulnerable to various types of damage, the No Action Alternative must

anticipate the possibility of degrees of seawall failure. Therefore, three No Action scenarios have been evaluated:

1. Minimal Damage: This scenario would not require a significant repair of the seawall, and any needed repairs could be undertaken by the City. Small failures caused by tidal erosion (as are currently happening today) or minor seismic events would result in settlement of the wall or collapse of the roadway or sidewalk on Alaskan Way. This scenario assumes continued operation of the seawall with ongoing maintenance as needed.
2. Loss of Functionality: This scenario would result from sustained damage, and the seawall would no longer be considered safe for public access and could no longer perform the majority of its essential functions. As with the Minimal Damage scenario, this scenario could result from either tidal or seismic events.
3. Collapse of the Seawall: This scenario would occur only as a result of seismic damage; however, collapse resulting from a seismic event could trigger additional damage from tidal erosion. Seawall failure would have significant impacts on the public, Seattle, the Puget Sound region, Washington State, and the nation. Loss of the seawall's function would disrupt or destroy the critical transportation infrastructure that runs along the Seattle waterfront, potentially displacing hundreds of thousands of vehicles on roadways, 30,000 daily ferry passengers who use Colman Dock ferry terminal, and 24 freight trains and six passenger trains that run near the waterfront. It would also jeopardize critical utility corridors that serve downtown Seattle and the region, and would impair the viability of the waterfront as a major tourist destination and regional economic engine.

Conditions without the project were defined as part of a separate Elliott Bay Seawall Feasibility Study, conducted by the United States Army Corps of Engineers (USACE). The "without project" conditions serve a similar purpose in the feasibility study as does the No Action Alternative under SEPA. The without project conditions are summarized below to provide additional detail about the No Action scenarios.

- The City would continue to repair minimal damage failures unless three or more sections of the seawall fail in a single year, at which point the seawall is assumed to have lost its functionality.
- The City would stabilize the shoreline following seawall collapse to minimize erosion impacts. This stabilization would help to prevent the permanent loss of landward structures, utilities, and the Burlington Northern Santa Fe (BNSF) rail line to erosion.
- If functionality of the seawall were lost, the City would construct a trestle bridge to maintain access to Colman Dock Ferry Terminal and Fire Station No. 5.
- If functionality of the seawall were lost, the City would repair or relocate affected utilities.

1.5 DESIGN FEATURES COMMON TO THE BUILD ALTERNATIVES

If implemented, the EBSP would replace the failing seawall that runs along Elliott Bay and underneath Alaskan Way and would restore and enhance aquatic habitat along the seawall's new face. A new

seawall would reduce the risk of seismic damage and protect Seattle's downtown waterfront from wind-driven storm waves and erosive tidal forces; safeguard major public and private utilities, including power for downtown Seattle and the region, natural gas, and telecommunications; support SR 99, Colman Dock ferry terminal, and rail lines; and enhance habitat for juvenile salmon and other marine life. Additionally, the project would be compatible with future improvements currently being planned at and near the waterfront.

All build alternatives encompass three major categories of design features: the new seawall itself, improvements to aquatic habitat, and improvements to upland areas. Each of these categories is described briefly below.

1.5.1 Seawall

The primary function of the new seawall is to provide protection from storm and wave erosion, impacts from floating objects, and resistance from lateral pressures such as those caused by an earthquake. A new seawall face would generally be placed either close to or somewhat landward of its current position. Depending on the build alternative selected, the final location of the seawall face would vary from approximately 3 feet waterward to 75 feet landward of the existing alignment. It would be most efficient to leave the existing seawall in place during construction of the new seawall and to build the new structure either behind or in front of the existing face.

The new seawall would also reduce the risks related to seismic activity. How these risks are reduced would differ between the alternatives. Soil improvement in the form of jet grouting with or without deep soil mixing (Alternatives A and C) would minimize the risk of liquefaction by physically stabilizing liquefiable soils behind the seawall, while the BSP method (Alternative B) would not prevent liquefaction but rather would resist the lateral spreading and migration of soil that results from liquefaction. Both methods would stabilize the seawall during seismic events. The design life of the new seawall is 75 years.

1.5.2 Habitat Improvements

Rebuilding the seawall would provide the opportunity to improve adjacent aquatic habitat. Habitat improvement measures would be implemented as part of each build alternative. These measures would be designed to restore a functional intertidal migration corridor along the seawall for juvenile salmonids, and would also improve ecosystem productivity to enhance the marine nearshore food web. Figure 1-3 shows a conceptual rendering of the proposed habitat improvements.

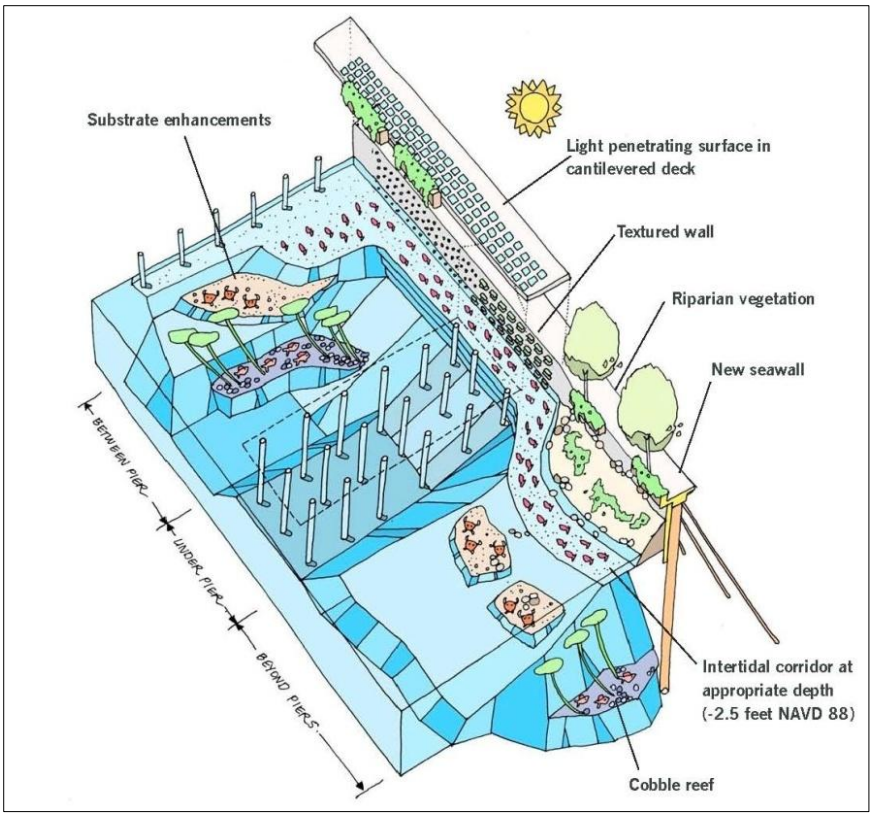


Figure 1-3. Conceptual Rendering of Proposed Habitat Improvements

The intertidal migration corridor for juvenile salmonids would be improved by:

- Modifying substrate depths to create a habitat bench and achieve appropriate intertidal and shallow-water habitat elevations;
- Improving the diversity of off-shore substrate by supplementing it with coarse substrate;
- Increasing textures on the seawall face to encourage the development of marine nearshore habitat and attachment of aquatic organisms;
- Adding riparian plants along the wall and sidewalk to provide food (insects and detritus) for migrating salmon; and
- Increasing daylight illumination of the habitat bench and other nearshore habitat by including LPS in a cantilevered or pile-supported sidewalk.

Enhanced ecosystem productivity would generally be accomplished by:

- Enhancing substrate by supplementing it with cobble, pea gravel, and shell hash; and
- Constructing the textured wall face, riparian plantings, LPS, and suitable bench substrate.

1.5.3 Upland Improvements

In addition to replacing the seawall and restoring aquatic habitat, the three build alternatives would provide a number of upland improvements. The existing Alaskan Way roadway, multi-use trail, and parking would be restored to their original function and capacity after construction. The restored

sidewalk along the waterfront would range from 15 to 30 feet in width and include a cantilevered portion with LPS that would benefit the marine habitat below. Viewing areas would be provided waterward of the sidewalk and would offer opportunities for public gathering space. New railings, formal and informal seating, bicycle racks, wayfinding elements, and other design amenities would also be included as project improvements. All build alternatives would restore the historic Washington Street Boat Landing, either maintaining its current location or moving it 15 feet waterward.

Currently, there are no water quality facilities for treating surface water runoff from Alaskan Way. Stormwater drainage pipes in the project area would be reconstructed and stormwater quality would be improved through the installation of treatment to meet code by removing the bulk of suspended solids, oils, and greases. These actions would improve water quality in the nearshore of the project area. It would be expected that new stormwater structures would initially require less maintenance than those currently in place and, as a result, have fewer detrimental impacts on the environment. As the project design moves forward, other stormwater management strategies could be identified that provide greater environmental benefit without increasing environmental impacts.

1.6 PROJECT CONSTRUCTION

1.6.1 Construction Schedule

Central Seawall construction is expected to begin in fall of 2013 and would progress from north to south, beginning in Zone 4 and ending in Zone 1. Based on current schedules, Central Seawall construction would last three to five construction seasons depending on the alternative, with construction seasons extending from approximately Labor Day to Memorial Day to avoid major disruption during the peak tourist season. The North Seawall would be built as a separate construction phase and would require an additional four construction seasons.

1.6.2 Temporary Roadway and Construction Work Zone

To accommodate construction activities during replacement of the seawall, the existing Alaskan Way roadway would be relocated beneath the Alaskan Way Viaduct. Three lanes of traffic would be maintained underneath the viaduct throughout construction. The resulting space along the waterfront would be used as a work zone during construction of the Central Seawall (Figure 1-4). During North Seawall construction, this dedicated construction work zone would not be available, and the temporary roadway would be accommodated in the available right-of-way.

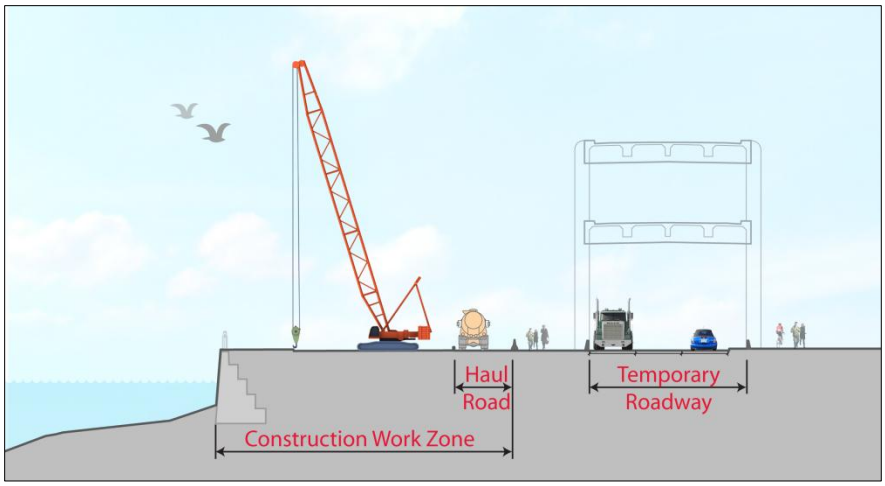


Figure 1-4. Construction Work Zone and Temporary Roadway

The construction work zone would extend from the western edge of the existing multi-use path on Alaskan Way to the water. Existing street trees would be removed to provide additional space within this area and would either be replaced as riparian plantings with the EBSP or replaced during future waterfront improvement projects. The existing streetcar tracks that run along Alaskan Way would also be removed during construction.

Construction would be staged from several locations within the work zone. Staging areas would vary in size and would be used for delivery and storage of construction materials and equipment. The staging areas would be sited to avoid disrupting access to piers, residences, and businesses along the waterfront. In addition to the upland staging areas, construction activities may also be staged from barges and tugs in Elliott Bay.

During Central Seawall construction, some temporary parking spaces could be provided as part of each construction stage. During the first stage of construction, parking could be provided on the existing Alaskan Way roadway south of the active work zone. During the later stages when construction has progressed to the southern portion of the project area, parking could be provided on the restored roadway to the north of active construction. During North Seawall construction, a similar program of temporary parking would be implemented, to the extent possible.

To the greatest extent possible, construction materials and personnel would be transported to the construction work zone and staging areas via freeways and arterials. However, other city streets could provide access to the site when needed. The eastern border of the construction work zone along Alaskan Way would serve as a haul road to channel truck traffic within the project area.

The existing multi-use trail would be maintained (with the potential for temporary detours), and access to the piers would be maintained throughout construction.

1.6.3 Construction Methods

The seawall would be replaced using soil improvement, BSP, or a combination of these two methods. A brief description of each method is provided below.

1.6.3.1 Soil Improvement

Soil improvement is a general term for a variety of techniques that are used to stabilize existing soils by improving their internal structure and strength. Two techniques that are being considered for the EBSP are jet grouting and deep soil mixing. Jet grouting consists of adding grout to existing soils to form a "block" of improved soil mass that extends down to the competent foundation below. This technique has been identified as a feasible way to strengthen the material underlying the project area, which includes an existing timber relieving platform, buried timber piles, utilities, and other potential obstructions.

Jet grouting creates circular columns of soil cement by means of a hollow drill pipe measuring a few inches in diameter that is inserted into the soil. Grout is then sprayed into the surrounding soil under high pressure through horizontal nozzles in the rotating drill pipe. This process cuts the existing soil and mixes the soil with the grout. The strength of the soil would be substantially improved through this process, thus greatly reducing the soil's potential for liquefaction during an earthquake.

The grout columns would be constructed in a grid pattern to create a block of improved soil. The grid pattern would be installed between the timber piles of the existing seawall to eliminate the need to remove the existing piles. The finished arrangement of the grouted columns would create a "spine" for the new seawall. The grouting process generates spoils that would be disposed of using appropriate means, in accordance with applicable regulations.

Deep soil mixing, another technique that could be used for soil improvement, uses an auger that penetrates the ground surface to mix and consolidate the underlying soils to a depth of up to 20 feet. With deep soil mixing, no grout is applied under pressure and there are minimal spoils for disposal.

1.6.3.2 Braced Soldier Piles

BSP is an alternative structural stabilization method. This method would involve drilling large holes (approximately 8 feet in diameter) to a depth of approximately 75 feet below the present street level of Alaskan Way where the firm layer of glacial till is located. An oscillator, a specialized piece of drilling equipment, would install a steel casing as the drilling progresses to prevent the holes from collapsing and to contain the soils to be excavated. The leading edge of the casing would be equipped with cutting teeth to carve through the timber boards and piles of the existing relieving platform and into the soils below.

Once the holes have been drilled and excavated to the final depth, a steel reinforcing cage would be placed into the shaft casing and the casing would be filled with concrete. The casing would be extracted as the concrete is poured and would leave behind a reinforced concrete cylinder, or soldier pile. A line of these soldier piles would be constructed to form the spine of the seawall. Soil anchors would then be installed to brace or tie back these soldier piles.

1.6.4 Soil Dewatering and Spoils Disposal

Regardless of the construction method that is selected, excavations into soils in the construction zone would need to be dewatered, which generally involves disposing of the wastewater offsite or pumping

the excess water to a location where it can be settled and/or before discharge. Wet spoils from jet grouting or other soil improvement activities must be managed or disposed of as well. SDOT is currently exploring various methods for managing and disposing wastewater and jet grout spoils, which would be detailed in the project's dewatering and erosion control submittals required as part of the Clean Water Act Section 401 and National Pollutant Discharge Elimination System (NPDES) construction general stormwater permit processes, as well as by the City's standard construction specifications.

1.6.5 Utility Protection and/or Relocation

The project area contains a large number of utilities, including water, sanitary sewer, combined sewer, stormwater, electrical transmission and distribution, steam, gas, fire alarm, and numerous telecommunication systems. These utilities range from major transmission lines serving portions of Seattle and the region to individual connections serving adjacent properties. As shown in Figure 1-5, some of these utilities are directly beneath the Alaskan Way roadway and sidewalk and above the relieving platform of the existing seawall, while others extend through the seawall to the piers.

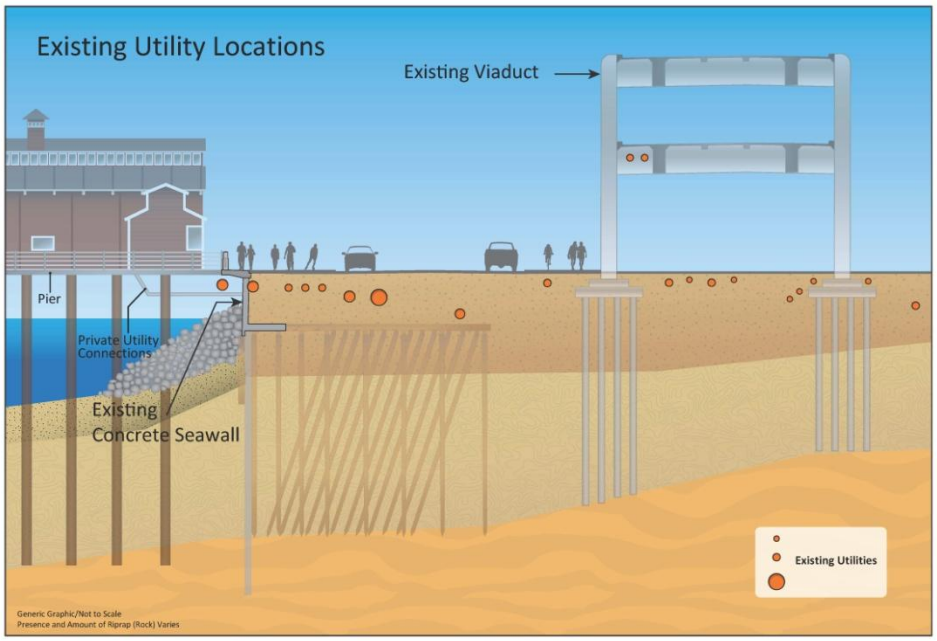


Figure 1-5. Representative Cross Section Showing Typical Existing Utility Locations within Project Limits

SDOT's objective will be to maintain utility service to the greatest extent possible during construction, although the means and methods for doing so would vary depending on the construction method used. Alternatives A and B assume that all soil overlying the relieving platform would need to be excavated. Excavation would require temporary or permanent relocation of the majority of existing utilities. Alternative C assumes that most soil improvement could be accomplished through small penetrations at street level, which would allow the majority of the utility lines above the relieving platform to remain in place during that construction activity. With either method, most individual service lines would be temporarily relocated and reinstalled in their final locations as seawall construction progresses. Final points of service to the waterfront piers would remain the same to alleviate the need to update the

facilities to the current Uniform Building Code. The final construction method chosen will not preclude the ability of utilities to provide future new services to the downtown waterfront area.

1.7 BUILD ALTERNATIVES

The preceding sections provided information on project elements that would be similar among the three build alternatives. The following discussion focuses on the primary differences among Alternatives A, B, and C in terms of the seawall's location, the configuration of Alaskan Way, habitat improvements, public amenities, and construction sequence and schedule. Table 1-1 (at the end of this chapter) compares key features of the alternatives.

1.7.1 Alternative A

Alternative A would reconstruct the seawall as close to its existing alignment as possible, with jet grouting forming the structural support. Habitat improvements would include the addition of shoreline enhancements and the installation of a continuous habitat bench and LPS at piers. Figures 1-18 and 1-19 at the end of this chapter depict Alternative A.

1.7.1.1 Seawall

In Alternative A, the new seawall would be reconstructed as close to the alignment of the existing seawall as possible, with only a minimal setback (as outlined in the bulleted list below). This placement would allow construction to proceed without requiring the removal of the existing wall first.

The approximate proposed location of the seawall face for Alternative A relative to the existing seawall face would be:

- Zone 1 – in place (no change),
- Zone 2 – 15 feet landward,
- Zone 3 – 3 feet waterward, and
- Zones 4, 5, and 6 – 10 feet landward.

In Zone 1, the seawall would be reconstructed in its existing location to minimize potential conflicts with construction of the SR 99 bored tunnel, which is being built as part of a separate project. In Zones 2, 4, 5, and 6, the new wall would be constructed behind (east of) the existing wall, and then the existing seawall west of the new seawall face would be demolished. In Zone 3, the new seawall structure would be constructed to the west of the existing wall, resulting in the new seawall face being set three feet waterward of its current location.

1.7.1.2 Roadway

The existing Alaskan Way is generally four lanes (two lanes in each direction), except in the vicinity of Colman Dock (Yesler Way to Spring Street), where it consists of one northbound lane and two southbound lanes. Alternative A would add a permanent northbound lane between S. Washington and

Madison Streets[1] to handle traffic in this segment headed to Colman Dock and through to other destinations. A temporary second northbound lane (constructed by the Washington State Department of Transportation [WSDOT]) is currently in place. Parking and loading zones in the finished configuration would be similar to today.

A sidewalk of approximately the same width as the existing sidewalk (15 to 20 feet) would be provided on the west side of the street. The sidewalk would be cantilevered or pile supported in Zones 2 through 6 and would extend back to the piers in all zones, with LPS provided where feasible. The mixed-use trail on the east side of Alaskan Way would be extended from its existing terminus north to Clay Street. At Clay Street, the trail would cross Alaskan Way and continue on the west side of Alaskan Way to Broad Street, where it would connect to the existing trail system that runs along Olympic Sculpture Park and Myrtle Edwards Park.

1.7.1.3 Habitat Improvements

Alternative A would provide an effective intertidal corridor along the seawall to support juvenile salmonid migration and would enhance ecosystem productivity. Habitat benches, a sidewalk with LPS, a textured wall face, subtidal substrate enhancements, cobble reefs, and riparian plants would be installed. No net loss of ecological function or intertidal elevation would occur.

1.7.1.4 Upland Improvements

Under Alternative A, public amenities would include the restored historic Washington Street Boat Landing, improved water-viewing opportunities at various locations, new or replaced railings, new sidewalks, waterfront planters, and street plantings. Reconstructed sidewalks would extend from the curb line of the restored Alaskan Way to the western edge of the existing sidewalk. These improvements would add variety to the waterfront by defining gathering spaces, viewing areas, and building entries.

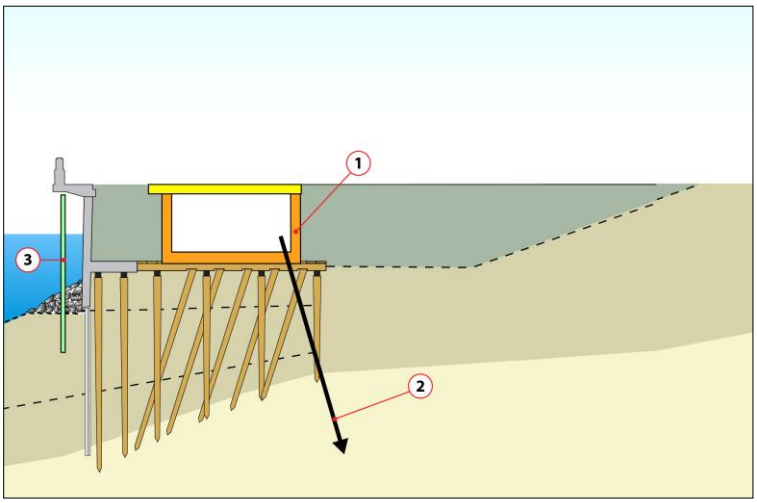
1.7.1.5 Construction and Schedule

Under Alternative A, the construction method proposed for the primary structural element of the seawall is soil improvement. With this method, construction of the Central Seawall would require approximately three construction seasons with two summer shutdown periods. Construction of the North Seawall would require an additional four construction seasons with three summer shutdown periods. The current plan for Alternative A is to begin construction of the Central Seawall in Zone 4, move southward to Zone 3, and then progress to Zones 2 and 1. The Central Seawall construction would be followed by the North Seawall construction in Zones 6 and 5.

The anticipated construction activities and probable sequence for Alternative A, using jet grouting for the soil improvement, are depicted in Figures 1-6 through 1-9. The figures describe four primary stages of work that would occur along the waterfront. The construction activities within each zone would vary

[1] The Elliott Bay Seawall Project would build the additional lane from S. Washington Street to Madison Street. The portion between S. King Street and S. Washington Street would be constructed as part of the Alaskan Way Viaduct Replacement Project.

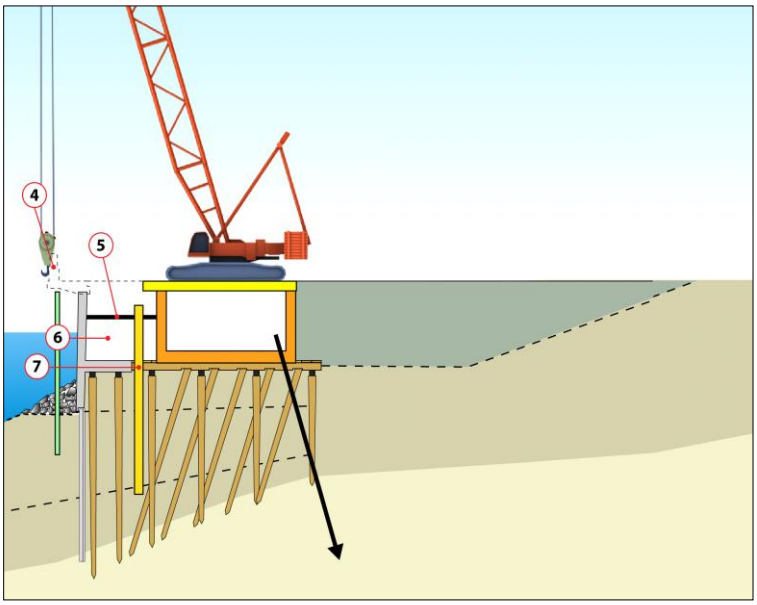
depending on the type of existing seawall. The figures depict the Type A seawall. (Type A seawall is a sheet-pile supported, reinforced, concrete face panel, which is tied back to a buried timber relieving platform supported by vertical and battered timber piles.) For Alternative A, it was assumed that the area above the existing relieving platform would be excavated before jet grouting begins.



Alternative A, Stage 1

1. Excavate to the top of relieving platform, relocate utilities, and install shoring
2. Install soil anchors
3. Remove existing riprap and install temporary containment wall

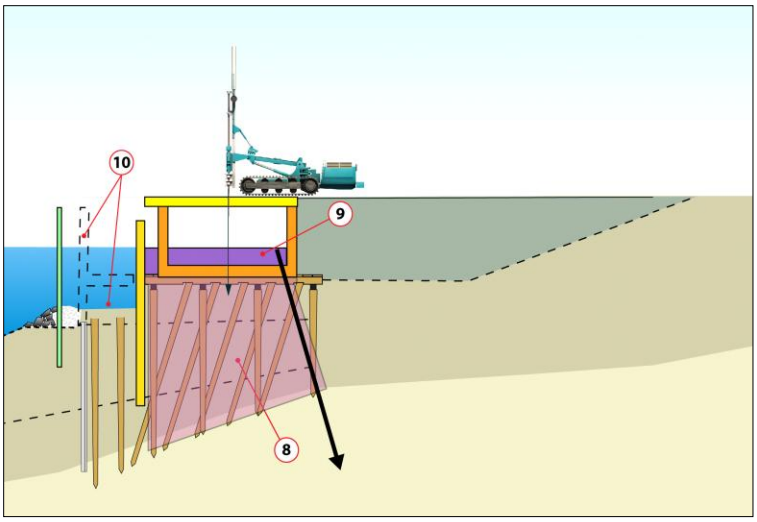
Figure 1-6. Alternative A, Stage 1



Alternative A, Stage 2

4. Remove existing cantilever sidewalk
5. Brace existing concrete face panel
6. Excavate remaining soil
7. Install concrete face panel

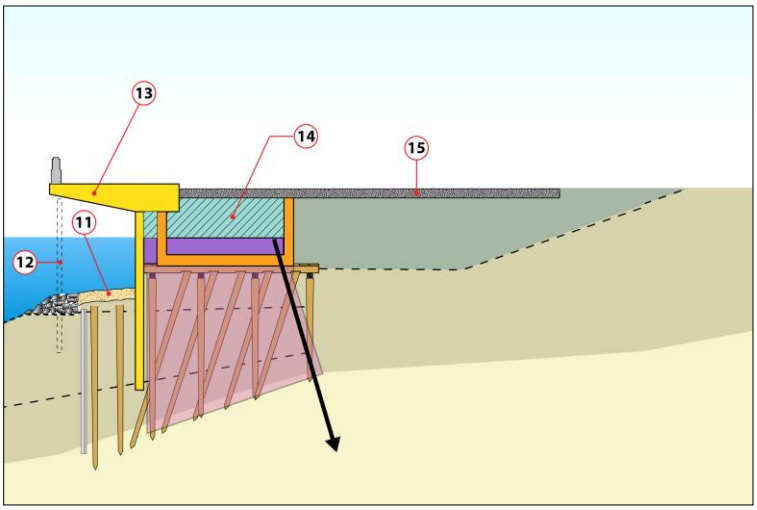
Figure 1-7. Alternative A, Stage 2



Alternative A, Stage 3

8. Install soil improvement (jet grouting)
9. Install anchor slab
10. Remove portion of existing wall

Figure 1-8. Alternative A, Stage 3



Alternative A, Stage 4

11. Place substrate
12. Remove temporary containment wall
13. Install sidewalk
14. Restore utilities and backfill
15. Complete restored roadway

Figure 1-9. Alternative A, Stage 4

1.7.2 Alternative B

Alternative B would move the seawall up to 75 feet landward of its current location, with BSP forming an underground wall structure to protect against coastal storm damage and seismic forces. In addition to the habitat improvements described for Alternative A, this alternative would construct a continuous habitat bench and continuous LPS at the piers. Figures 1-20, 1-21, and 1-22 at the end of this chapter depict Alternative B.

1.7.2.1 Seawall

Under Alternative B, the new seawall would be constructed up to 75 feet east of the existing seawall alignment and would provide a range of potential design opportunities. The approximate proposed location of the seawall face for Alternative B, relative to the existing seawall face, would be:

- Zone 1 – 0 to 15 feet landward,
- Zone 2 – 15 feet landward,
- Zone 3 – 30 feet landward,
- Zone 4 – 30 to 75 feet landward following the restored road curb alignment, and
- Zones 5 and 6 – 10 feet landward.

In Zones 1, 2, 5, and 6, the new wall would be constructed 10 to 15 feet east of the existing wall. In Zones 3 and 4, the new wall would be constructed 30 to 75 feet farther east, allowing greater flexibility for future habitat and public amenity spaces. This eastward realignment would largely reshape the downtown Seattle waterfront. After the new seawall was in place, the existing seawall would be demolished.

1.7.2.2 Roadway

Under Alternative B, the lane configuration of Alaskan Way would remain identical to the current configuration because of the confined space that would be available between the location of the seawall (eastward of the existing seawall) and the existing Alaskan Way Viaduct structure. A temporary northbound lane between Yesler Way and Spring Street has been installed by WSDOT, and it may be used during seawall construction.

Similar to the other build alternatives, the existing roadway, sidewalk, and multi-use trail would be restored to their original function and capacity after construction, with the multi-use trail connecting to the existing trail system that runs along Olympic Sculpture Park and Myrtle Edwards Park. However, due to space constraints, southbound parking and loading in Zone 3 may be restricted between University and Madison Streets.

1.7.2.3 Habitat Improvements

Alternative B would include the installation of habitat benches, a sidewalk with LPS, a textured wall face, subtidal substrate enhancements, cobble reefs, and riparian plants. However, the intertidal habitat

would be larger because the seawall would be set back farther east (landward). Alternative B would provide substantial enhancements within the new aquatic land available in Zones 1, 3, and 4.

Zone 1 would include an intertidal habitat bench and backshore that would be bordered by riparian plants, rocks, and drift logs. In Zone 3, the 30-foot seawall setback would allow the installation of a confined-substrate habitat bench with LPS installed above. In Zone 4, the 75-foot seawall setback would allow expanded upland riparian planting or increased intertidal habitat.

1.7.2.4 Upland Improvements

Alternative B would improve water viewing at various locations and provide additional public gathering spaces, as well as interpretive, recreational, and cultural opportunities. The new sidewalks would be enhanced with LPS and reconfigured with planters and new or replaced railings along the length of the seawall. These additional and enhanced gathering and overlook spaces would be provided in Zones 1, 3, 4, 5, and 6.

In Zone 1, Washington Street Boat Landing would be restored and reinstalled within the Washington Street right-of-way, west of its current location to improve its connection to the water. A new gangway and short-stay boat moorage could be created to restore the landing's historic connection with Elliott Bay. North of the boat landing, steps and a boardwalk (Option 1) or boulders (Option 2) could be added for seating and for physical access to or viewing of the new intertidal habitat bench.

Zones 3, 5, and 6 would include viewpoints between the piers. These viewpoints would create opportunities for public gathering, seating, and water viewing. The viewpoints would be parallel with the adjacent piers, thereby directing the view out to Elliott Bay. The viewpoints would include seating steps and stairs to bring people closer to the water.

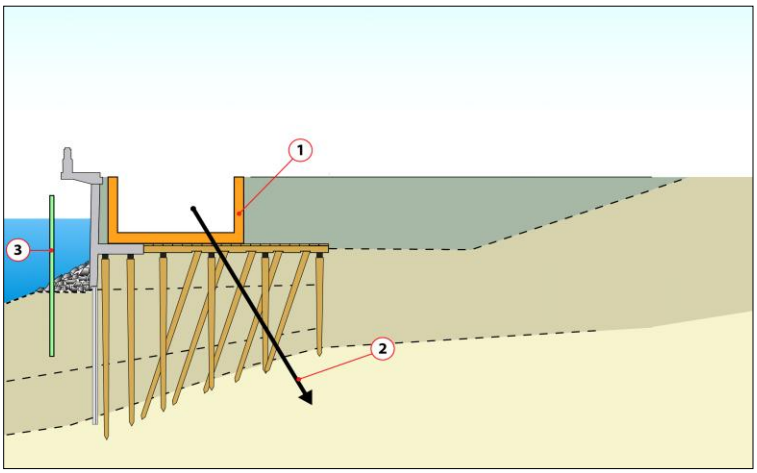
In Zone 4, the proposed seawall setback of 30 to 75 feet would provide two types of opportunities: a water plaza (Option 1) or a land plaza (Option 2). In Option 1, openings in the expansive plaza and walk would allow users to view tide pools and aquatic life below. In Option 2, raised planters would be filled with riparian plants, logs, and stones that would be reminiscent of Puget Sound shorelines.

1.7.2.5 Construction and Schedule

Under Alternative B, the design option proposed for the primary structural element of the seawall is BSP installed by means of a drilled-shaft construction method. With this method, construction of the Central Seawall would require approximately five construction seasons with four summer shutdown periods. Construction of the North Seawall would require an additional four construction seasons, similar to Alternatives A and C, although the duration may be slightly longer.

Access during construction would be more difficult than for either Alternatives A or C because the eastward setback of the seawall would restrict the construction staging areas to the project ends (i.e., north and south extents), instead of alongside the construction work zone. Under Alternative B, it would not be possible to maintain a continuous construction haul road because of the seawall setback in Zones 3 and 4. The construction of a land plaza or water plaza in Zone 4 would increase the duration of construction.

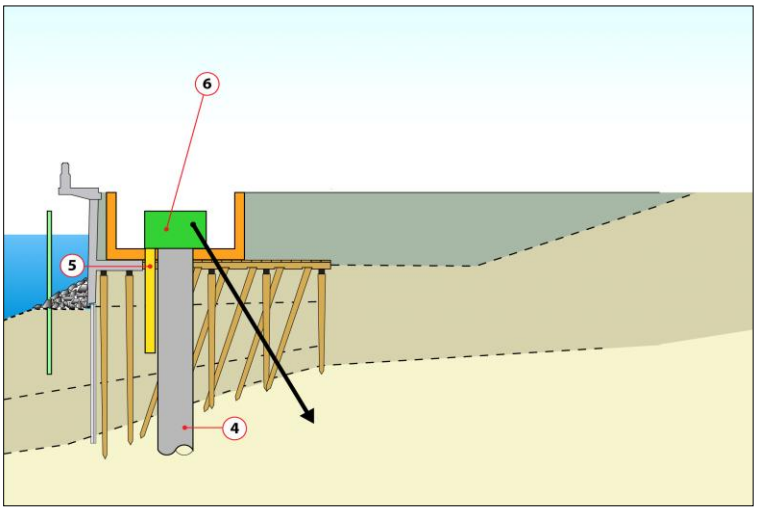
Construction of the Central Seawall would begin in Zone 4, move southward to Zone 3, and then progress to Zones 2 and 1. The Central Seawall construction would be followed by the North Seawall construction in Zones 6 and 5. The anticipated construction stages for Alternative B (assuming a Type A existing seawall) are shown in Figures 1-10 through 1-13.



Alternative B, Stage 1

1. Excavate to top of relieving platform, relocate utilities, and install shoring
2. Install soil anchors
3. Remove existing riprap and install temporary containment wall

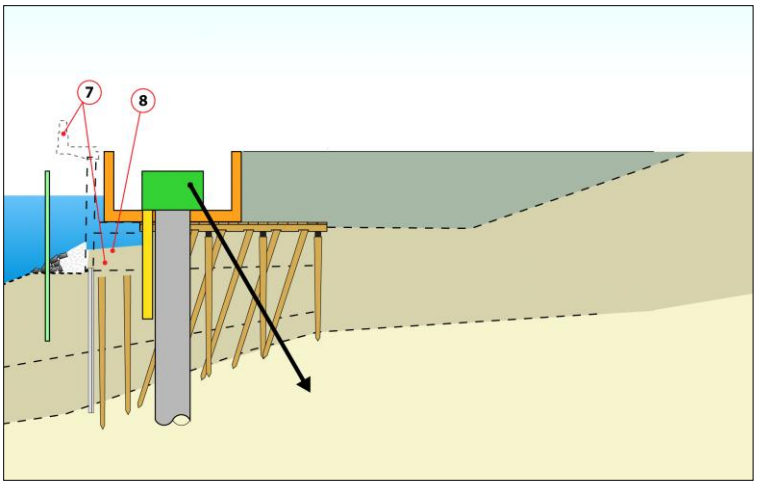
Figure 1-10. Alternative B, Stage 1



Alternative B, Stage 2

4. Drill shaft
5. Install concrete face panel
6. Cast concrete anchor cap

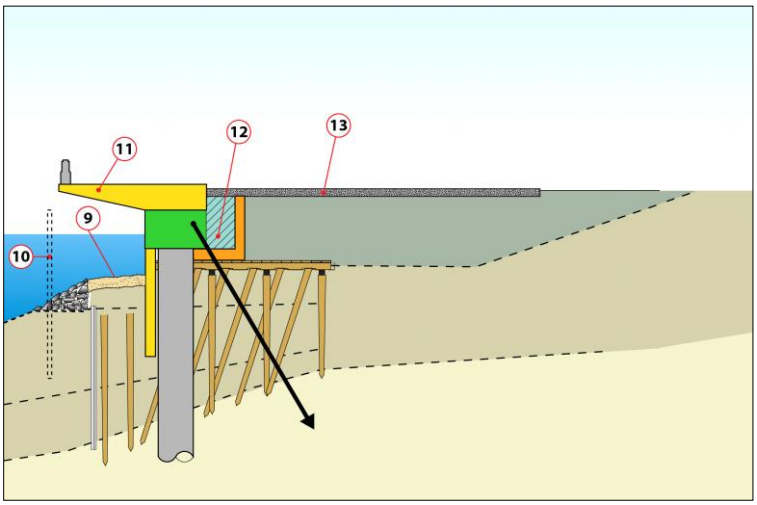
Figure 1-11. Alternative B, Stage 2



Alternative B, Stage 3

7. Remove existing cantilever sidewalk
8. Remove portion of existing wall

Figure 1-12. Alternative B, Stage 3



Alternative B, Stage 4

9. Place substrate
10. Remove temporary containment wall
11. Install sidewalk
12. Restore utilities and backfill
13. Complete restored roadway

Figure 1-13. Alternative B, Stage 4

1.7.3 Alternative C

Alternative C would move the seawall up to 15 feet landward of its current location and would use soil improvements (likely including both jet grouting and deep soil mixing) to provide structural support. Alternative C would also provide a continuous habitat bench and continuous LPS in addition to shoreline enhancements. Figures 1-23 and 1-24 at the end of this chapter depict Alternative C.

1.7.3.1 Seawall

Under Alternative C, the seawall would be constructed approximately 10 to 15 feet landward of the existing seawall alignment along its entire length. The setback proposed for Alternative C would allow soil improvements to proceed without first removing the existing seawall. The approximate proposed location of the seawall face for Alternative C relative to the existing seawall face would be:

- Zones 1 and 2 – 15 feet landward,
- Zone 3 – 10 to 15 feet landward, and
- Zones 4, 5, and 6 – 10 feet landward.

1.7.3.2 Roadway

The existing roadway is generally four lanes (two lanes in each direction), except in the vicinity of Colman Dock (Yesler Way to Spring Street), where it consists of one northbound lane and two southbound lanes. Alternative C would add a permanent northbound lane between S. Washington and Madison Streets[2] to support traffic bound for Colman Dock and other destinations. A temporary second northbound lane (constructed by WSDOT) is currently in place and could be used during seawall construction. Parking and loading zones would be similar to those present today.

A sidewalk of approximately the same width as the existing sidewalk (15 to 20 feet) would be provided on the west side of the street after construction. The sidewalk alignment would be cantilevered or pile supported and would extend back to the piers in all zones. The mixed-use trail on the east side of Alaskan Way would be extended north from its existing terminus to Clay Street, where it would cross Alaskan Way and continue on the west side of the street to Olympic Sculpture Park and Myrtle Edwards Park.

1.7.3.3 Habitat Improvements

Like Alternatives A and B, Alternative C would include a number of habitat improvements. These improvements would extend 10 to 45 feet from the face of the new seawall. An intertidal bench would be installed at the base of the seawall to form a shallow angle to the seafloor and provide shallower water for juvenile salmon migration. Installation of a textured seawall face panel would support the development of marine nearshore habitat. Restoration of riparian areas along the back beach area in Zone 1 would include species of riparian and beach shrubs native to Puget Sound.

---

[2] The Elliott Bay Seawall Project would build the additional lane from S. Washington Street to Madison Street. The portion between S. King Street and S. Washington Street would be constructed as part of the Alaskan Way Viaduct Replacement Project.

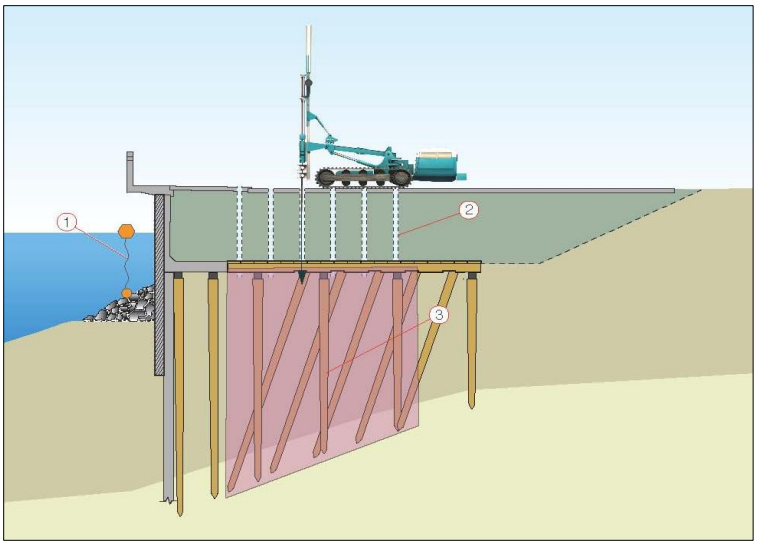
1.7.3.4 Upland Improvements

Under Alternative C, the restored sidewalk space would be enhanced with LPS and include new or upgraded railings, historic elements, wayfinding features, and lighting. Water-viewing opportunities would be preserved or enhanced at various locations, and additional viewing opportunities would be included at Spring and University Streets in Zone 3. In Zone 1, the Washington Street Boat Landing would be restored and reinstalled within the S. Washington Street right-of-way.

1.7.3.5 Construction and Schedule

For Alternative C, the construction method proposed for the primary structural element of the seawall is soil improvement. Alternative C assumes that the soil improvement would be accomplished from street level, without excavating the soils over the relieving platform. After seawall stabilization, the area above the relieving platform would be excavated to allow for installation of the new seawall face and sidewalk. With this method, construction of the Central Seawall would require approximately three construction seasons with two summer shutdown periods. Subsequent construction of the North Seawall would require an additional four construction seasons.

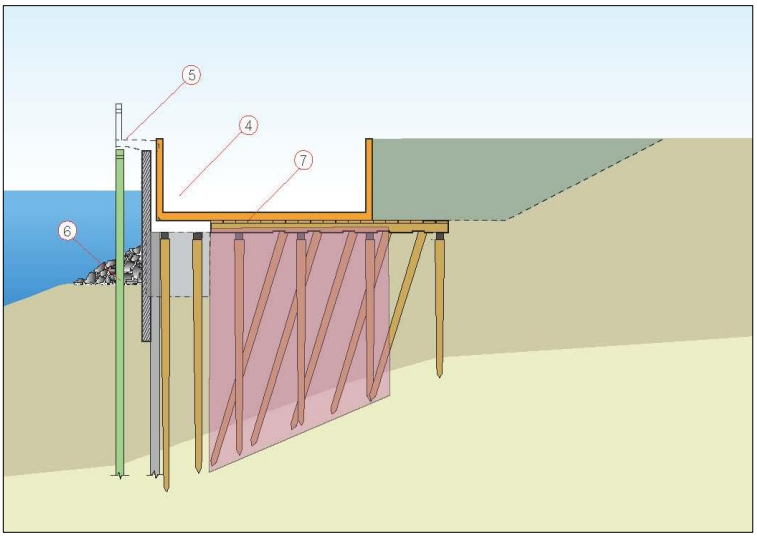
The anticipated construction activities and probable sequence for Alternative C, using soil improvement, are depicted below. The figures describe four primary stages of work that would occur along the waterfront. The activities within each zone would vary depending on the type of existing seawall present. Figures 1-14 through 1-17 are representative of the expected Alternative C construction sequence and depict the Type A seawall.



Alternative C, Stage 1

1. Place in-water containment curtain
2. Pre-drill and fill existing voids beneath timber relieving platform
3. Install soil improvement (jet grout)

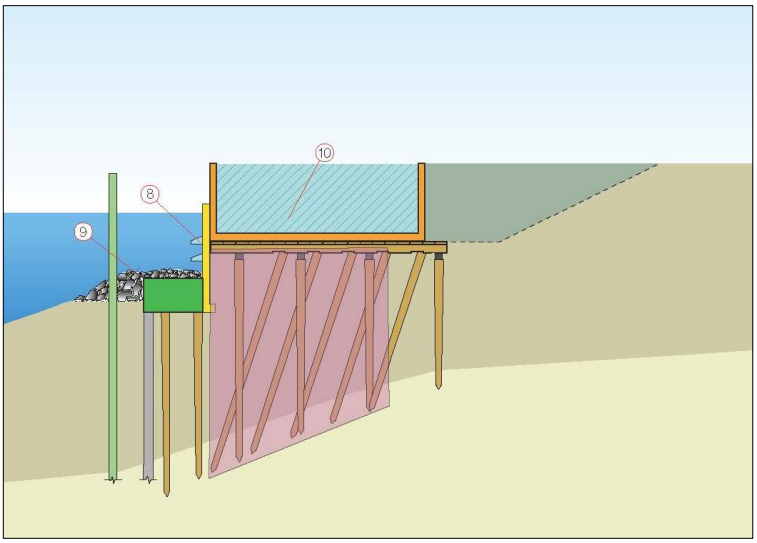
Figure 1-14. Alternative C, Stage 1



Alternative C, Stage 2

4. Relocate utilities
5. Remove existing sidewalk and pavement
6. Install temporary containment wall
7. Excavate to timber relieving platform

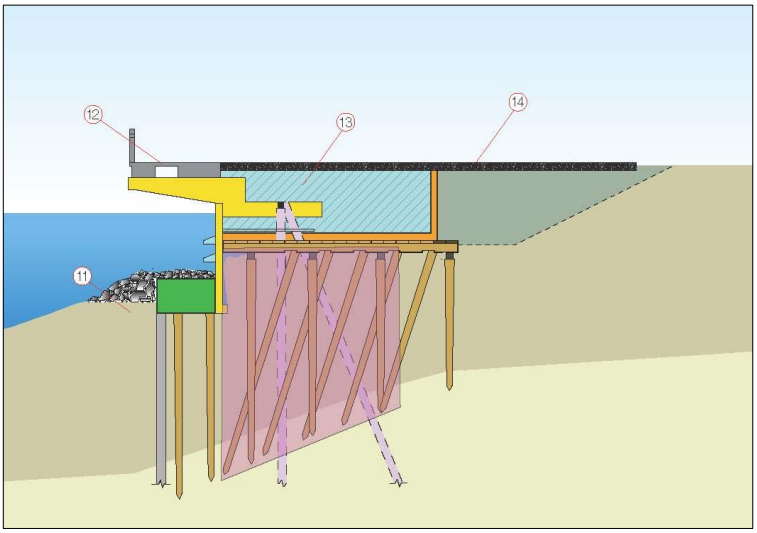
Figure 1-15. Alternative C, Stage 2



Alternative C, Stage 3

8. Remove portion of existing wall and install new face panels and habitat shelves
9. Place habitat bench

Figure 1-16. Alternative C, Stage 3



Alternative C, Stage 4

11. Remove temporary containment wall
12. Install cantilevered sidewalk with light penetrating surface
13. Restore utilities
14. Restore roadway for local traffic

Figure 1-17. Alternative C, Stage 4

TABLE 1-1. COMPARISON OF FEATURES OF THE THREE ELLIOTT BAY SEAWALL PROJECT BUILD ALTERNATIVES

Project Feature	Alternative A	Alternative B	Alternative C
Construction Method	Soil improvement	Braced soldier piles	Soil improvement
Central Seawall Construction Duration	3 construction seasons	5 construction seasons	3 construction seasons
North Seawall Construction Duration	4 construction seasons	4 construction seasons	4 construction seasons
Zone 1			
Face of Seawall Location	Existing location	0 to 15 feet landward	15 feet landward
Habitat Improvements	• Riparian plantings • Substrate enhancement • Cobble reef • Textured seawall face	• Riparian plantings • Substrate enhancement • Cobble reef • Expanded habitat bench and backshore	• Riparian plantings • Substrate enhancement • Expanded habitat bench and backshore
Upland Improvements	• Washington Street Boat Landing restoration • New or restored railings	• Washington Street Boat Landing restoration (up to 15 feet waterward of existing location) • Steps, boardwalk, and overlook (Option 1) • Short-stay boat moorage • New or restored railings	• Washington Street Boat Landing restoration (up to 15 feet waterward of existing location) • New or restored railings
Transportation Features	• Restored sidewalk • Restored multi-use trail • Restored roadway with additional northbound lane from S. Washington to Madison Street	• Restored sidewalk • Restored multi-use trail • Restored roadway	• Restored sidewalk • Restored multi-use trail • Restored roadway with additional northbound lane from S. Washington to Madison Street
Zone 2			
Face of Seawall Location	15 feet landward	15 feet landward	15 feet landward
Habitat Improvements	• Confined substrate habitat bench • Textured seawall face • Intermittent LPS	• Confined substrate habitat bench • Textured seawall face • Continuous LPS	• Confined substrate habitat bench • Textured seawall face • Continuous LPS
Upland Improvements	• Same as existing	• Same as existing	• Same as existing
Transportation Features	• Restored sidewalk • Restored multi-use trail • Restored roadway with additional northbound lane from S. Washington to Madison Street	• Restored sidewalk • Restored multi-use trail • Restored roadway	• Restored sidewalk • Restored multi-use trail • Restored roadway with additional northbound lane from S. Washington to Madison Street

Project Feature	Alternative A	Alternative B	Alternative C
Zone 3			
Face of Seawall Location	3 feet waterward	30 feet landward	10 to 15 feet landward
Habitat Improvements	• Confined substrate habitat bench and expanded habitat bench • Textured seawall face • Intermittent LPS at piers • Riparian plantings	• Confined substrate habitat bench and expanded habitat bench • Textured seawall face • Continuous LPS • Riparian plantings	• Confined substrate habitat bench and expanded habitat bench • Textured seawall face • Continuous LPS
Upland Improvements	• New or restored railings • Street plantings • Viewing area	• New or restored railings • Street plantings • Enhanced viewpoints with seating	• New or restored railings • Street plantings • Enhanced viewpoints
Transportation Features	• Restored sidewalk • Restored multi-use trail • Restored roadway	• Restored sidewalk • Restored multi-use trail • Restored roadway	• Restored sidewalk • Restored multi-use trail • Restored roadway
Zone 4			
Face of Seawall Location	10 feet landward	30 to 75 feet landward	10 feet landward
Habitat Improvements	• Confined substrate habitat bench and expanded habitat bench • Substrate enhancements • Textured seawall face • Intermittent LPS at piers • Cobble reefs • Riparian plantings	• Confined substrate habitat bench and expanded habitat bench • Substrate enhancements • Textured seawall face • Continuous LPS • Cobble reefs • Riparian plantings • Daylighting of water plaza	• Confined substrate habitat bench and expanded habitat bench • Substrate enhancements • Textured seawall face • Continuous LPS • Daylighting of portions of cantilevered sidewalk
Upland Improvements	• New or restored railings • Street plantings • Viewing area	• New or restored railings • Street plantings • Creation of a land or water plaza • Enhanced viewpoints	• New or restored railings • Street plantings
Transportation Features	• Restored sidewalk • Restored multi-use trail • Restored roadway	• Restored sidewalk • Restored multi-use trail • Restored roadway	• Restored sidewalk • Restored multi-use trail • Restored roadway

Project Feature	Alternative A	Alternative B	Alternative C
Zone 5			
Face of Seawall Location	10 feet landward	10 feet landward	10 feet landward
Habitat Improvements	• Confined substrate habitat bench • Riparian plantings • Textured seawall face	• Confined substrate habitat bench • Riparian plantings • Textured seawall face	• Confined substrate habitat bench • Riparian plantings • Textured seawall face • Continuous LPS
Upland Improvements	• New or restored railings • Street plantings • Viewing area	• New or restored railings • Street plantings • Expanded viewpoints	• New or restored railings • Street plantings • Enhanced viewpoints
Transportation Features	• Restored sidewalk • Restored multi-use trail • Restored roadway	• Restored sidewalk • Restored multi-use trail • Restored roadway	• Restored sidewalk • Restored multi-use trail • Restored roadway
Zone 6			
Face of Seawall Location	10 feet landward	10 feet landward	10 feet landward
Habitat Improvements	• Confined substrate habitat bench and expanded habitat bench • Substrate enhancement • Textured seawall face • Riparian plantings • Intermittent LPS at piers • Cobble reefs	• Confined substrate habitat bench and expanded habitat bench • Substrate enhancement • Textured seawall face • Riparian plantings • Intermittent LPS at piers • Cobble reefs	• Confined substrate habitat bench and expanded habitat bench • Substrate enhancement • Textured seawall face • Riparian plantings • Continuous LPS
Upland Improvements	• Restored or new railings • Viewing area	• Restored or new railings • Enhanced viewpoints	• Restored or new railings • Enhanced viewpoints
Transportation Features	• Restored sidewalk • Extended multi-use trail • Restored roadway	• Restored sidewalk • Extended multi-use trail • Restored roadway	• Restored sidewalk • Extended multi-use trail • Restored roadway

Note: LPS – light-penetrating surfaces

This page intentionally left blank.

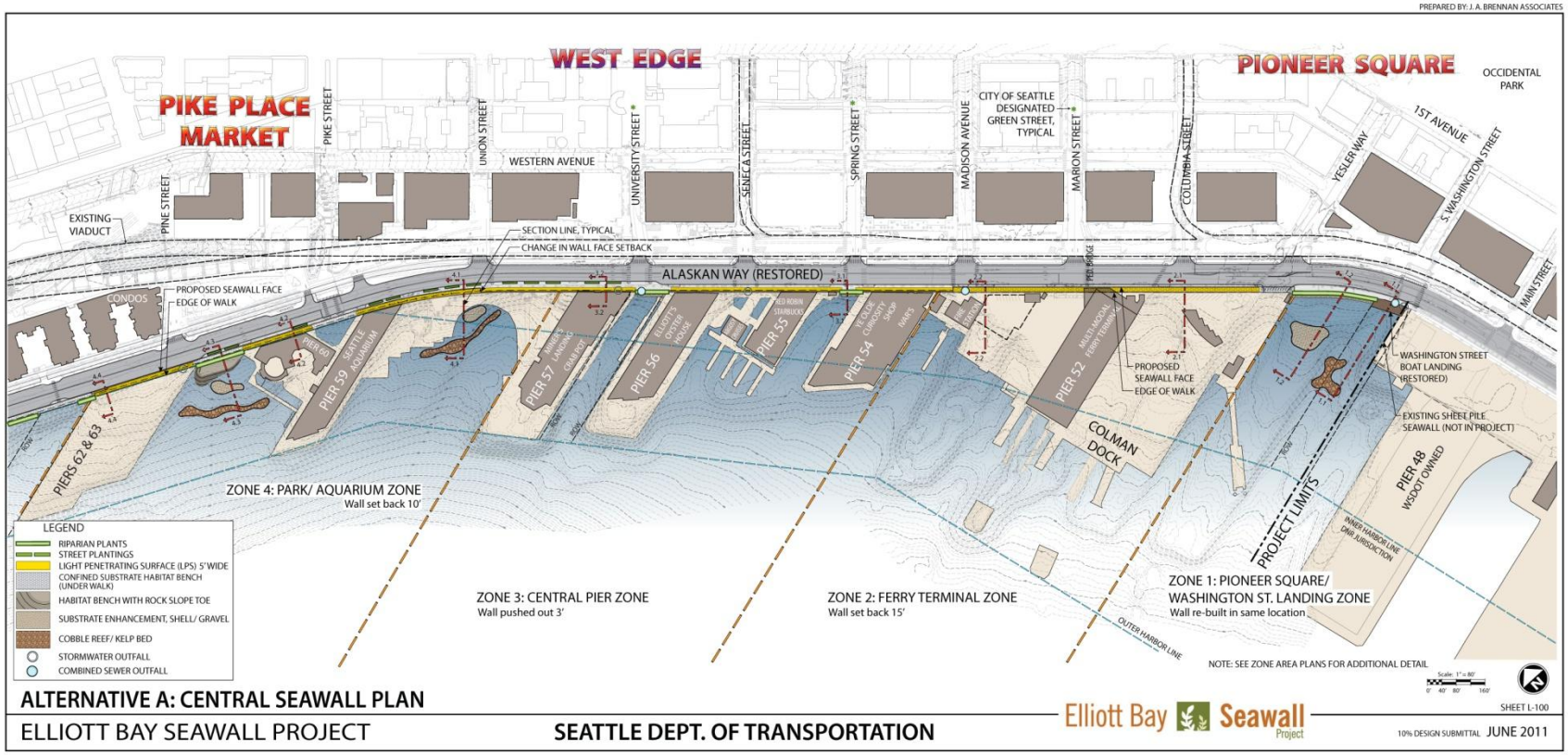


Figure 1-18. Alternative A: Central Seawall Plan

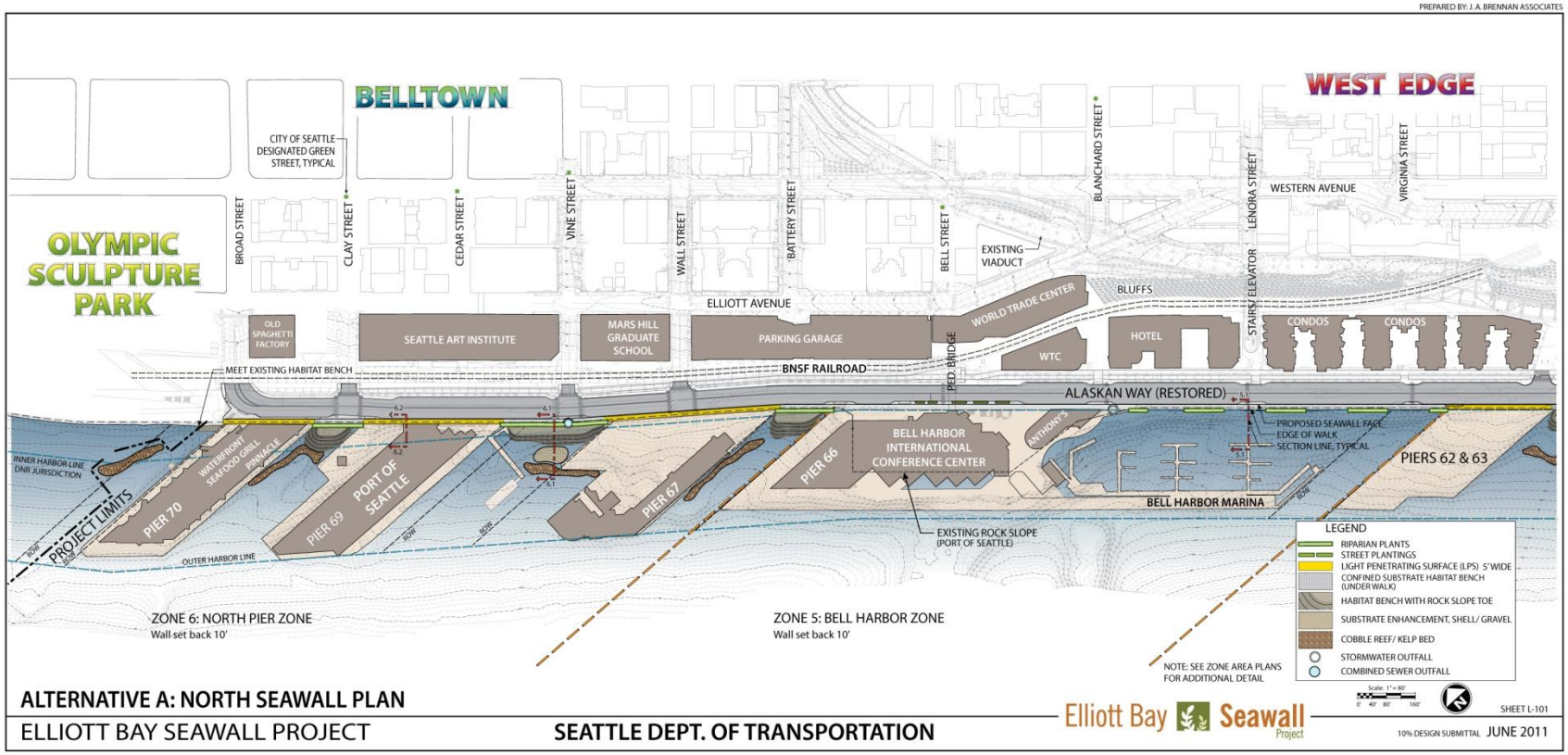


Figure 1-19. Alternative A: North Seawall Plan

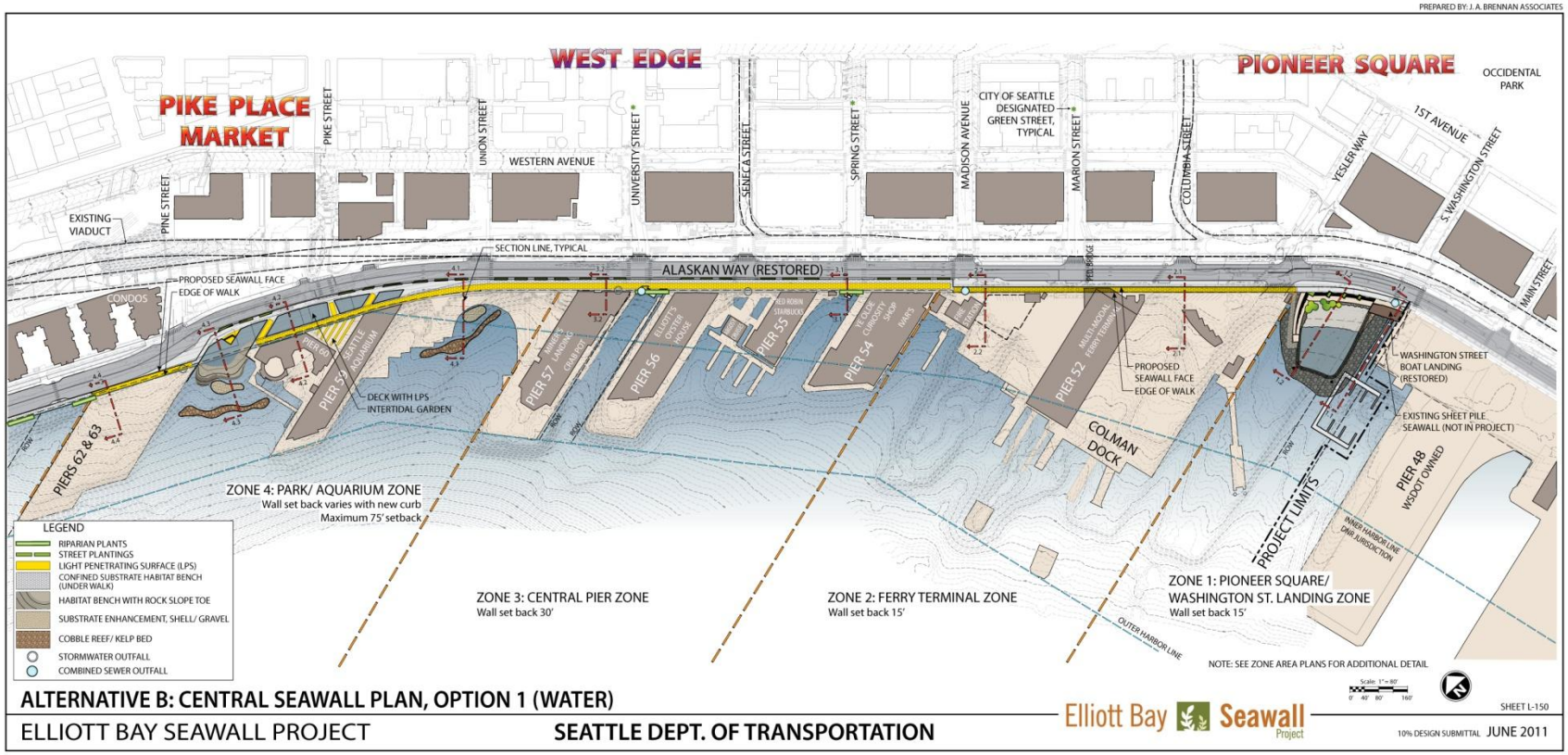


Figure 1-20. Alternative B: Central Seawall Plan, Option 1

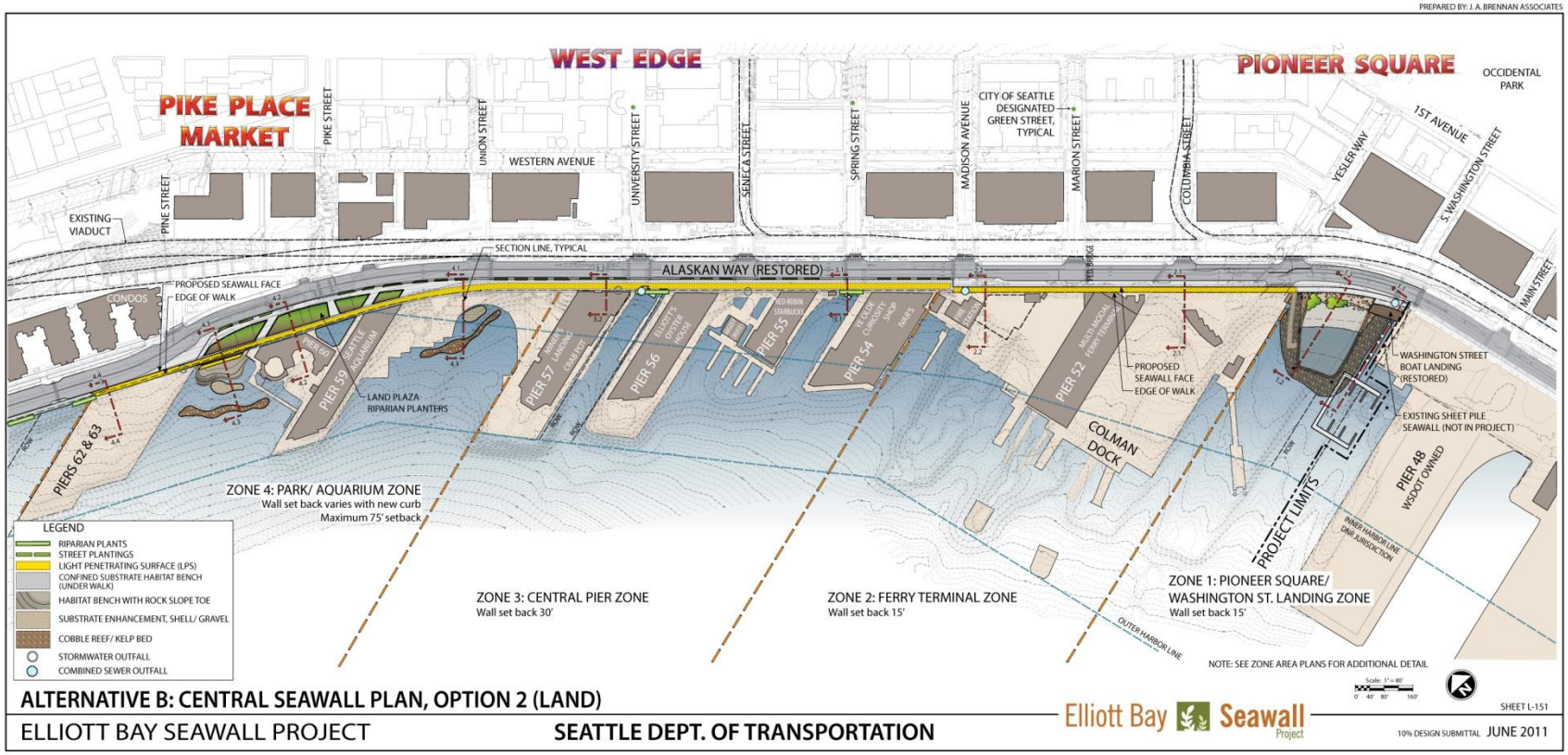


Figure 1-21. Alternative B: Central Seawall Plan, Option 2

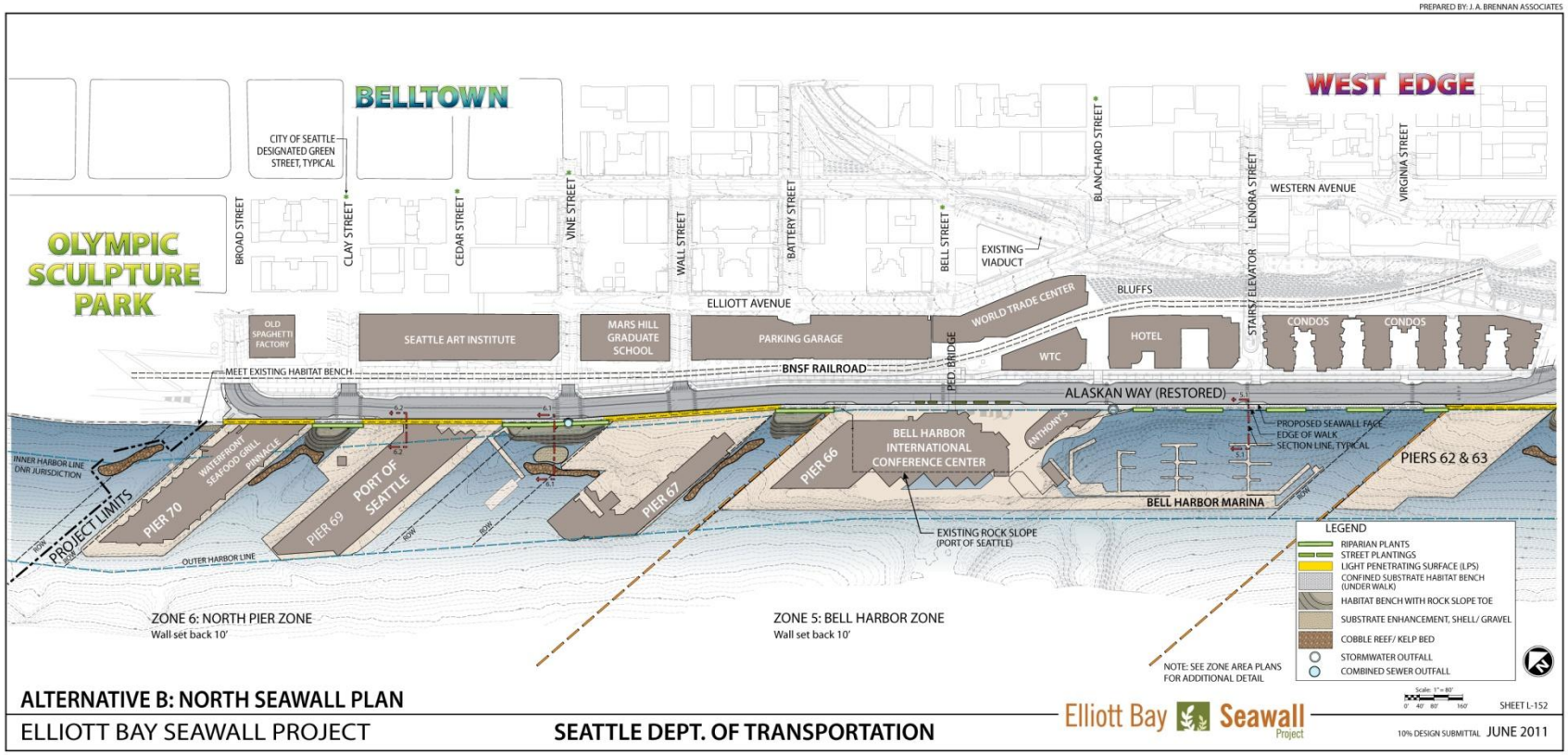


Figure 1-22. Alternative B: North Seawall Plan

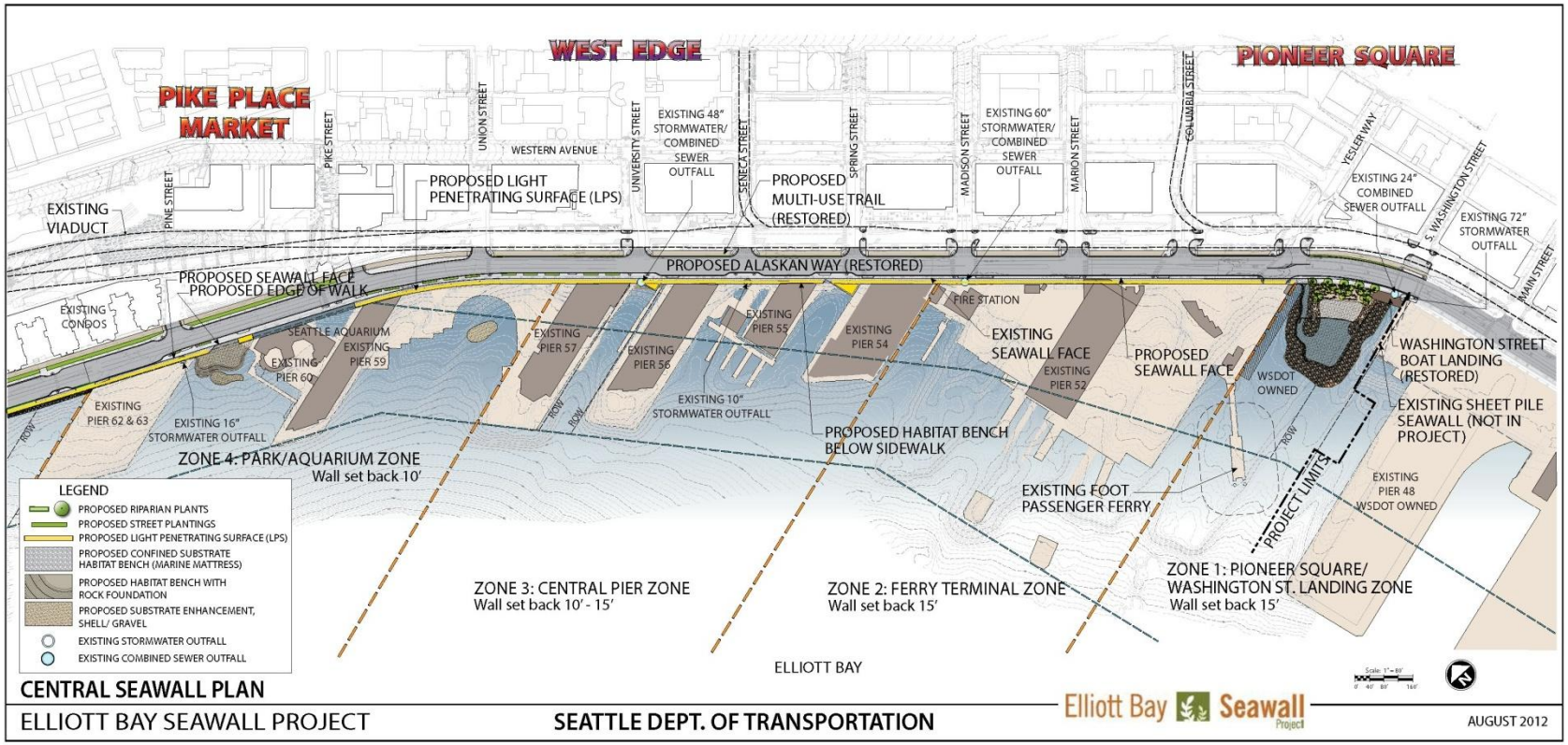


Figure 1-23. Alternative C: Central Seawall Plan

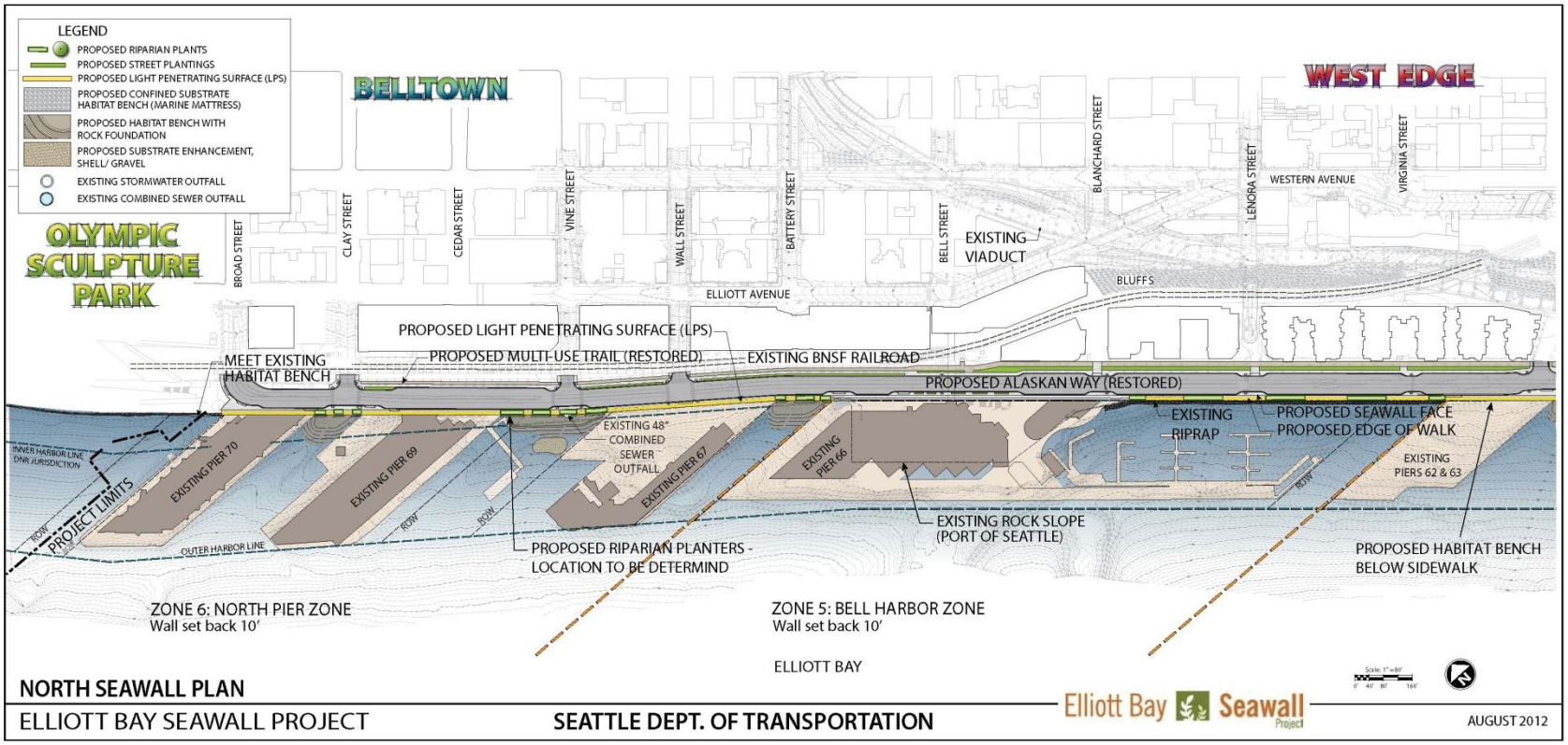


Figure 1-24. Alternative C: North Seawall Plan

This page intentionally left blank.

CHAPTER 2. METHODOLOGY

The *Elliott Bay Seawall Project Geology and Soils Methodology Technical Memorandum* (SDOT 2010) contains a detailed description of the methodology used for this Discipline Report.

The objective of the Geology and Soils Discipline Report is to describe the geologic conditions in the study area and identify construction and operational effects that the EBSP could have on geology, soils and groundwater.

2.1 STUDY AREA

The study area for evaluation of geology- and soils-related EBSP effects extends along the seawall from Western Avenue or Elliott Avenue on the east, to the ends of the piers on the west. The south and north ends of the EBSP are S. Washington Street and Broad Street, respectively. The geologic environment and soils within this area are evaluated in this Discipline Report. The study considered geology and soils extending to a minimum of 40 feet below the ground surface (bgs).

2.2 REGULATIONS AND GUIDELINES

The City of Seattle Environmentally Critical Areas Ordinance SMC 25.09 (City of Seattle 2006); the USACE Coastal Engineering Manual (EM 1110-2-1100) (USACE 2008); and the USACE Coastal Revetments, Seawalls, and Bulkheads Engineering Manual (EM 1110-2-1614) (USACE 1995) were considered when describing geology- and soils-related impacts. Other locally referenced guidelines that were used include the WSDOT Geotechnical Design Manual (WSDOT 2011) and Environmental Procedures Manual (WSDOT 2010).

2.3 SOURCES OF DATA

The geologic evaluation along the seawall alignment was performed by reviewing existing subsurface data collected for the Alaskan Way Viaduct and Seawall Replacement Program (AWVSRP) and reviewing published geologic literature for the project area. The sources reviewed are indicated in Chapter 3. The primary source for geology and soils information is the January 2011 Geotechnical Data Summary Report prepared for the EBSP (Shannon & Wilson 2011).

2.4 ANALYSIS OF EXISTING CONDITIONS

The analyses of existing conditions discussed in this Discipline Report address the following geology- and soils-related issues:

- Topographic and geologic setting;
- Tectonics and seismicity, including evaluation of the Seattle Fault Zones and other shallow crustal seismicity and sources, and the Cascadia Subduction Zone;
- Site geology, in-water sediment, and subsurface soils conditions;

- Geologic hazards, including landsliding, erosion, fault rupture, liquefaction, ground motion amplification, and tsunamis; and
- Groundwater, including regional groundwater systems and flow, site groundwater conditions, groundwater recharge and discharge, and current aquifer use.

2.5 ANALYSIS OF ENVIRONMENTAL EFFECTS

The analysis of geology and soils environmental effects was performed by evaluating the following items in relation to the EBSP:

- Unknown subsurface conditions,
- Seismic considerations,
- Ground settlement,
- Soil improvement,
- Groundwater levels and flow,
- Excavations and dewatering,
- Pile driving,
- Fill placement,
- Erosion and sediment transport, and
- Stockpiles and soil disposal.

The evaluations were made based on experience with similar projects and similar soil conditions, as well as preliminary engineering analyses. Effects of both construction and operations of the EBSP were evaluated.

2.6 DETERMINING MITIGATION MEASURES

Mitigation measures were developed to avoid, minimize, and compensate for unavoidable adverse effects on identified geology- and soils-related effects. The potential mitigation measures were selected based on experience with similar projects and the results of feasibility evaluations and preliminary engineering analyses. Best Management Practices (BMPs) will mitigate many of the identified effects. Some of the mitigation measures have additional effects on the geology and soils environment (e.g., soil improvement); therefore, additional mitigation measures were presented in these cases.

CHAPTER 3. COORDINATION AND INFORMATION SOURCES

This Discipline Report was prepared based on subsurface data collected by Shannon & Wilson, Inc. Archive information was obtained from the City, King County, and WSDOT. Subsurface data were collected from the following sources:

- Shannon & Wilson, Inc. project files;
- WSDOT files;
- GEO-MAP Northwest;
- Seattle Department of Planning and Development; and
- Washington State Department of Ecology (Ecology).

In addition to reviewing the site-specific subsurface data from these various sources, published geologic literature were reviewed for the project area. These data include the following:

- City of Seattle Environmentally Critical Areas Ordinance and Maps;
- United States Geological Survey Geology Maps;
- Department of Natural Resources Maps;
- Department of Ecology Coastal Zone Atlas of Washington; and
- Microzonation Maps for the Seattle, Washington, Metropolitan Area.

Field explorations were performed for the AWVSRP between 2001 and 2010. These explorations were reviewed for applicability to the EBSP alignment. No additional field explorations were performed for the preparation of this Discipline Report. The AWVSRP subsurface data and related engineering analyses are summarized in the following reports:

- August 2002 Geotechnical and Environmental Data Report (GEDR);
- January 2003 Geotechnical Analysis for Alaskan Way Seawall;
- October 2004 Seismic Ground Motion Study Report;
- August 2005 GEDR;
- April 2006 Utility Geoprobe Report;
- April 2007 GEDR for Electrical Utility Explorations;
- April 2007 Geotechnical and Environmental Data and Dewatering Feasibility Report;
- October 2007 GEDR for Phase 1 Archeological Explorations;
- December 2007 GEDR for Utilidor Explorations;
- May 2009 Seismic Ground Motion study Supplement for 1,000-Year Ground Motion;
- May 2010 GEDR for SR 99 Bored Tunnel Alternative Design-Build Project; and
- June 2010 Geologic Characterization Interim Letter for SR 99 Bored Tunnel Alternative Design-Build Project.

In addition to the reports listed above, the January 2011 Geotechnical Data Summary Report (Amended November 2011) prepared for the EBSP was reviewed. The subsurface data in these reports were used to develop the Affected Environment section of this report and to identify operational and construction effects, mitigation measures, and benefits of the EBSP. Other than obtaining the subsurface data, no other coordination with agencies was required to prepare this Discipline Report.

CHAPTER 4. AFFECTED ENVIRONMENT

The subsurface conditions along the study area were evaluated by reviewing existing available subsurface information and published literature. This information was used to develop a description of the existing geologic environment that may be affected by the EBSP.

4.1 TOPOGRAPHIC AND GEOLOGIC SETTING

The study area is located in the central portion of the Puget Sound Basin, an elongated, north-south depression situated between the Olympic Mountains and the Cascade Range. Repeated glacial events of this region, as recently as about 13,500 years ago, strongly influenced the present-day topography, geology, and groundwater conditions in the Seattle area. The topography is dominated by a series of north-south ridges and troughs formed by glacial erosion and sediment deposition. Puget Sound, Lake Washington, and other large water bodies now occupy the major troughs.

Geologists generally agree that the Puget Sound area was subjected to six or more major glacial events during the last two million years. The glacial ice for these events originated in the coastal mountains of Canada and generally flowed southward into the Puget Sound region. The maximum southward advance of the ice was about halfway between Olympia and Centralia. The ice is estimated to have been about 3,000 feet thick in the project area during the most recent glacial episode in central Puget Lowland (Vashon Stade of Fraser Glaciation).

The sediment distribution in the Puget Sound area is complex as a result of the repeated glacial events. Each glacial event deposited new sediments and partially eroded previous sediments. During the intervening periods when glacial ice was not present, normal stream processes, wave action, and landsliding eroded and reworked some of the glacially derived sediments, further complicating the geologic setting as seen today. When the last ice covering the project area receded, it left a landscape sculpted into a series of north-trending ridges and valleys. These deep valleys were partially or completely filled with recessional glacial deposits and recent Holocene deposits. Geophysical surveys indicate that approximately 1,300 to 3,500 feet of sediment overlie the bedrock in the study area (Yount et al. 1985).

The existing Elliott Bay Seawall is located at the base of (west of) the hills (e.g., Capitol Hill) that comprise most of downtown Seattle. These hills slope down into Elliott Bay, with a maximum local relief of about 400 feet. Based on historic topographic information, a bluff rose above the bay between Pike and Broad Streets, while slopes were gentle south of Columbia Street. Beneath Elliott Bay, slopes were fairly uniform. This topography has been modified by shoreline erosion, localized landslides, and alluvial (river) and lahar (volcanic mud flow) deposition. The greatest postglacial changes in topography, however, have been caused by human activities that began circa 1900 during the early development of Seattle. Large-scale earth-moving projects over the past 100 years in support of urban development and growth in the Puget Sound region have modified the landscape and created land where there was once Puget Sound and slight inclines where there were steep hills. This process of excavation, regrading and filling of depressions and tidelands, has shaped the downtown Seattle area for residential and commercial development and expansion of the waterfront terminals. The existing seawall is founded in

the original beach soils and is backfilled with granular soils obtained from the Cedar River to the current street elevation.

4.2 TECTONICS AND SEISMICITY

The study area is located in a region where numerous small to moderate earthquakes and occasional strong shocks have occurred in recorded history. Much of this seismicity is the result of ongoing relative movement and collision between tectonic plates. These tectonic plates include the Juan de Fuca Plate and the North American Plate, and the intersection of these two plates is called the Cascadia Subduction Zone, as shown in the gray shaded area in Figure 4-1.

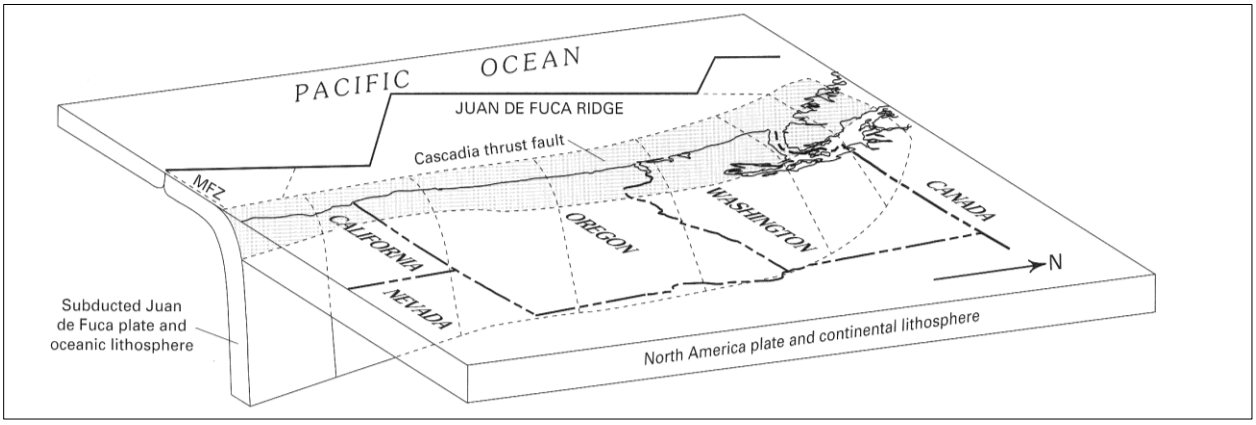


Figure 4-1. Location of Cascadia Subduction Zone (from Rogers et al. 1996)

As these two plates collide, the Juan de Fuca Plate is being driven to the northeast, beneath the North American Plate. The action of one plate being driven below another is called subduction. The relative movements of these plates are shown schematically in Figure 4-2.

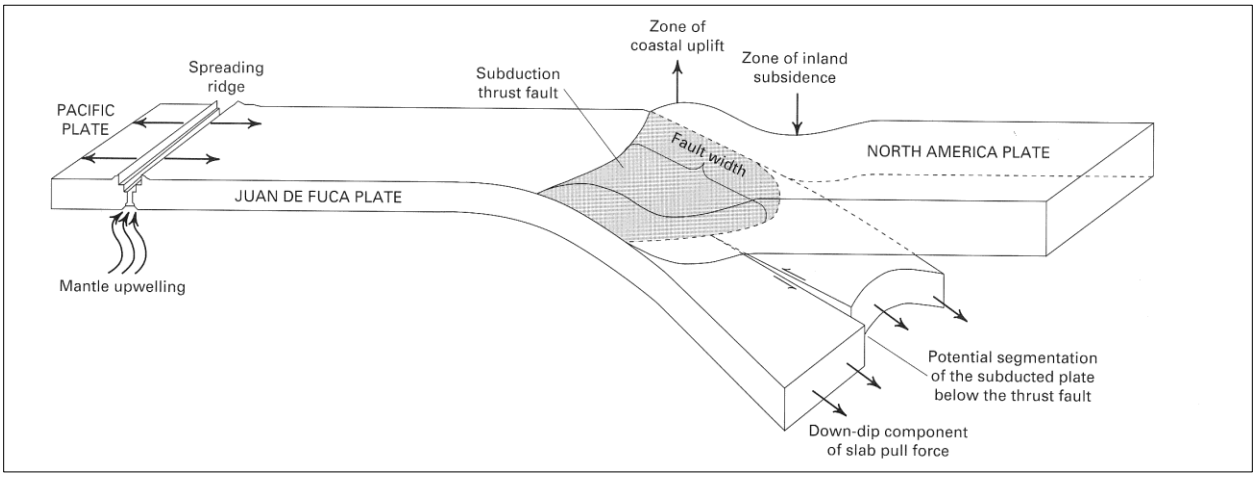


Figure 4-2. Schematic of Subduction of the Juan de Fuca Plate under the North American Plate (from Rogers et al. 1996)

The relative plate movements result not only in east-west compression; but also in shearing, clockwise rotation, and north-south compression of the crustal blocks that form the leading edge of the North American Plate (Wells et al. 1998). It is estimated that much of the compression may be occurring within the more fractured, northern Washington block that underlies the Puget Lowland.

Within the present understanding of the regional tectonic framework and historical seismicity, three broad earthquake source zones are identified. These include a shallow crustal source zone, a deep source zone within the portion of the Juan de Fuca Plate subducted beneath the North American Plate (deep intraslab zone), and an interplate zone where the brittle portions of the Juan de Fuca and North American plates are in contact in the Cascadia Subduction Zone. The locations of these earthquake source zones are shown in Figure 4-3.

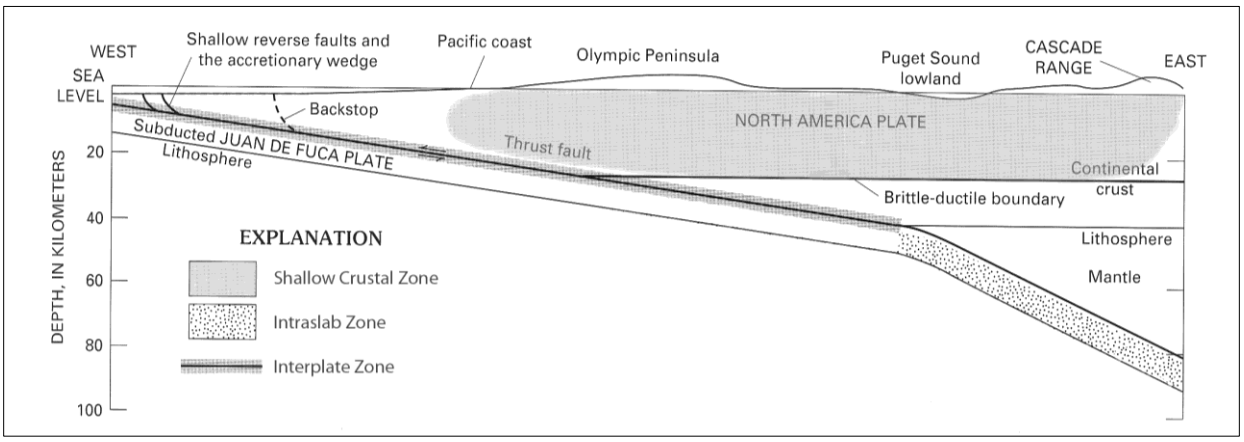


Figure 4-3. Locations of Earthquake Source Zones (adapted from Rogers et al. 1996)

Two of these zones, the shallow crustal zone and the deep intraslab zone, have produced most of the region's historical seismic activity.

4.2.1 Shallow Crustal Zone

The majority of historical earthquakes have occurred within the shallow crustal zone at depths of about 12 miles (20 kilometers [km]) or less. With the exception of the 1872 North Cascades earthquake, all historical shallow crustal earthquakes have not been greater than magnitude 5.75. The North Cascades earthquake of December 15, 1872, is the largest historical shallow crustal earthquake to have occurred in Washington and is estimated to have been about magnitude ±7.0 (Malone and Bor 1979; Bakun et al. 2002). The fault on which this earthquake occurred has not been found, but it may be near the southeast end of Lake Chelan.

Shallow crustal earthquakes have not typically occurred in recorded historical times (about the past 170 years) along crustal faults identified by geologists in western Washington. Until the late 1980s, it had generally been accepted that shallow crustal events within the Puget Sound region would be relatively small and limited to a maximum magnitude of about 6.0. However, geologic evidence developed during the 1990s indicates that the previously identified geophysical lineaments in western Washington are capable of producing earthquakes with magnitudes up to 7.5.

The closest crustal fault to the EBSP site is the Seattle Fault (or Seattle Fault Zone). The Seattle Fault is believed to be a thrust or reverse fault, with the bedrock south of the fault being shoved up and over the bedrock and soil to the north of the fault. This fault breaks up within a few miles of the ground surface, creating a number of rupture surfaces or splays at the ground surface. The rupture zone at the ground surface is approximately two to four miles (three to six km) wide, north to south (Johnson et al. 1999). The fault zone extends from the Kitsap Peninsula near Bremerton in the west to the Sammamish Plateau in the east. In downtown Seattle, the locations of fault splays that rupture the ground surface are not well known. The northernmost splay of the Seattle Fault is located about 1.4 miles south of the study area. Some current fault models suggest that the main fault (as opposed to the splays) does not extend to the ground surface near Seattle, but extends farther north and is buried a few miles below the ground surface in downtown Seattle. While no large historical earthquakes have occurred in the Seattle Fault Zone, geologic studies have shown that it is an active fault, with the most recent large event (estimated at magnitude 7.0) occurring approximately 1,100 years ago (e.g., Atwater and Moore 1992; Bucknam et al. 1992; Jacoby et al. 1992; Karlin and Arbella 1992; Schuster et al. 1992; Pratt et al. 1997; Johnson et al. 1999; Brocher et al. 2001).

4.2.2 Deep Intraslab Zone in the Juan de Fuca Plate

The largest historical earthquakes to affect the study area originated in the subducted Juan de Fuca Plate (deep intraslab zone) at depths of 32 miles (50 km) or greater (see Figure 4-3). These events include the magnitude 7.1 Olympia earthquake of April 13, 1949, the magnitude 6.5 Seattle-Tacoma earthquake of April 29, 1965, and the recent magnitude 6.8 Nisqually earthquake of February 28, 2001. Earthquakes generated from the intraslab zone are likely caused by deformation of the subducting Juan de Fuca Plate beneath the North American Plate.

4.2.3 Interplate Zone

Within the Cascadia Subduction Zone, the interface (interplate zone) between the Juan de Fuca Plate and the North American Plate (see Figure 4-3) has been identified as capable of producing very large earthquakes. No large interplate earthquakes have occurred in this zone during recorded historical times (about the past 170 years). However, an earthquake-generated tsunami that hit Japan in the year 1700 is believed to have been generated from a magnitude 9.0 earthquake in the Cascadia Subduction Zone (Satake et al. 1996). Recent geologic evidence suggests that the coastal estuaries have experienced rapid subsidence at various times within the last 2,000 years and that this subsidence may have been the result of large interplate earthquakes that originated in the interplate zone (e.g., Atwater 1987 and 1992; Grant 1989; Darienzo and Peterson 1990; Clarke and Carver 1992; Atwater and Hemphill-Haley 1997). Other evidence of large interplate earthquakes within the Cascadia Subduction Zone includes the following:

- The presence of submarine landslide deposits in deep-sea channels off the coast of Washington and Oregon (Adams 1996);
- The presence of buried soils at Humboldt Bay (Clarke and Carver 1992) and in northern Oregon (Darienzo and Peterson 1995; Peterson and Darienzo 1996);

- Interbedded peat and mud at Coos Bay, Oregon (Nelson et al. 1996);
- Buried scarps near Willapa Bay (Meyers et al. 1996); and
- Buried soils at Grays Harbor (Shennan et al. 1996).

Taken together, these different observations present strong evidence that the Cascadia Subduction Zone has produced, and remains capable of producing, strong earthquakes. Work to date suggests that earthquake magnitudes may range in magnitude from 8.0 to 9.0 and may occur at time intervals ranging from 400 to 1,000 years.

4.3 SITE GEOLOGY

The study area is situated in the Seattle Basin, which is filled with over 1,500 feet of glacial and nonglacial sediments overlying bedrock. Glacial deposits are those that are deposited by the action of glaciers. Nonglacial deposits are those that are deposited when glaciers are not present, such as through natural water flow processes, landsliding, and wave action. Many of the glacial and nonglacial sediments have been glacially overridden, which means that the soils were compacted by the overriding weight of glacial ice as the glaciers advanced through the region. These glacially overridden soils are present in the subsurface below downtown Seattle and also underlie the younger, relatively loose and soft, postglacial soils that were deposited along the Seattle waterfront and Duwamish River delta. The geology in Seattle was further modified in the late 1800s and early 1900s when portions of the City were regraded. Soil removed from the upper hills was transported to the low areas of Seattle along the waterfront and the tidelands south of Yesler Way.

4.3.1 Holocene Soil Deposits

The glacially overridden deposits along the waterfront are overlain by a thick sequence of very loose to dense or very soft to very stiff soils. These materials were deposited during the Holocene Era after the retreat of the last glacier in the Seattle area (Vashon) and are considered to be “recent” in terms of geologic depositional time. A summary of the types of Holocene geologic units encountered along the seawall alignment are presented in Table 4-1. The distribution of these deposits within each project zone is presented in Section 4.4.2.

TABLE 4-1. GEOLOGIC UNITS AND GENERAL DESCRIPTIONS – HOLOCENE DEPOSITS

Unit Name	Abbrev.	Unit Description
Fill	Hf	Fill, both engineered* and non-engineered*, placed by humans. Various materials, including debris (timbers, sawdust, coal slag, timber piles, railroad construction debris, and other materials); cobbles and boulders common; commonly dense or stiff if engineered, but very loose to dense or very soft to stiff if non-engineered.
Landslide Deposits	Hls	Deposits transported by landslides, normally at and adjacent to the toe of slopes. Disturbed, heterogeneous mixture of several soil types; loose or soft, with random dense or hard pockets.
Alluvium	Ha	River or creek deposits, normally associated with historical streams, including overbank deposits. Sand, silty sand, gravelly sand; very loose to very dense.
Estuarine Deposits	He	Estuary deposits of the ancestral Duwamish River. Silty clay and fine sand; very soft to stiff or loose to dense.
Beach Deposits	Hb	Deposits along present and former shorelines of Puget Sound and tributary river mouths. Silty sand, sandy gravel; sand; scattered fine gravel, organic and shell debris; loose to very dense.
Reworked Glacial Deposits	Hrw	Glacially deposited soils that have been reworked by fluvial or wave action. Heterogeneous mixture of several soil types; lies over glacially overridden soils; loose to dense.

Note: *Engineered fill assumes quality control during placement using specified compaction criteria, including field density testing, select fill materials, moisture conditioning, appropriate compaction equipment, and proper lift thicknesses. Non-engineered fill is typically loosely dumped or hydraulically placed with little or no quality control.

The thickness of the Holocene deposits varies along the EBSP alignment. South of S. Washington Street, the thickness of the Holocene deposits along the seawall is generally less than 35 feet. To the north, the thickness increases to an average of about 50 feet along most of the seawall. The maximum thickness of the Holocene deposits is between Madison and Marion Streets, where reworked glacial deposits (Hrw) extend to about 95 feet below the ground surface. The primary Holocene deposits that are encountered along the EBSP alignment are fill (Hf), estuarine (He) and beach (Hb) deposits. More detailed descriptions of the thickness, type, and distribution of Holocene deposits by EBSP zone are presented in Section 4.4.2.

The fill deposits (Hf) along the waterfront contain wood debris. Numerous wood piers and historic structures were present along the waterfront prior to construction of the seawall. These structures were likely supported by timber piles that extended into the beach deposits. Therefore, wood debris consisting of horizontal and vertical timbers and piles, mill ends, sawdust, and wood chips may be present within the fill deposits and potentially within the underlying estuarine (He) and beach (Hb) deposits. The depth and extent of the wood debris varies along the EBSP alignment. Based on historical information, the south end of the EBSP is located near the former site of a large sawmill (Yesler's Mill). It is likely that large deposits of floating wood, piles for pier structures, and wood debris were present in this area before fill was placed circa 1900.

4.3.2 Quaternary Soil Deposits

The glacially overridden deposits underlying the Holocene soils were deposited during the Quaternary Era and are divided into two main categories: (1) soils deposited by the last known glacial event in the Seattle area (Vashon), and (2) soils deposited by earlier glacial events (pre-Vashon). The only Vashon soil unit encountered along the EBSW alignment is lodgement till (Qvt). This deposit was laid down along the base of the glacial ice and typically consists of gravelly, silty sand and silty, gravelly sand (locally known as "hardpan"). This unit is typically very dense and commonly contains cobbles and boulders. This unit was only found in Zones 4 and 5, as discussed in Sections 4.4.2.4 and 4.4.2.5, respectively.

Most of the glacially overridden deposits encountered along the EBSP alignment were deposited during or between pre-Vashon glacial events. They include both glacial deposits (soil deposited by the action of glacial ice) and non-glacial deposits (soil deposited by other geologic processes between glacial events) deposits. A summary of the nomenclature used to refer to the pre-Vashon geologic units as well as general information regarding the depositional environment and basic soil characteristics are presented in Table 4-2. Further discussions related to which of these units are present within each project zone are presented in Section 4.4.2.

TABLE 4-2. GEOLOGIC UNITS AND GENERAL DESCRIPTIONS – PRE-VASHON DEPOSITS

Unit Name	Abbrev.	Unit Description
Fluvial Deposits	Qpnf	Non-glacial alluvial deposits of rivers and creeks. Clean to silty sand, gravelly sand, sandy gravel, locally slightly clayey to clayey (weathered); scattered organics; very dense.
Lacustrine Deposits	Qpnl	Non-glacial, fine-grained lake deposits in depressions, large and small. Fine sandy silt, silty fine sand, and clayey silt; scattered to abundant fine organics; dense to very dense or very stiff to hard.
Mudflow Deposits	Qpnm	Non-glacial distal deposits of mass movements such as landslides or lahars. Stratified or irregular bodies of a heterogeneous mixture of gravel, sand, silt, and clay; pumice, obsidian, and ash common; rare organics (charcoal); very stiff to hard or very dense.
Paleosol	Qpns	Non-glacial, buried, weathered horizon. Clay-rich with various amounts of clastic debris; commonly contains organic material; typically greenish in color; hard or very dense.
Outwash	Qpgo	Glaciofluvial sediment deposited as the glacial ice advanced through the Puget Lowland. Clean to silty sand, gravelly sand, sandy gravel; very dense.
Glaciolacustrine Deposits	Qpgl	Fine-grained glacial flour deposited in proglacial lake in Puget Lowland. Silty clay, clayey silt with interbeds of silt and fine sand; very stiff to hard or very dense.
Till	Qpgt	Lodgment till laid down along the base of the glacial ice. Gravelly silty sand, silty gravelly sand (hardpan); cobbles and boulders common; very dense.
Glaciomarine Deposits	Qpgm	Till-like deposit with clayey matrix deposited in proglacial lake by icebergs, floating ice, and gravity currents. Heterogeneous and variable mixture of clay, silt, sand, and gravel; rare shells; cobbles and boulders common; very dense or hard.

4.4 EXISTING CONDITIONS

This section describes the current condition of the existing seawall and the adjacent subsurface soil and groundwater conditions. The discussions in this Discipline Report refer to six zones established by the project team, as illustrated in Chapter 1. The locations of these zones are indicated in Figure 4-4. The existing seawall types (see Section 4.4.1) and locations of subsurface explorations are also shown in Figure 4-4.

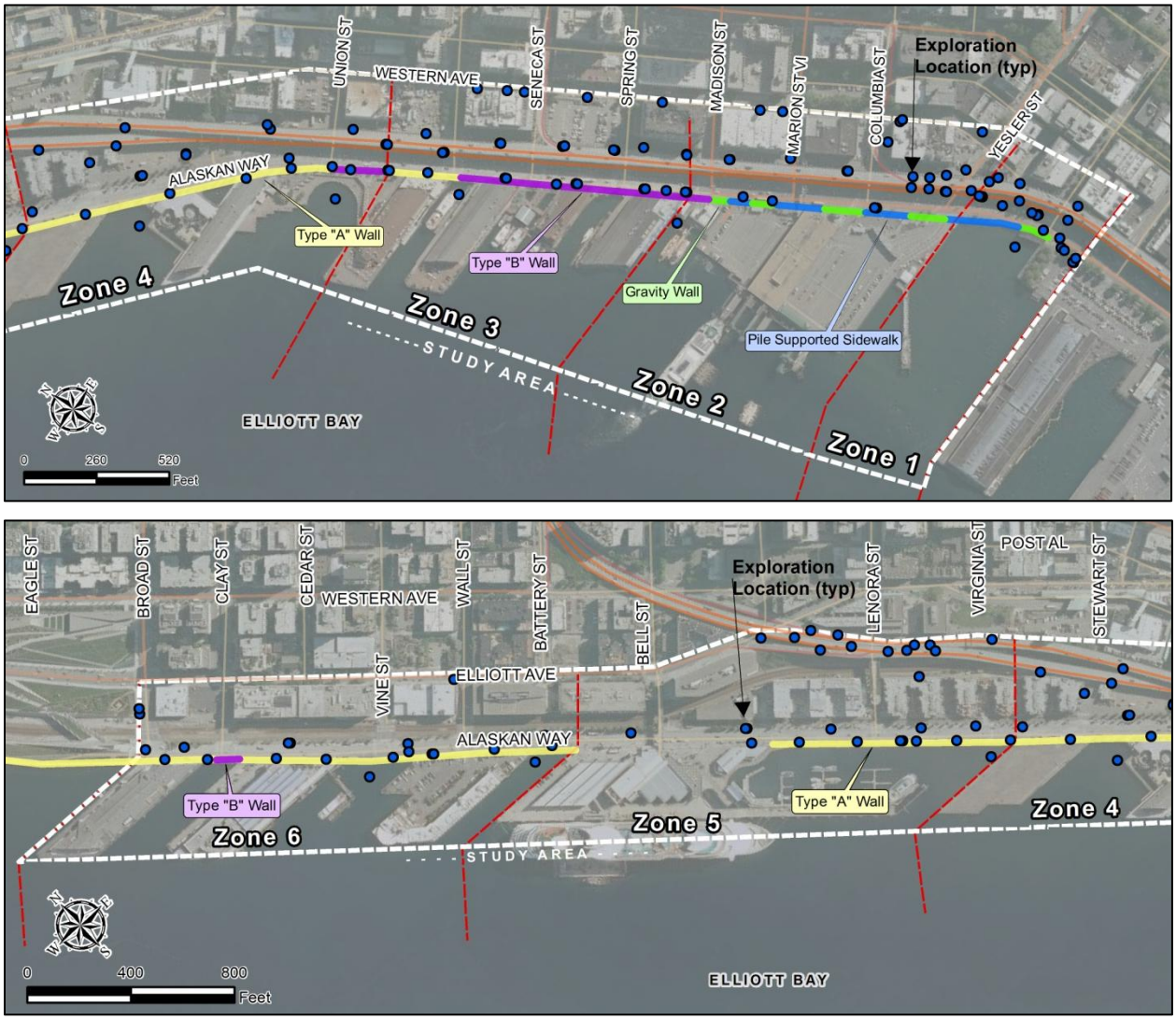


Figure 4-4. Map of Study Area and Project Zones

4.4.1 Existing Seawall

The existing seawall is approximately 7,900 feet long, extending from Bay Street on the north to S. Washington Street on the south, and supports the Alaskan Way street and sidewalk. Portions of the existing seawall are over 90 years old, are in poor condition, and may suffer significant damage in a major earthquake. The purpose of the EBSP is to replace the existing seawall from S. Washington Street

on the south to Broad Street on the north. Waterside habitat improvements are proposed from the north side of Pier 48 on the south to just north of Pier 70 on the north.

The seawall configuration varies along its alignment. The locations of the seawall types are indicated in Figure 4-4 and in the profiles presented in Section 4.4.2. The types of seawalls that are present include the following:

- **Type A Wall:** Constructed circa 1934, these walls consist of a sheet-pile-supported, reinforced concrete face panel tied back to a buried timber relieving platform (east of the wall) supported by vertical and battered timber piles. The seawall is laterally restrained by the piles beneath the relieving platform that are battered out toward Elliott Bay, and the piles are restrained by the weight of the fill on top of the relieving platform. Type A walls typically have an exposed height of 15 to 20 feet and a relieving platform width of about 40 feet. Type A walls are generally located north of Union Street and have total length of approximately 5,300 feet. This wall type is present in Zones 3 through 6.
- **Type B Wall:** Constructed circa 1934, these walls are similar to Type A walls except that the reinforced concrete face panel is supported by a master pile wall consisting of H-piles with steel sheet-pile lagging. In addition to the concrete face panel connection to the relieving platform, the master pile wall is connected to the relieving platform by an angled tie rod. Type B walls have an exposed height of up to 40 feet and a relieving platform width of about 60 feet. Type B walls are generally located south of Union Street and have total length of approximately 1,400 feet. This wall type is present primarily in Zone 3, with smaller sections in Zones 4 and 6.
- **Gravity Walls and Pile-Supported Sidewalks:** The 1,200 feet of seawall south of Madison Street consist primarily of two wall types: a timber-pile-supported, unreinforced concrete gravity wall (with adjacent sidewalk structure) constructed circa 1915 and a pile-supported, reinforced concrete sidewalk frame (that also acts as a wall) constructed circa 1964. Much of the 1964 concrete sidewalk frame seawall was rebuilt in 1987 using pre-stressed concrete piles. These wall types are present in Zones 1 and 2.

The seawall has a long history of problems due to sheet-pile corrosion and deterioration of the timber relieving platforms for the Type A and B walls. Test pits completed in 2002 (Shannon & Wilson 2003) revealed that the timber cap beams and connections to the face panels are deteriorated in many areas along the seawall. Some of the deck planks are also deteriorated. The deterioration of the timber portions of the relieving platform is primarily due to marine borer organisms.

4.4.2 Subsurface Soil Conditions

The subsurface soil conditions along most of the EBSP alignment consist of engineered and non-engineered fills overlying estuarine deposits, beach deposits, and glacially overridden soils. The following sections describe the subsurface soil conditions adjacent to the existing seawall in each project zone.

4.4.2.1 Zone 1 – Pioneer Square/Washington Street Boat Landing

The southern limit of the EBSP is located just south of Pier 48, at the south end of the existing seawall. Zone 1 extends north from this location to the south side of Pier 51, from about S. Jackson Street to

Yesler Way (see Figure 4-4). The south 120 feet of seawall consists of a pile-supported concrete gravity wall with an adjacent pile-supported sidewalk structure. The remainder of the seawall in this area consists of a pile-supported, reinforced concrete sidewalk frame. A generalized subsurface profile indicating the subsurface conditions, existing explorations, street alignments, and extent of the seawall types in this zone is shown in Figure 4-5.

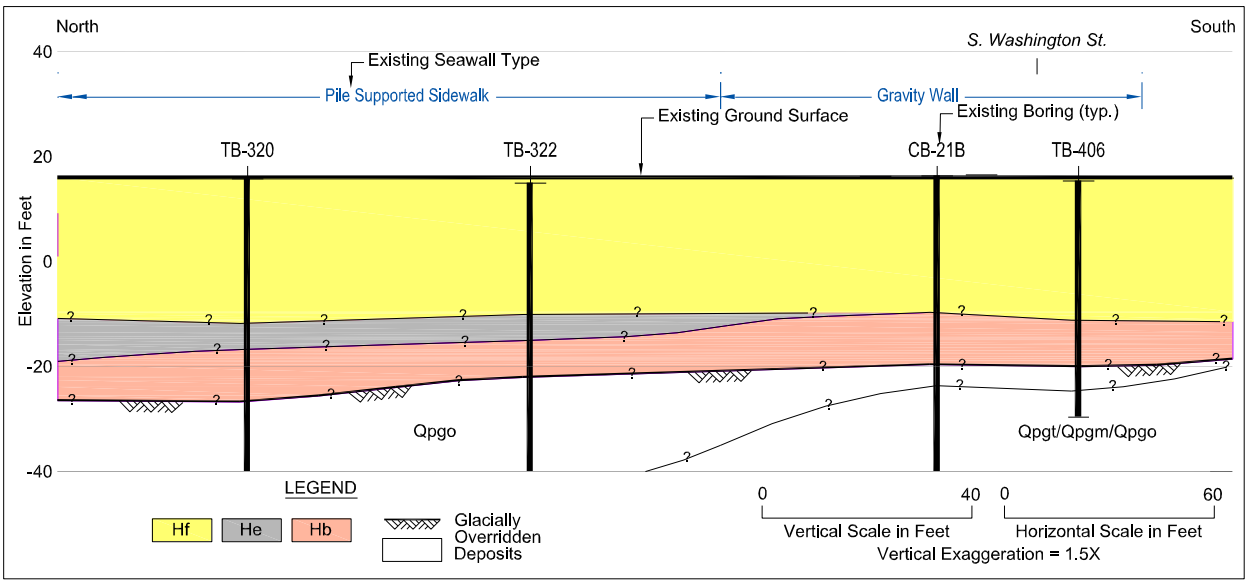


Figure 4-5. Generalized Subsurface Conditions in Zone 1 – Pioneer Square/S. Washington Street Boat Landing

As shown in the generalized subsurface profile above for Zone 1, the Holocene soil units generally consist of about 20 to 25 feet of fill (Hf) overlying thin layers (less than 10 feet thick) of estuarine (He) and beach (Hb) deposits. The fill deposits consist of a mixture of clay, silt, sand, and gravel, and ranges in density from very loose to medium dense. The fill also contains wood layers up to 15 feet thick, especially near the northern end of Zone 1. The estuarine deposits consist of very loose and very soft to soft silty clay and clayey silt. The beach deposits consist of dense to very dense, sandy gravel and gravelly sand.

Glacially overridden soils were encountered about 30 to 40 feet bgs. The upper zone of the glacial deposits primarily consists of glaciomarine (Qpgm), outwash (Qpgo) and fluvial (Qpnf) deposits. Although not shown in Figure 4-5, glacial deposits below elevation -40 feet included glaciolacustrine (Qpgl) and glacial till (Qpgt) deposits. The density of the glacial deposits is typically hard and very dense.

Most of the groundwater monitoring devices in this zone are located below elevation -40 feet. Several wells along the south end of Zone 1 are located within the beach deposits and indicate a groundwater level of about 10 to 13 feet bgs. No tidal monitoring was performed.

4.4.2.2 Zone 2 – Ferry Terminal

This zone of the EBSP is located adjacent to Colman Dock Ferry Terminal, approximately between Yesler Way and Madison Street (see Figure 4-4). The seawall in this area consists of alternating sections of a pile-supported concrete gravity wall (with adjacent sidewalk structure) and a pile-supported, reinforced

concrete sidewalk frame. Portions of the sidewalk frame sections were rebuilt in 1987. A generalized subsurface profile indicating the subsurface conditions, existing explorations, street alignments, and extent of the seawall types in this zone is shown in Figure 4-6.

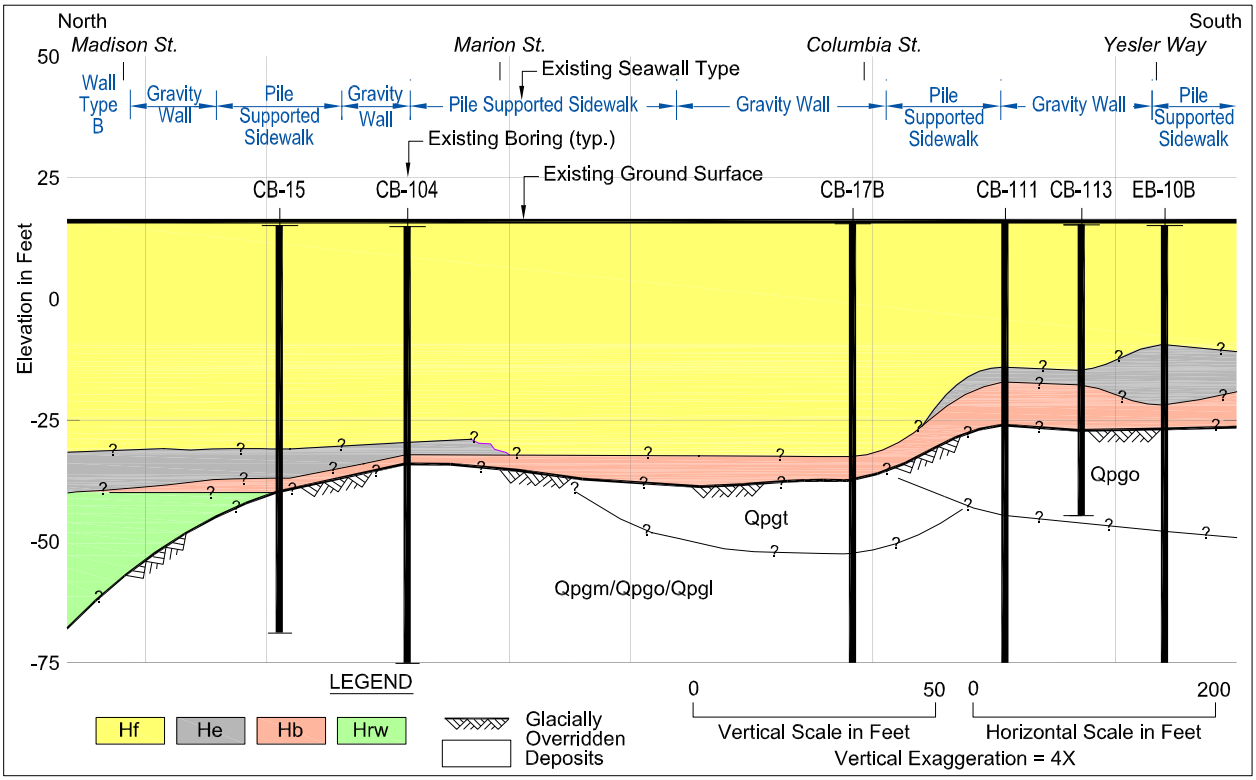


Figure 4-6. Generalized Subsurface Conditions in Zone 2 – Ferry Terminal

The thickest deposits of fill (Hf) along the EBSP alignment are encountered in Zones 2 and 3. As shown in the generalized subsurface profile above, the fill thickness in Zone 2 ranges from 40 to 45 feet north of Columbia Street. The fill overlies thin layers (less than five feet thick in most locations) of estuarine (He) and beach (Hb) deposits. The fill deposits consist of a mixture of silt, sand, and gravel, and ranges in density from very loose to medium dense. The fill also contains wood layers up to 20 feet thick near the southern end of Zone 2. The estuarine deposits consist of very loose and very soft, silty clay and clayey silt. The beach deposits consist of loose to very dense, sandy gravel and gravelly sand. At the northern end of Zone 2, reworked glacial deposits (Hrw) were encountered. This subsurface condition is discussed further in Section 4.4.2.3.

Glacially overridden soils were encountered about 40 to 55 feet bgs along most of Zone 2. Near the north end of Zone 2, the depth to the top of the glacially overridden soil increases to as much as 85 feet in an area where reworked glacial deposits (Hrw) were encountered (see Section 4.4.2.3). The upper zone of the glacial deposits primarily consists of glaciomarine (Qpgm), outwash (Qpgo), and glaciolacustrine (Qpgl) deposits. A zone of glacial till (Qpgt) was encountered between Columbia and Marion Streets. Below the depth range shown in Figure 4-6, the glacial deposits primarily consist of interbedded layers of Qpgm and Qpgl. The density is typically hard and very dense.

Most of the groundwater monitoring devices in this zone are located below elevation -40 feet. One observation well located adjacent to boring EB-10B is screened within the fill deposits. Tidal monitoring performed at this location indicates that, for an Elliott Bay tide ranging from elevation -2 to +9 feet, the groundwater level varied in near direct response to the tide, ranging from elevation 0 to +8 feet (about seven to 15 feet bgs).

4.4.2.3 Zone 3 – Central Pier

Zone 3 includes the portion of the seawall adjacent to Piers 54 through 57, approximately from Madison Street to just north of University Street (see Figure 4-4). Most of the seawall in this area is a Type B seawall. The northern 128 feet of the seawall in this zone (near University Street) is a Type A seawall. A generalized subsurface profile indicating the subsurface conditions, existing explorations, street alignments, and extent of the seawall types in this zone is shown in Figure 4-7.

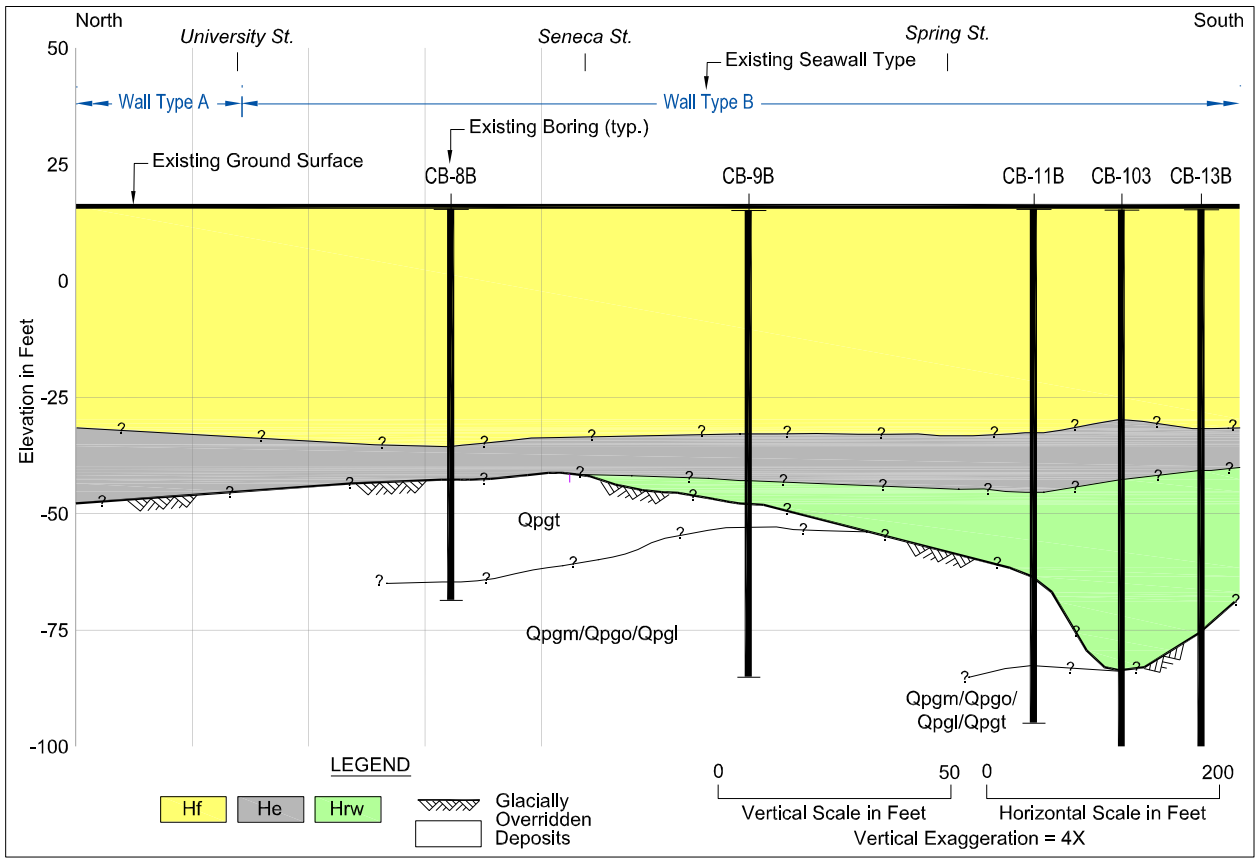


Figure 4-7. Generalized Subsurface Conditions in Zone 3 – Central Pier

The fill (Hf) deposits in Zone 3 are about 45 to 50 feet thick and are underlain by estuarine deposits (He) ranging in thickness from about five to 15 feet. The fill deposits consist of a mixture of silt, sand, and gravel, and ranges in density from very loose to loose in most locations. The fill also contains wood layers up to 15 feet thick in localized areas. The estuarine deposits consist of very loose and very soft, silty clay and clayey silt. At the south end of Zone 3, reworked glacial deposits (Hrw) consisting of loose

to medium dense sand and silty sand were encountered in a subsurface depression to a maximum depth of about 100 feet bgs.

Except in area south of Spring Street, glacially overridden soils were encountered about 60 to 70 feet bgs along most of Zone 3. South of Seneca Street, the upper zone of the glacial deposits primarily consists of glaciomarine (Qpgm), outwash (Qpgo), and glaciolacustrine (Qpgl) deposits. North of Seneca Street, the estuarine soils are underlain by glacial till (Qpgt). The density of the glacial deposits is typically hard and very dense.

The only groundwater monitoring devices located above the glacially overridden soils in this zone are in boring CB-11B. A vibrating wire piezometer located at the bottom of the Hrw deposit in this boring indicates groundwater levels ranging from nine to 12 feet bgs. An observation well screened within the upper 20 feet of the fill indicates groundwater levels ranging from seven to 12 feet bgs. No tidal monitoring was performed at this location.

4.4.2.4 Zone 4 – Park/Aquarium

Zone 4 is located adjacent to Waterfront Park and the Seattle Aquarium (Pier 59). The north end of this zone is located north of Pier 63, approximately from just north of University Street to Virginia Street (see Figure 4-4). The southern 220 feet of the existing seawall in this zone is a Type B seawall. The remainder of the seawall in Zone 4 is a Type A seawall. A generalized subsurface profile indicating the subsurface conditions, existing explorations, street alignments, and extent of the seawall types in this zone is shown in Figure 4-8.

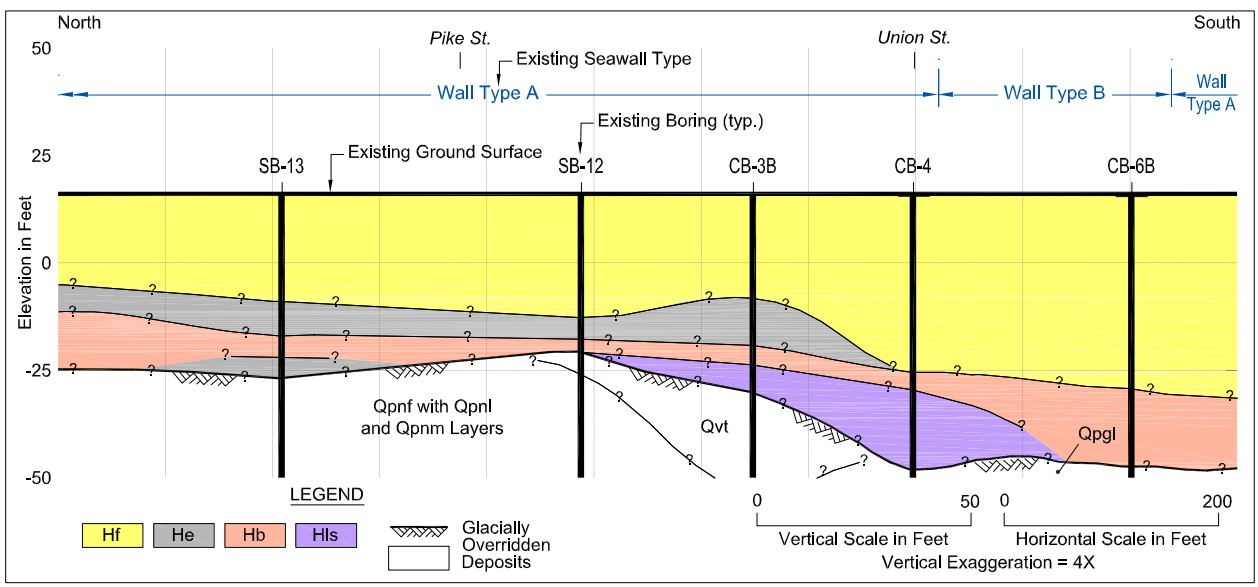


Figure 4-8. Generalized Subsurface Conditions in Zone 4 – Park/Aquarium

At the south end of Zone 4, the depth to the top of the glacially overridden deposits is about 60 to 65 feet bgs. This depth decreases north of Union Street to a depth of about 40 feet bgs at Pike Street and to the north. The Holocene soils overlying the glacially overridden deposits include fill (Hf), estuarine (He), beach (Hb), and landslide deposits (Hls). The landslide deposits were primarily located in the vicinity of

Union Street and were up to 20 feet thick. North of Pike Street, the fill deposits in Zone 4 are about 20 to 25 feet thick and are underlain by estuarine deposits (He) and beach deposits (Hb) ranging in thickness from about five to 15 feet. South of Union Street, the fill is about 40 to 45 feet thick and is underlain by beach deposits up to 15 feet thick. The fill deposits consist of a mixture of silt, sand, and gravel, and ranges in density from very loose to dense. The estuarine deposits consist of very loose and very soft, silty clay and clayey silt. The beach deposits consist of loose to very dense, sandy gravel and gravelly sand. The landslide deposits consist of silty clay soils that have a highly variable consistency ranging from soft to stiff. It should be noted that near the transition between Zones 3 and 4 (compare Figure 4-7 and Figure 4-8); the soil underlying the fill changes from estuarine deposits to beach deposits. The nature and location of this transition is not known due to limited subsurface information.

South of Union Street, the glacially overridden deposits underlying the beach and landslide deposits consists primarily of glaciolacustrine deposits (Qpgl). North of Union Street, the glacially overridden soils primarily consisted of fluvial deposits (Qpnf). Thin layers (less than 5 feet thick) of lacustrine (Qpnl) and mudflow (Qpnm) deposits were encountered in localized areas within the Qpnf. A zone of Vashon glacial till (Qvt), up to 25 feet thick, was encountered between Union and Pike Streets. The density of the glacial deposits is typically hard and very dense.

One observation well in boring SB-13 (screened within the fill deposits) is located in this zone. The groundwater level ranged from 10 to 13 feet bgs in this well. No tidal monitoring was performed.

4.4.2.5 Zone 5 – Bell Harbor

Zone 5 is located adjacent to the Bell Harbor Conference Center and marina, approximately between Virginia Street and Battery Street (see Figure 4-4). The existing seawall in this area is a Type A seawall. During construction of the Bell Harbor Conference Center, the Port of Seattle placed fill adjacent to about 590 feet of the seawall at the north end of Zone 5. A generalized subsurface profile indicating the subsurface conditions, existing explorations, street alignments, and extent of the seawall types in this zone is shown in Figure 4-9.

The subsurface conditions in Zone 5 generally consist of about 15 to 25 feet of fill (Hf) overlying estuarine (He) and beach (Hb) deposits. In Zone 5, the fill deposits (Hf) are thinner and the beach (Hb) deposits thicker than the rest of the seawall alignment to the south. The fill deposits consist of a mixture of silt, sand, and gravel, and ranges in density from loose to dense. Within Zone 5, the estuarine deposits are primarily encountered south of Blanchard Street and range in thickness from about 5 to 20 feet. The estuarine deposits consist of very loose to medium dense silt and very soft to very stiff, silty clay and clayey silt. The beach deposits in Zone 5 are generally 10 to 25 feet thick south of Blanchard Street and up to 40 feet thick (interbedded thin estuarine layers) north of Blanchard Street. The beach deposits consist of loose to very dense silty, gravelly sand with zones of sandy gravel.

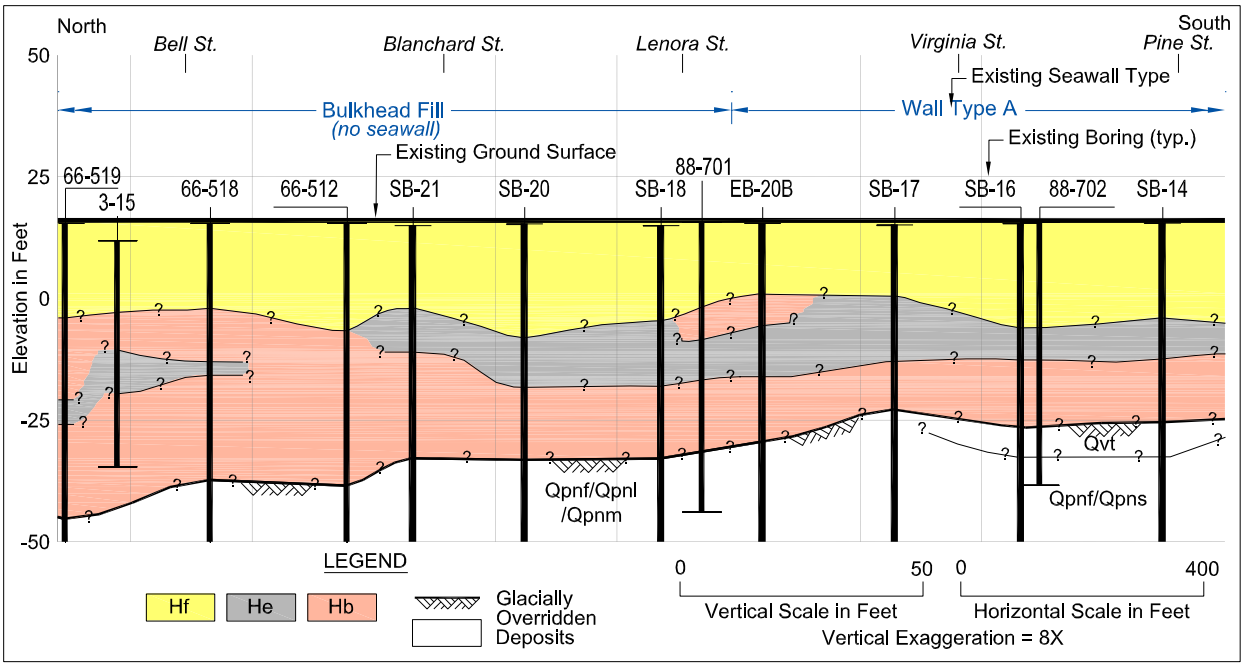


Figure 4-9. Generalized Subsurface Conditions in Zone 5 – Bell Harbor

The depth to the top of the glacially overridden deposits in Zone 5 generally increases from south to north, from about 40 feet bgs near Pike Street to about 60 feet bgs north of Bell Street. The primary glacially overridden deposit in this area is fluvial (Qpnf). Thin layers of paleosol (Qpns), lacustrine (Qpnl), and mudflow (Qpnm) deposits are encountered at localized areas within the Qpnf. Between Pine and Virginia Streets, a thin layer (less than five feet thick) of Vashon glacial till (Qvt) was encountered at the top of the glacially overridden soil zone. The density of the glacial deposits is typically hard and very dense.

Within Zone 5, the groundwater monitoring devices installed south of Lenora Street are located within the glacially overridden deposits below elevation -40 feet and, therefore, are not useful for evaluating the effects of the proposed build alternatives. Several monitoring wells near Blanchard Street are screened within the upper fill deposits and indicate groundwater levels ranging from nine to 12 feet bgs. No tidal monitoring was performed.

4.4.2.6 Zone 6 – North Pier

Zone 6 includes Piers 67 through 70, and ends just south of the Olympic Sculpture Park, north of Pier 70, approximately from Battery Street to Broad Street (see Figure 4-4). This is the northern extent of the EBSP alignment. Most of the seawall in this zone is a Type A wall. The only exception is a 175-foot-long section of Type B wall between Piers 69 and 70 (near Clay Street). A generalized subsurface profile indicating the subsurface conditions, existing explorations, street alignments, and extent of the seawall types in this zone is shown in Figure 4-10.

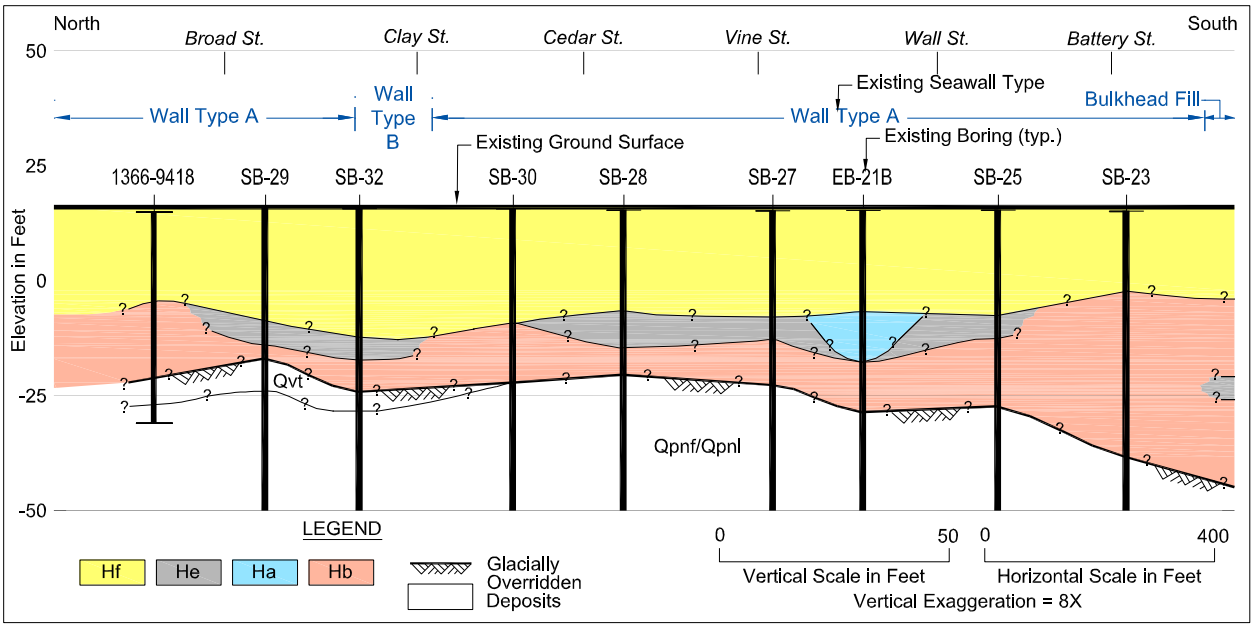


Figure 4-10. Generalized Subsurface Conditions in Zone 6 – North Pier

The fill deposits in Zone 6 are about 20 to 40 feet thick. The fill deposits consist of a mixture of silt, sand, and gravel, and ranges in density from loose to dense. A localized area of alluvium (Ha), consisting of loose to medium dense sand was encountered below the fill between Wall and Vine Streets. In the remainder of this zone north of Wall Street, the fill is underlain by very soft to soft estuarine (He) silt and loose to dense sandy beach (Hb) deposits ranging in thickness from about five to 15 feet. South of Wall Street, the thickness of the beach deposits increases to about 40 feet. The beach deposits contain localized areas of gravel.

The depth to the top of the glacially overridden deposits ranges from about 60 feet bgs at the south end of Zone 6 to about 30 feet bgs at the north end of Zone 6. The primary glacially overridden deposit in this area is fluvial (Qpnf). Thin layers of lacustrine (Qpnl) deposits were observed at localized areas within the Qpnf. The density of the glacial deposits is typically hard and very dense.

Several observation wells are screened within the fill deposits in this zone. The groundwater levels observed in these wells generally ranged from about nine to 12 feet. No tidal monitoring was performed.

4.5 GEOLOGIC HAZARDS

Geologically hazardous areas are defined in the Washington Administrative Code (WAC 365-190-030) as areas that are not suited to locating commercial, residential, or industrial development consistent with public health or safety concerns because of their susceptibility to erosion, sliding, earthquake, or other geological events. Washington State's Growth Management Act (Revised Code of Washington, Chapter 36.70A) requires all cities and counties to identify geologically hazardous areas within their jurisdictions and formulate development regulations for their protection. Seismic and other building code standards

have been developed to reduce the risk of catastrophic failure of structures due to geologic events and conditions such as liquefaction, earthquakes and subsidence.

The City has developed regulations for environmentally critical areas and associated maps (City of Seattle 2006). These regulations require that detailed geotechnical studies be prepared to address specific standards relating to site soils and geology, seismic hazards, and facility design. The following sections summarize the types of geologic hazards that may be expected within the study area. Many of these hazards are interrelated.

4.5.1 Landslides

The City has identified landslide-prone areas that include steep slopes, known landslide areas, and areas with landslide potential because of geologic conditions. Steep slopes are defined by the City as slopes steeper than an average of 40 percent and with at least 10 feet of vertical change. East of the seawall, some of the slopes at the ground surface in downtown Seattle may be classified as steep. However, because these areas are fully developed with buildings, roadways, and other structures, the potential for landslides is low.

Undeveloped steep slopes are present within about 350 feet of the seawall between about Stewart Street and Blanchard Street. The steeper parts of the slopes in this area range from about 50 to 100 percent. In the past few years, several small, shallow landslides have occurred on these slopes. They are typically one to three feet deep and 10 to 30 feet wide. No recent deep-seated landslides have been observed in this area. During a seismic event, increased shallow landsliding may occur in this area. The closest point of these steep slopes to the seawall is just north of Bell Street, where the steep slope is present about 150 feet from the seawall. Based on the observed size of the historical landslides on these steep slopes, the potential for landsliding to affect the EBSP is low.

Some of the submarine slopes west of the seawall would be classified as steep. However, because these slopes are underwater, they are not included in the steep slopes mapped by the City. The risk of landsliding on these slopes is low, although localized sloughing could occur during seismic events.

4.5.2 Erosion

The study area is classified primarily as urban development and is, therefore, not an erosion hazard area. The steep slopes mentioned above have experienced rill erosion in the past. Piping and subsurface erosion is causing material to pass through gaps in the existing seawall, resulting in subsidence behind the seawall. Erosion via coastal storm-driven and localized wave action through corroded gaps in the steel sheet pile of the seawall is also occurring (PBPower/BJT Associates 2003). Additionally, wave action along the front of the seawall is occasionally severe enough to displace existing riprap and other fill materials, requiring periodic replenishment of the riprap protection.

4.5.3 Fault Rupture

The study area is located near the Seattle Fault Zone. As described in Section 4.2.1, the fault breaks up within a few miles of the ground surface, creating a number of rupture surfaces or splays. The northernmost splay of the Seattle Fault is located about 1.4 miles south of the study area. Geologic

evidence gathered over the last 10 years suggests that surface rupture of this fault zone occurred as recently as 1,100 years ago, with as much as 22 feet of vertical displacement (Bucknam et al. 1992). Recent trenches excavated along the fault locations indicate that there have been about three events during which the surface was ruptured in the past 10,000 years (Nelson et al. 2000). On average, the recurrence interval over the last 16,000 years for large-magnitude events on the Seattle Fault appears to be about 3,000 to 5,000 years, with individual recurrence intervals ranging from as short as about 200 years to as long as 12,000 years (Johnson 2004). Also, fault splays in the northern portion of the zone appear to be the most recently active and capable of rupturing the ground surface, resulting in several feet of vertical offset.

Because the northernmost splay is located south of the study area, rupture of the ground surface and vertical offset in the area of the EBSP is not anticipated. However, intense ground shaking in the direction of the fault rupture at sites located within a few miles of the fault is another effect of fault rupture. The intense ground shaking "pulses" or directivity effects is the result of constructive wave interference in the direction of the fault rupture.

4.5.4 Liquefaction

Soil liquefaction occurs in loose, saturated, sandy soil when the water pressure in the pore spaces approaches a level that is sufficient to separate the soil grains from each other. This phenomenon occurs during ground shaking and results in a reduction of the shear strength of the soil (a quicksand-like condition). The reduction in strength depends on the degree and extent of the liquefaction. Liquefaction can result in ground settlement, lateral spreading (lateral ground movement on gentle slopes), landsliding, localized ground disruptions from sand boils (ejection of sand and water at the ground surface), and reduced vertical and lateral capacity for structure foundations. Buildings, bridges, and other structures founded on or in potentially liquefiable soils may settle, tilt, move laterally, or collapse. The degree of liquefaction depends on the consistency and density of the soil, the grain size distribution of the soil, and the magnitude of the seismic event. Settlement could also result from partial liquefaction or densification of unsaturated sand.

Geologic units in the study area that typically have a high susceptibility to liquefaction include the recent fill (Hf), alluvial (Ha), and beach (Hb) deposits present below the groundwater table. Liquefaction studies in the Puget Sound region have found that glacially overridden deposits have a low susceptibility to liquefaction. The entire EBSP alignment is located within the liquefaction hazard area that has been mapped by the City (City of Seattle 2006).

When soils liquefy, they have a tendency to flow in the downslope direction towards the nearest free face (the existing seawall). This phenomenon is known as lateral spreading. Depending on the existing seawall integrity, forces due to lateral spreading may cause the seawall to tilt, move laterally, or collapse.

4.5.5 Ground Motion Amplification

The presence of soil above bedrock can change the intensity of ground shaking felt at the ground surface compared to the intensity that would be felt if only bedrock were at the ground surface. Very soft or

loose soils that liquefy during a seismic event may cause the ground shaking to be amplified (greater than that felt on rock) or attenuated (less than that felt on rock). The amplification and attenuation that a soil might cause also depends on the underlying bedrock ground motion frequency and intensity, which are affected by the earthquake size and distance. For small or distant earthquakes that cause low intensities of shaking, the soft soils are likely to amplify the ground shaking. For large, nearby earthquakes that cause more intense shaking, little amplification or even attenuation of higher-frequency ground motions is possible. However, for the same nearby earthquake, low-frequency ground motions at liquefiable sites are likely to be amplified.

4.5.6 Seiches and Tsunamis

Seiches and tsunamis are short-duration, earthquake-generated water waves. Seiches are waves that occur in enclosed bodies of water, and tsunamis are waves that generally occur in the open ocean. The extent and severity of these waves depend on ground motions, fault offset, and location. Results of studies of these types of waves in Puget Sound are presented on the Tsunami Hazard Map of the Elliott Bay Area (Walsh et al. 2003). These studies indicated that a magnitude 7.3 to 7.6 earthquake caused by a rupture of the Seattle Fault may result in a wave that would inundate much of the waterfront to depths in excess of 6 feet. On average, the recurrence interval over the last 16,000 years for large-magnitude events on the Seattle Fault appears to be about 3,000 to 5,000 years, with individual recurrence intervals ranging from as short as about 200 years to as long as 12,000 years (Johnson 2004).

Tsunamis generated from large earthquakes in the Pacific Ocean basin could also result in tsunami runup along the waterfront. Data from a tsunami generated by the 1964 Alaska earthquake in Prince William Sound show a tsunami run-up of 0.8 foot in Elliott Bay (Wilson and Torum 1972).

4.6 REGIONAL GROUNDWATER SYSTEMS

The two main aquifer systems in the Seattle area are within glacially overridden alluvial deposits composed of coarse-grained sediments, such as sand and gravel that were deposited by glacially fed streams. In addition to the two main aquifers, several other near-surface geologic units may yield sufficient water for domestic use. Recent alluvial soils deposited by modern rivers and streams may be a local source of groundwater, depending on the thickness and permeability of the soils. Hydraulic connection between the near-surface alluvial deposits and the underlying aquifers is often limited by the presence of fine-grained deposits, including layers of clay and silt.

4.6.1 Regional Groundwater Flow

Groundwater flow in the Seattle area is generally controlled by the complex distribution of fine- and coarse-grained deposits, local topography, areas where precipitation provides recharge to aquifers, and areas where groundwater discharges. Groundwater recharge in the study area typically occurs in the upland areas including Capitol Hill and Queen Anne Hill. Groundwater movement from these recharge areas is predominantly downward toward the discharge areas in Elliott Bay.

The direction of groundwater movement is also controlled in part by the hydraulic conductivity of the soil (ability of the soil to transmit water). Groundwater flow in water-bearing units at and below sea

level is primarily governed by the hydraulic gradient (difference in water levels) between groundwater and surface water discharge areas. The hydraulic gradient determines the potential for groundwater to move in a particular direction, with groundwater moving from high to low water levels. Inland, away from surface water discharge areas, the hydraulic gradients are typically downward. However, along the EBSP alignment, groundwater flow is generally upward as the groundwater discharges to Elliott Bay.

4.6.2 Site Groundwater Conditions

Groundwater along the waterfront is encountered at about 7 to 15 feet bgs within the fill deposits (Hf) and varies with the tide in Elliott Bay. Observed groundwater levels within each zone are discussed in Section 4.4.2. The magnitude of the tidal fluctuation in the shallow water table behind the seawall may depend on the seawall type and its integrity. In the vicinity of Yesler Way where the seawall is a pile-supported gravity section, the water table changes in near direct response to the tide level in Elliott Bay. For an 11-foot tide variation in this area, a groundwater level variation of eight feet was measured in several observation wells screened within the fill deposits. Along the remainder of the waterfront, where the seawall generally consists of Type A and B walls, the water table fluctuation in the fill deposits is typically less than three feet. In contrast, groundwater levels measured in the deeper coarse-grained soils show a higher response to Elliott Bay tides, with fluctuations ranging from approximately one to seven feet. Because the proposed build alternatives would primarily be located within the upper 50 feet bgs, groundwater levels in the deeper Quaternary deposits would generally not be affected by the project.

Within the fill, there is a wide range of hydraulic conductivity values as a result of the highly variable nature of this deposit. The relative hydraulic conductivity of the glacially overridden deposits along the waterfront portion of this area is low for the fine-grained silt and high for the coarse-grained sand and gravel. Groundwater flow occurs primarily in the coarse-grained sand and gravel layers that are confined by overlying fine-grained soils. In general, groundwater flow in the Holocene soil deposits is horizontal toward Elliott Bay. Along most of this waterfront area, there is an upward hydraulic gradient as groundwater flows to the Elliott Bay discharge area. However, the intervening layers of fine-grained soils slow the vertical movement of groundwater between layers.

4.6.3 Groundwater Recharge and Discharge

Recharge to the aquifers in the study area occurs as precipitation infiltrates into the subsurface within and east of the study area. The average annual precipitation for the Seattle area is approximately 34 inches. Recharge by precipitation is controlled by a number of parameters, including ground slope, the area covered by pavement or buildings, and the soil's ability to transmit water. In areas where the ground slope is steep, water would run off the face of the slope, and little water would infiltrate the subsurface on the slope. At the base of the slope, the runoff may collect and recharge depending on the amount of covered area and soil conditions. In covered areas, such as the area adjacent to the seawall, precipitation would run off the area, typically to the combined sewer system or to the storm drain system that discharges to Elliott Bay. Therefore, little recharge is likely to occur for the EBSP, which is in an area with a high density of buildings and pavement.

4.6.4 Current Aquifer Use and Institutional Use Prohibitions

Until the 1890s, Seattle relied on small, privately owned wells, springs, and distribution systems for its water supply. The City began developing surface water drinking water sources in 1890 with the purchase of the Spring Hill and Union Water Companies. The City then developed the Cedar River watershed and opened the water system in 1901. The use of private wells for drinking and industrial water purposes decreased after 1901, and today there are no longer any drinking water wells within the study area. Groundwater use in study area is currently limited to emergency and industrial uses as the City has a large municipal water system.

No active drinking water wells have been identified in the study area. However, based on a review of Ecology records, four water rights are known to exist within approximately one mile of the study area:

- A certificate for groundwater withdrawal from a well was issued in 1971 for the former Troy Laundry Company located at the corner of Thomas Street and Fairview Avenue N. The current status of the well is unknown.
- A groundwater right has been issued for Safeco Field for irrigation of the playing field. The water supply is from the permanent drainage system beneath the sports facility.
- A groundwater right has been issued for the Port of Seattle at Terminal 91. The Terminal 91 well, located in the upland area north of the Magnolia Bridge, is screened from 340 to 445 feet bgs and is used for industrial water supply.
- A groundwater right for an emergency backup water supply well has been issued for Swedish Medical Center/Providence campus, which is located at 500 17th Avenue.

Because of the presence of a municipal water system in the Seattle area, groundwater use is generally limited to emergency and industrial supply wells for non-drinking use. The nearest known drinking water wells are the Highline Aquifer system wells, located north of the Seattle-Tacoma International Airport (about six miles south of the study area), which are part of the City water system. These wells are screened in older coarse-grained deposits. The Highline Aquifer system is not hydraulically connected to the aquifers below the study area.

4.6.4.1 Sole Source Aquifers

No sole source aquifers are located within five miles of the study area.

4.6.4.2 Wellhead Protection Areas

The nearest wellhead protection area is for the Highline Aquifer system wells. The study area is outside of the 10-year capture zone for the Highline Aquifer wellhead protection area. The study area does not overlap with any wellhead protection areas.

This page intentionally left blank.

CHAPTER 5. CONSTRUCTION EFFECTS AND MITIGATION

Construction effects are related primarily to earthwork and occur during construction or within a short time thereafter. The potential geology- and soils-related effects of the build alternatives would generally be related to the effects of earthwork on existing features (e.g., structures and utilities). The No Action Alternative does not include earthwork; therefore, no construction effects would occur.

5.1 NO ACTION ALTERNATIVE

No construction is proposed for the No Action Alternative, thus there are no anticipated effects. Refer to Section 6.1 for a discussion of operational and continued maintenance effects likely to occur for the No Action Alternative.

5.2 CONSTRUCTION EFFECTS

The anticipated construction approaches for the build alternatives are presented in Chapter 1. Other modifications associated with roadway and habitat improvements for each alternative are also presented in Chapter 1. Contractors may elect to use different construction approaches (or perform the work in a different order) than are described in Chapter 1. Also, depending on location, variations to the anticipated construction approaches may be necessary to install temporary access areas in order to perform excavation, and/or to accommodate site-specific issues. However, the effects described in the following sections are anticipated to cover most of the anticipated effects that could occur due to construction. The following sections present discussions of different types of construction effects and related mitigation measures for the build alternatives.

5.2.1 Common to All Build Alternatives

Several geology- and soils-related construction effects are common for all build alternatives. These include effects related to erosion and sediment transport, existing surface features, construction vibrations, removal of existing structures, and stockpiles and spoils disposal.

5.2.1.1 Erosion and Sediment Transport

Surficial areas in the vicinity of the new seawall and beneath new sidewalks or roadways would be cleared of all existing pavement, vegetation, and debris, and stripped of organic soils. The debris resulting from these clearing activities would be removed from the area. The prepared ground surface would have high erosion potential if exposed during the rainy season or in the presence of surface water. Any areas that are disturbed during construction would be subject to increased erosion if proper control measures are not performed.

Within construction areas, the tires and tracks of heavy equipment may sink into the soft surface soil if no work pad is present. The tires of the construction vehicles could also carry soil onto roadways when leaving construction areas and traveling along haul routes unless appropriate BMPs are implemented.

5.2.1.2 Existing Pavement

Construction traffic may cause settlement, potholes, cracks, and other damage to existing roadways and sidewalks. Haul routes between staging areas and the construction site may experience this type of damage. The degree of damage to existing pavements would depend on the condition of the pavement subgrade, the pavement section strength, and the weight of construction traffic.

5.2.1.3 Construction Vibrations

Many construction activities could cause vibration of the ground and adjacent structures. Some of these construction activities include pile installation (either by impact or vibratory methods), sheet-pile installation, and soil improvement. Effects related to vibrations are discussed further in the Noise and Vibration Discipline Report (SDOT 2012a). Construction vibrations generally decrease exponentially with distance from the source. The vibrations could cause ground settlement and damage to utilities and structures.

5.2.1.4 Fill Placement and Compaction

Non-habitat-related fills (about 10 to 15 feet thick) will be placed above the soil improvement zone (Alternatives A and C) or around the drilled shaft cap (Alternative B) to restore the street grade landward of the seawall. Placement and compaction of fill materials adjacent to existing walls or structures could cause damage to the walls or structures because of the fill and compaction loading. If backfilling and compacting operations are performed during wet weather the fill materials may not achieve the desired degree of compaction. Improperly compacted fills could settle over time.

Offshore habitat-related fills are included in all build alternatives. Depending on the soil conditions, the fill weight, and the mudline slope, instability of the submarine slope could occur during fill placement. In addition, placement of the fill could result in settlement of the underlying sediments. This potential instability and settlement could cause damage to adjacent features including existing pile supported structures and the new seawall structure. Settlement could also impose downdrag loads on the piles, which could result in settlement of the structures that they support.

5.2.1.5 Temporary Excavation Support

Various shoring wall types may be selected to support temporary excavations. Shoring wall types that may be used include soldier pile and lagging walls, sheet-pile walls, or diaphragm walls. Depending on the excavation depths and subsurface conditions, the walls could be cantilevered, tied back, or internally braced. Improper construction of the wall and tiebacks or braces could result in excessive lateral displacement, settlement, and subsequent loading of adjacent ground and nearby roadways, railways, utilities, and structures. For example, ground movement could occur if braces are not properly installed at appropriate elevations. In general, soil near shoring walls could have a settlement magnitude equal to about 50 to 100 percent of the wall's horizontal displacement. Excessive settlement and lateral deformation could affect or apply loads to nearby roadways, railways, utilities, and structures. Construction equipment working adjacent to the top of shoring walls may cause wall movement and ground settlement.

5.2.1.6 Excavations and Dewatering

Excavations would be made for construction of the seawall, removal of the existing seawall, and relocation of utilities. Conventional equipment, including excavators and backhoes, would likely be used to perform the excavation. Excavations could cause sloughing of soils and lateral movement or settlement of nearby existing roadways, railways, structures, and utilities if proper excavation support and dewatering techniques are not used.

The water table along the seawall is located at about seven to 15 feet bgs and varies with the tide level in Elliott Bay. In areas where excavations extend below the water table, dewatering of soils within and below the excavation may be necessary. If the excavation dewatering effort were to fail or to prove inadequate for any reason, ground loss may occur within the excavation. This loss could result from running (flowing) ground, piping, or base heave due to uplift conditions. This could cause settlement of utilities, roadways, and other facilities adjacent to the excavations.

Dewatering activities could drawdown the water table outside the excavation depending on the subsurface soil and groundwater conditions, the wall type, and the amount of dewatering required. If the amount of drawdown outside of the excavation is greater than the existing seasonal or tidal fluctuation of the groundwater, settlement of the ground surface could occur and potentially affect nearby roadways, railways, structures, and utilities. Settlement could also induce additional loads on nearby existing features. Where existing structures are founded on timber piles, extended groundwater lowering could contribute to pile decay.

Construction dewatering would not affect public or private groundwater supplies. Groundwater is not used as water supply in the study area. No wellhead, aquifer protection, or sole source aquifer plans exist in the area.

5.2.1.7 Dredging

Dredging would be performed at several locations along the EBSP alignment for all build alternatives to remove the existing seawall and prepare habitat areas. During dredging, sediment may enter the water during transport from the dredging bucket to the barge and from the barge to the disposal site. This is addressed further in the Water Resources Discipline Report (SDOT 2012b).

If dredging is performed in front of the existing seawall prior to its replacement, the loss of passive soil resistance against the wall base could result in undermining of the seawall. This could cause lateral movement of the wall and settlement of the ground surface, which could potentially affect nearby roadways, railways, structures, and utilities.

5.2.1.8 Pile Installation

New piles may be installed to support overlooks, sidewalk extensions, walkways, and confined substrate for all build alternatives. Selection of the appropriate pile types would depend on subsurface conditions underlying the structures, site constraints, and constructability. Pile types that may be used include prestressed octagonal concrete piles, steel pipe piles, and steel H-piles. These piles may be driven or vibrated into the ground, depending on the soil conditions and required pile penetration.

Sheet piles may be installed as temporary excavation support for all build alternatives. Sheet piles can be pushed, driven, or vibrated into the ground. As discussed in Section 4.3.1, large amounts of wood and debris are located at some locations along the EBSP alignment. Existing riprap is also present in some of the sheet-pile installation areas. Installation of sheet piles through wood and riprap may be difficult. The presence of wood could result in misalignment of the sheet piles, resulting in leakage and discontinuities in the temporary retaining walls. Vibration also may also occur due to installation of sheet piles.

Pile installation (either by impact or vibratory methods) would result in noise and vibration effects to people, structures, and utilities near the pile driving activities. Noise and vibration effects are discussed further in Noise and Vibration Discipline Report (SDOT 2012a). The effects of noise and vibration on fish and other wildlife are discussed in the Fish, Wildlife, and Vegetation Discipline Report (SDOT 2012c). When a pile encounters obstructions during driving, vibrations could increase because of harder driving conditions. This could also result in increased ground movement and damage to adjacent features.

5.2.1.9 Ground Anchor Installation

All build alternatives include installation of ground anchors to supplement lateral resistance for the new seawall system. Ground anchors may consist of tiebacks or micropiles. Installation of ground anchors typically involves drilling a hole with a casing through a no-load zone and then drilling further into the ground without a casing. Grout can be injected with or without pressure using a tremie method. For the EBSP, pressurized grouting is not required because the purpose of the anchor is to resist earthquake inertial loads only.

During drilling of anchor holes, ground loss could occur in soft soils, sandy soils, and/or water bearing soils. This ground loss could migrate to the ground surface and result in settlement of adjacent structures, utilities, and pavements.

As discussed in Section 4.3.1, large amounts of wood and debris were encountered at some locations along the EBSP alignment. Installation of anchors through this material may be difficult and could result in improper grouting and ground loss. The presence of wood could also result in misalignment of the anchors.

5.2.1.10 Removal of Existing Structures

All of the build alternatives include removal of portions of the existing seawall structure. If deep foundations are to be removed, vibration techniques used for removal may result in damage to adjacent structures and utilities, depending on the soil conditions and proximity. If foundation elements remain in place and are located beneath new fills or roadways, the presence of the foundation element would create a hard spot that could result in differential settlement.

5.2.1.11 Spoils Disposal

Spoils consist of soil or other debris that is removed from a construction activity. Each alternative would generate a different volume of spoils (see subsequent sections) that will need to be handled, stored, and disposed of. Based on soil and groundwater characterization performed along the EBSP alignment,

various spoils management and disposal strategies would be developed. Most of the spoils would likely require off-site disposal.

Some of the spoils could be contaminated because they contain debris, wood, and potential contaminants. Disposal and volume estimates of these types of soils are discussed further in the Contaminated Materials Discipline Report (SDOT 2012d).

Spoils that are removed from the site would be hauled in trucks, rail cars, or barges to a predetermined disposal site. During transport, spoils could spill, which could result in deposition of dust or debris on the roadways, on rail corridors, or in water unless appropriate BMPs are implemented.

5.2.1.12 Stockpiles

Imported structural fill may be stored in stockpiles at staging areas located along the study area. Effects of stockpiles may include settlement of the ground surface in the stockpile areas and erosion and sediment transport. Utilities and pavement beneath stockpiles could be damaged due to settlement and lateral movement caused by the weight of the stockpile materials. If stockpiles are placed adjacent to the existing seawall or shoring walls, lateral movement of the wall could occur.

If the stockpiles are not suitably protected, surface water erosion could result in deposition of sediment onto adjacent properties, streets, and stormwater drains. Stockpiles of material to be used as landscaping or structural fill could become wet and unsuitable for use as fill if left uncovered during rainy periods and appropriate BMPs are not implemented.

5.2.2 Alternative A

The new seawall in Alternative A would be constructed using a soil improvement system that consists of improving the ground behind the seawall using jet grout and/or deep soil mixing and ground anchors, as described in Section 1.7.1.1. The wall pull back would be minimized, ranging from about 0 to 15 feet from the current seawall location. Earthwork for the seawall construction primarily includes excavation, soil improvement, structural facing wall installation, ground anchor installation, and fill placement. Other non-habitat-related earthwork includes installation of piles, grading for roadways, trenching for utilities, and removal of the existing seawall. Habitat-related activities include placement of tidal habitat fills and marine mattresses. General geology- and soils-related construction effects for some of these activities are presented in Section 5.2.1 because they are common to all build alternatives. Additional effects specifically related to Alternative A are presented in the following sections.

5.2.2.1 Soil Improvement

Soil improvement would be performed as part of Alternative A to stabilize potentially liquefiable soils behind the new seawall and to provide a reinforced soil mass that can act as a retaining structure. Common local soil improvement methods include deep soil mixing, jet grouting, vibro-replacement, and compaction grouting. Because of the presence of the existing relieving platform timber piles and other constructability issues, jet grouting would likely be used to perform the soil improvement. Deep soil mixing may also be used in some areas where the timber relieving platform is not present (e.g. for gravity walls in Zones 1 and 2). The soil improvement zone would extend beneath a portion of the

relieving platform down to the top of the glacially overridden deposits. The soil improvement zone would be about 20 feet wide at the top of the relieving platform, increasing in width with depth to about 30 to 40 feet wide near the top of the glacially overridden soil deposits. An area replacement ratio of about 40 to 50 percent (fraction of soil that is grouted and improved) would be targeted.

Jet grouting is typically performed by pushing, drilling, or jetting a grout pipe into the ground to the depth to be treated, and then forcing water and/or air through the pipe to erode the soil. Simultaneous with the water/air erosion of soil, cement grout is injected to mix with and replace the eroded soil. The resulting material is an engineered grout that solidifies in situ to become soil cement. Jet-grout columns would be of variable diameters, with more erodible sands and silts forming a larger diameter column (up to about five feet in diameter) than less erodible clays and glacial till soils.

If the jet-grouting process is not properly controlled, gaps in the improved area could occur when soils that do not easily erode (e.g., clay) are encountered. In addition, when obstructions such as boulders, logs, piles, concrete, or other large debris are encountered, shadowing can occur (i.e., the obstruction would partially block the extent of the jet grouting), which would result in gaps in the improved zone. Gaps could also be created by misalignment of grout columns. Because the jet grouting would be performed in the midst of the timber piles of the existing relieving platform, numerous obstructions would be present, resulting in a high potential for shadowing.

Depending on the existing soil conditions, methods of construction, and extent of treated/untreated ground, utilities and foundation elements may settle or heave when jet-grout operations are performed nearby. If jet grouting is performed near existing structures or utilities, excessive pressure could cause damage to the existing facilities. Grout injected into the soil may also travel through open soil layers or through the existing seawall and enter Elliott Bay. The jet-grouting process may also introduce additional loads to the seawall structure. This could cause distress or localized failures to the seawall. Jet grouting is not anticipated to cause destabilization of adjacent facilities.

Deep soil mixing is an in-situ soil mixing technology that mixes existing soil with cement grout using mixing shafts consisting of auger cutting heads, discontinuous auger flights, and mixing paddles. The mixing equipment varies from single- to eight-shaft configurations, depending on the purpose of the deep mixing. Too rapid advance or withdrawal of the deep soil mixing augers and inadequate control of grout pumping rates could cause heave or settlement of nearby sidewalks, streets, utilities, and structures.

Jet-grout operations typically produce spoil volumes equal to about 50 to 70 percent of the volume of soil treated. Depending on the equipment and operators, deep soil mixing could produce spoil equal to about 25 to 30 percent of the volume of soil treated. These spoils would consist of a mixture of eroded soil and cement grout that is flushed to the ground surface during soil improvement operations. If not properly contained, spoils may migrate onto adjacent streets, properties, or Elliott Bay.

5.2.2.2 Spoils Disposal

About 111,000 cubic yards of material would be generated from the proposed excavations for Alternative A. In addition, about 102,000 cubic yards of spoils would be generated from the soil improvement activities. In general, the soils encountered above the relieving platform consist of sand

and gravel that was taken from the Cedar River and barged in to the Seattle waterfront for use as fill during the original seawall construction. Some of the remaining fill soils that would be excavated below the relieving platform may contain wood, debris and potential contaminants. In addition, about 1,000 cubic yards of sediment would be dredged from Elliott Bay for placement of substrate enhancements and may contain contaminants, debris, and riprap. These potentially contaminated soils cannot be reused as fill but must be treated and disposed of according to State regulations. Disposal and volume estimates of these types of soils are discussed further in the Contaminated Materials Discipline Report (SDOT 2012d). Other effects of spoils disposal are described in Section 5.2.1.11.

5.2.2.3 Habitat Bench between Piers 54 and 55

Alternative A includes constructing a habitat bench that consists of placing up to 20 feet of marine mattresses between Piers 54 and 55 to create the habitat bench at elevation -2.5 feet. Dredging (up to 15 feet deep) would be required to create the 20-foot-thick habitat bench. A riprap buttress would be placed at the toe of the marine mattress bench.

General effects related to dredging are presented in Section 5.2.1.7. The dredging process would remove sediment from in front of the new seawall. This would result in a reduction in passive soil resistance in front of the seawall prior to placement of the marine mattresses. This could result in lateral movement of the seawall structure and potential damage to overlying and adjacent pavements, utilities, and other structures.

5.2.3 Alternative B

The new seawall in Alternative B would be constructed using a BSP system that consists of installing large-diameter (up to eight feet) drilled shafts along the new seawall alignment as described in Section 1.7.2.1. The new seawall would be pulled back as much as 75 feet in some locations. Inclined ground anchors would be connected to the drilled shafts to provide additional lateral support for seismic loading conditions. Earthwork for the seawall construction primarily includes excavation, drilled shaft installation, structural facing wall installation, ground anchor installation, and fill placement. Other non-habitat-related earthwork includes installation of piles, grading for roadways, trenching for utilities, and removal of the existing seawall. Habitat-related activities include placement of tidal habitat fills, marine mattresses, large beach areas, and improved ground upland areas. General geology- and soils-related construction effects for some of these activities are presented in Section 5.2.1 because they are common to all build alternatives. Additional effects specifically related to Alternative B are presented in the following sections.

5.2.3.1 Drilled Shafts

Drilled shafts up to eight feet in diameter may be used to construct the new seawall. Drilled shafts consist of reinforced concrete piles that are constructed in pre-drilled holes. Spoils are generated by removal of the soil from the drilled hole. Stability of the hole is typically controlled by means of temporary casings and/or drilling fluid. After the hole is excavated, a reinforcement cage is lowered into the hole and the hole is backfilled with concrete.

Unstable soil and unfavorable groundwater conditions are present below the ground surface in numerous locations along the EBSP alignment. Caving or sloughing of soil within open-hole excavations could result in ground settlement and potential damage to nearby pavements, structures, and utilities. Migration of concrete into Elliott Bay could occur through open soil layers.

The eight-foot-diameter drilled shafts may be installed at a 10 feet center-to-center spacing. This would result in a two-foot-wide gap in between the drilled shafts. Depending on the soil and groundwater conditions, if the wall face is exposed to air or water, soil behind the wall could cave or slough in between the shafts, resulting in ground loss. The ground loss could migrate to the ground surface as settlement and result in damage to adjacent pavements, utilities, and structures.

5.2.3.2 Spoils Disposal

Up to 248,000 cubic yards of material would be generated from the proposed excavations (including drilled shafts) for Alternative B. These volumes assume that Option 1 is selected and, therefore, represent the maximum volume of spoils that would be generated. This volume includes both soils from behind the existing seawall and sediments from Elliott Bay (primarily from Option 1 near the Seattle Aquarium). In general, the soils encountered above the relieving platform consist of sand and gravel that was taken from the Cedar River and barged in for use as fill during the original seawall construction. Some of the remaining fill soils that would be excavated below the relieving platform may contain wood, debris, and potential contaminants. These potentially contaminated soils cannot be reused as fill but must be treated and disposed of according to State regulations. Disposal and volume estimates of these types of soils are discussed further in the Contaminated Materials Discipline Report (SDOT 2012d). Other effects of spoils disposal are described in Section 5.2.1.11.

5.2.3.3 Intertidal Habitat Bench near Washington Street Boat Landing

Alternative B includes constructing a large habitat bench north of Washington Street Boat Landing adjacent to the seawall. Creation of this bench would require placement of about 20 to 30 feet of granular fill and riprap in the water. The existing ground could settle several feet as the fill is placed. Additional settlement could occur over the long term as fine-grained soil deposits are compressed. This fill would extend near the existing pile-supported docks north and south of the habitat bench (Colman Dock and Pier 48). Depending on the proximity and height of the fill, the existing pile foundations could experience additional loads due to the soil settlement (downdrag loads). This could result in settlement of the overlying docks and facilities.

Most of the existing topography adjacent to the habitat bench is gently sloping. However, localized steeper areas may become unstable when the fill is placed; resulting in localized ground movement around the habitat bench. This ground movement could result in additional loading on nearby pile foundations and settlement of the bench.

5.2.3.4 Habitat Area at the Seattle Aquarium

Alternative B includes constructing a large new habitat area at the Seattle Aquarium. Because the new seawall would be set back by as much as 75 feet, the section of land between the existing seawall and

new seawall can be partially reclaimed as habitat area. Either a water plaza (Option 1) or a land plaza (Option 2) would be constructed in this area.

5.2.3.4.1 Option 1 – Water Plaza

Option 1 includes excavation and dredging the area between the existing seawall and new seawall to create a water plaza. Riprap and other material would be placed in the excavated area to create tide pools, habitat benches, and other aquatic features. Placement of this fill is not anticipated to result in geology- and soils-related impacts because the weight of the new fill would be less than the weight of the material that was excavated from this area.

New pile-supported concrete walks would be constructed at several areas to provide access to Piers 59 and 60 and the Seattle Aquarium. New piles would be installed next to existing pile-supported structures. These existing structures could settle due to adjacent pile installation (impact driving or vibration) activities. Other effects related to pile driving are discussed in Section 5.2.1.8.

5.2.3.4.2 Option 2 – Land Plaza

In Option 2, the land between the existing seawall and the new seawall would remain and would be improved in place. A new retaining wall would be constructed along the west side of the soil improvement zone. The open land areas would be landscaped and riprap and habitat benches would be constructed in the water west of the soil improvement zone.

To mitigate potential liquefaction and lateral spreading, the soil in between the existing seawall and new seawall would be improved. Soil improvement methods that may be used include jet grouting and deep soil mixing. Construction effects related to soil improvement would be similar to those presented in Section 5.2.2.1.

A new retaining wall would be required along the west side of the soil improvement zone. The new wall may consist of a sheet-pile wall or a diaphragm wall. Construction effects related to this wall would be similar to those described in Section 5.2.1.5. Additional piles would be driven to support walkways and overlooks. Construction effects related to pile installation would be similar to those described in Section 5.2.1.8.

5.2.4 Alternative C

The new seawall in Alternative C would be constructed using a soil improvement system similar to Alternative A, as described in Chapter 1. The new seawall would be pulled back landward from 6 to 15 feet along the entire alignment. Earthwork for the seawall construction primarily includes excavation, soil improvement, structural facing wall installation, ground anchor installation, and fill placement. Other non-habitat-related earthwork includes installation of piles, grading for roadways, trenching for utilities, and removal of the existing seawall. Habitat-related activities include placement of tidal habitat fills and marine mattresses. General geology- and soils-related construction effects for some of these activities are presented in Section 5.2.1 because they are common to all build alternatives. Additional effects of Alternative C are similar to Alternative A in most cases because these two alternatives use the same method of seawall construction.

5.2.4.1 Soil Improvement

Soil improvement would be performed as part of Alternative C to stabilize potentially liquefiable soils behind the new seawall and to provide a reinforced soil mass that can act as a retaining structure. The effects on geology and soils for this construction would be similar to those described for Alternative A in Section 5.2.2.1.

5.2.4.2 Spoils Disposal

About 125,000 cubic yards of material would be generated from the proposed excavations for Alternative C. In addition, about 102,000 cubic yards of spoils would be generated from the soil improvement activities. In general, the soils encountered above the relieving platform consist of sand and gravel that was taken from the Cedar River and barged in to the Seattle waterfront for use as fill during the original seawall construction. Some of the remaining fill soils that would be excavated below the relieving platform may contain wood, debris and potential contaminants. In addition, about 1,000 cubic yards of sediment would be dredged from Elliott Bay for placement of substrate enhancements and may contain contaminants, debris, and riprap. These potentially contaminated soils cannot be reused as fill but must be treated and disposed of according to State regulations. Disposal and volume estimates of these types of soils are discussed further in the Contaminated Materials Discipline Report (SDOT 2012d). Other effects of spoils disposal are described in Section 5.2.1.11.

5.2.4.3 Habitat Bench between Piers 54 and 55

Alternative C includes constructing a habitat bench between Piers 54 and 55 similar to Alternative A. Construction effects on geology and soils would be the similar to those presented for Alternative A in Section 5.2.2.3. For Alternative C, much of the fill placed for the habitat bench and confined substrate fill will be located in the wall pullback zone. This will reduce the potential risk of settlement and effects on adjacent piers.

5.2.4.4 Intertidal Habitat Bench near Washington Street Boat Landing

Alternative C includes constructing a large intertidal habitat bench north of Washington Street Boat Landing adjacent to the seawall, similar to Alternative B. Construction effects on geology and soils would be the same as those presented for Alternative B in Section 5.2.3.3.

5.3 INDIRECT EFFECTS

No indirect effects related to geology and soils have been identified related to construction activities.

5.4 MITIGATION MEASURES

Mitigation measures for the construction effects are based on the site information and standard design and construction procedures in use at the time this Discipline Report was prepared. The construction of the EBSP would be observed by experienced engineers or technicians, who would observe the construction activities and provide recommendations to minimize the geology- and soils-related effects.

The geology- and soils-related effects can generally be mitigated through the use of BMPs and good workmanship during construction.

5.4.1 Common to All Build Alternatives

The construction effects identified in Section 5.2.1 are common to all build alternatives. This section discusses mitigation measures for these effects.

The EBSP will be designed by experienced engineers based on the existing site conditions, the available subsurface information, and design procedures and criteria approved by the City. Subsurface explorations should be performed as described in Section 6.4.1 to mitigate the potential for unknown subsurface conditions to affect the construction of the build alternatives.

5.4.1.1 Erosion and Sediment Transport

Construction BMPs are required by the City for major projects, including construction-staging barrier berms, filter fabric fences, temporary sediment detention basins, and use of slope coverings to contain sediment on site. These BMPs would be effective in protecting water resources and reducing erosion from the construction areas. Erosion control measures suitable to the site conditions would be included as part of the design. More detailed information regarding BMPs is included in the Water Resources Discipline Report (SDOT 2012b). Temporary erosion and sediment control plans will be prepared for approval in accordance with BMPs included in the current Seattle Municipal Stormwater Code (Ordinance 123105) and the Seattle Municipal Grading Code (Ordinance 123107).

Erosion control measures include vegetative and structural controls. Structural controls would primarily be used because the project corridor is highly developed. Structural controls consist of artificial means of preventing sediment from leaving the construction area (e.g. silt fences, ditches, berms, tire wash areas, etc.). Proposed mitigation measures would comply with stormwater design and treatment procedures in the current version of the Seattle Municipal Stormwater Code (Ordinance 123105). Such procedures follow the National Pollutant Discharge Elimination System (NPDES) guidelines administered by Ecology. An NPDES Construction Stormwater General Permit may be required for the project. The NPDES permit would list specific BMPs required for the project. The erosion and sediment control measures should be in place before any clearing, grading, or construction.

5.4.1.2 Existing Pavement

Construction traffic would be routed onto City-approved haul routes, which include roadways that are capable of handling heavy loading. In areas where construction traffic cannot be rerouted onto suitable roadways, existing roadways would either have to be improved prior to construction or repaired following construction. Alternatively, smaller and lighter construction equipment could be used in some areas. Since the project is located in an urban area, it is likely that many roads are already designed to accommodate truck loading. To reduce dust during hauling, the loads would be covered during transport.

5.4.1.3 Construction Vibrations

Several of the proposed construction methods could cause vibration resulting in ground settlement and damage to utilities and structures. The actual vibration and settlement levels that occur as a result of construction depend on many factors, including subsurface conditions, construction methods, and quality of the work. Allowable vibration levels would be established by the City for critical structures and utilities near the construction activities. Preconstruction surveys would be performed to establish a baseline. During construction, monitoring of vibrations could be performed to confirm that allowable vibration levels are not being exceeded. In areas where vibration cannot be tolerated, consideration should be given to construction methods that limit vibration.

Vibratory methods for sheet-pile installation would not be allowed in areas where vibrations may affect adjacent facilities. Depending on the soil conditions, the sheet piles could be pushed into the ground without vibration. If the soil conditions are too dense, pre-drilling could be performed to prepare holes for the sheet piles, or alternative shoring methods could be considered.

5.4.1.4 Fill Placement and Compaction

Fills would not be placed adjacent to walls or other settlement-sensitive structures unless the structures can accommodate (or be designed to accommodate) the increased pressures due to the placement and compaction of the fill. Suitable structural fill materials should be used to construct the fills, as described in Section 6.4.4. The material would be compacted to the compaction criteria required by the City.

5.4.1.5 Temporary Excavation Support

Proper construction procedures should be used to install temporary retaining walls for excavations. Appropriate selection of wall type can mitigate ground movement, seepage, and other identified effects. For all of the potential wall types that may be used, proper construction procedures would mitigate potential settlement and ground movement adjacent to the wall.

Temporary excavations should be adequately shored to mitigate potential sloughing of soils and lateral movement or settlement of nearby existing roadways, railways, structures, and utilities. The shoring system would consider the loads applied due to construction equipment working behind the top of the excavation and any other surcharge loads. Stockpiles should be placed a minimum of twice the excavation depth away from the top of the excavation to mitigate the effect of the stockpile load on the excavation stability. The use of temporary tiebacks or other bracing would also reduce the potential for ground movement adjacent to deep excavations.

5.4.1.6 Excavations and Dewatering

The contractor should control the entry of water into excavations. Dewatering of soils within and below excavations may be performed to control inflow, remove water from excavations, and reduce hydraulic forces that could destabilize excavations. Dewatering would be performed in compliance with permits obtained for the project (e.g., King County Industrial Wastewater Discharge Permit) and could be accomplished by using a combination of sumps, well points, and/or dewatering wells. Dewatering would

be performed until construction of the subsurface structures is completed. Handling and disposing of contaminated and clean water is discussed in the Water Resources Discipline Report (SDOT 2012b).

Dewatering systems should be operated so as to minimize the drawdown of the water table outside of the excavation in areas where adjacent structures may be affected. Mitigation measures include the use of groundwater recharge wells, dewatering in small sections, or use of barriers (e.g., sheet piles, diaphragm walls) to isolate the water table within the excavation. Dewatering and recharge wells should be carefully constructed to the specified design of the well depth, length, screen, and filter pack. Proper maintenance of the wells should be performed to ensure that they are working as designed. Monitoring of the water table and settlement outside of the excavation should be performed to confirm that the dewatering system is working as designed.

5.4.1.7 Dredging

The design of the new seawall and temporary shoring walls would consider the final configuration of the mudline west of the wall as well as the temporary dredging that may be performed prior to placement of marine mattresses and other toe materials. In areas where the new seawall cannot accommodate proposed temporary dredge depths, dredging should be performed in small sections to minimize loss of passive resistance against the wall. Large temporary dredge areas should not be left open for significant periods of time. Temporary dredging should not be performed directly in front of the existing seawall. As part of the construction, a temporary barrier would be installed west of the existing seawall to protect Elliott Bay from construction activities. This barrier could consist of a sheet-pile cofferdam, floating silt curtain or other barrier.

5.4.1.8 Pile Installation

Pile installation (either by impact or vibratory methods) may be required for sidewalk and ramp foundation and sheet-pile installation. Preconstruction surveys of existing structures and vibration monitoring during pile installation may be required to monitor potential damage to adjacent sensitive structures. With some pile installation methods, adjustments in the hammer size, frequency, or energy can be made to reduce vibrations. Other methods that may reduce vibrations include pre-drilling or using vibratory hammers where the vibration frequency can be controlled. Mitigation measures for noise and vibration effects are discussed further in Noise and Vibration Discipline Report (2011b).

5.4.1.9 Ground Anchor Installation

Anchor holes would be drilled in a manner that would minimize ground loss and not endanger previously installed anchors or undermine existing pavement, foundations, or utilities. The contractor should be prepared to drill through water-bearing fill with varying amounts of wood, brick, concrete, cinder, mortar, asphalt, and charcoal debris. Casing and downhole hammer may be required.

The no-load zone lengths should not be left open overnight. In the anchor no-load zone, tieback holes could be filled with a material such as a sand pozzolan mixture that would prevent caving, but would not adhere to the tieback rod. Alternatively, a bond breaker could be used around the ties in the no-load zone, and the zone could be filled with concrete or lean concrete backfill.

5.4.1.10 Removal of Existing Structures

The project includes removal of portions of the existing seawall structure. If deep foundations are to be removed, vibratory techniques would only be used in areas where adjacent structures or utilities would not be substantially affected. Non-vibratory techniques (e.g., excavation of the foundation element) would be used in areas where adjacent utilities or structures cannot tolerate vibration or settlement. Excavations that are necessary for the removal of foundation elements would have similar effects as those discussed previously for excavations. As part of the construction, a temporary barrier would be installed west of the existing seawall to protect Elliott Bay from construction debris. This barrier could consist of a sheet-pile cofferdam, floating silt curtain or other barrier.

If foundations are left in place, they may result in a stress concentration (hard spot) beneath new facilities. This could be partially mitigated by excavating a portion of the upper part of the foundation element and placing softer material to diffuse the effect of the hard spot.

5.4.1.11 Spoils Disposal

Construction BMPs would mitigate some of the construction effects related to spoils disposal. These may include structural controls such as cleaning tires and tracks on heavy equipment before they travel along haul routes and covering truck loads to mitigate sediment deposit onto roadways. Construction BMPS would be performed in accordance with applicable project permits (e.g., NPDES permit) Additional mitigation measures for spoils disposal are included in the Contaminated Materials Discipline Report (SDOT 2012d).

5.4.1.12 Stockpiles

A stated in Section 5.4.1.1, stockpiles would be covered to prevent erosion and sediment transport. Where feasible, stockpiles would not be placed directly over utilities or pavements that could be damaged from loads and ground settlement caused by the stockpiles. In areas where this is not possible, stockpile heights could be limited so that excessive settlement or damage of underlying utilities or pavements does not occur.

5.4.2 Alternative A

In addition to the mitigation measures discussed in Section 5.4.1, mitigation would be required for the proposed soil improvement effects associated with rebuilding the seawall and the effects unique to the habitat improvements included in Alternative A.

5.4.2.1 Soil Improvement

Soil improvement methods would generally be used to construct the new seawall structure for Alternative A. Soil improvements should be performed by contractors with experience in the jet-grouting and/or deep soil mixing technique. During installation, monitoring of adjacent utilities or structures should be performed. In general, jet grouting and deep soil mixing do not cause vibrations. Spoils generated from soil improvement activities would be contained within the excavation created for anchor installation. If this excavation is not performed prior to soil improvement activities, proper

containment of the soil-cement spoils could be provided by constructing berms or other barriers around the construction area. Proper containment would mitigate migration of spoils onto adjacent streets or properties.

The jet-grouting process should be properly controlled so that gaps in the improved area do not occur when soils of low erodibility are encountered. In addition, shadowing could occur when obstructions such as wood debris are encountered, resulting in unintended gaps in the improved zone. The spacing of jet-grout columns may have to be decreased in areas where low erodibility soils or obstructions are encountered. Where contiguous improved soil is needed, the jet-grouting spacing should be close enough so that obstructions are encapsulated in the jet grout.

To mitigate excessive pressure on or leakage of jet grout into adjacent utilities or structures, the jet-grouting pressure would be controlled carefully near the ground surface, near existing outfalls and other utilities that will be supported in place, and near the face of the existing seawall. Jet-grouting spacing and pressure may have to be decreased near critical utilities or structures. Sheet piles or other barriers would be installed on the water side of the soil improvement area to prevent jet-grout migration into Elliott Bay. Prior to jet-grouting operations, existing voids or holes that are discovered within and below the seawall during a pre-activity inspections would be filled to prevent migration of the grout. Jet grouting could also be performed in a semicircular pattern adjacent to the protective sheet piles to control potential migration of the grout. Utilities could also be inspected in advance and any holes repaired prior to jet grouting.

During deep soil mixing operations, care should be taken to avoid rapid advance or withdrawal of the deep soil mixing augers and inadequate control of grout pumping rates. Deep soil mixing should not be performed immediately adjacent to existing utilities or structures because temporary loosening of the soil could cause settlement. Spoils should be properly contained by constructing berms or other barriers around the construction area. Proper containment would mitigate migration of spoil material onto adjacent streets or properties. If obstructions are encountered, jet grouting could be considered to extend the improvement to a deeper depth or a larger plan area.

5.4.2.2 Habitat Bench between Piers 54 and 55

The primary effect of the habitat bench is related to temporary dredging activities. Mitigation measures for temporary dredging would be similar to those discussed in Section 5.4.1.7.

5.4.3 Alternative B

In addition to the mitigation measures discussed in Section 5.4.1, mitigation would be required for the proposed drilled shaft installation effects associated with rebuilding the seawall and the effects unique to the habitat improvements included in Alternative B.

5.4.3.1 Drilled Shafts

Drilled shafts would generally be used to construct the new seawall structure for Alternative B. Slurry and/or casing can be used to mitigate potential caving of the side walls in the drilled hole. Casing can be installed by twisting, driving, or vibrating the casing into the ground. Vibration or driving methods

should not be used in areas that are close to adjacent structures. The use of slurry could also be used to mitigate potential heave and erosion that could be caused by groundwater pressures in sandy soils.

In areas where the drilled shafts are not interconnected to form a solid wall (i.e., no space in between the shafts), care would be taken when exposing the face of the wall to prevent soil migration between the shafts. If soil migration is observed, grouting or other soil stabilization means may be required to prevent soil from migrating through the inter-shaft zone.

5.4.3.2 Intertidal Habitat Bench near Washington Street Boat Landing

Mitigation measures for the construction effects related to fill placement, potential instability, and downdrag on adjacent piles would be similar to those presented in Section 5.4.1.4.

5.4.3.3 Habitat Area at the Seattle Aquarium

The construction effects identified for the water plaza (Zone 4, Option 1) included effects related to fill placement and pile installation. Mitigation measures for these effects would be similar to those discussed in Sections 5.4.1.4 and 5.4.1.8, respectively.

The construction effects identified for the land plaza (Zone 4, Option 2) include installation of retaining walls, pile foundations, and soil improvements. Mitigation measures for walls and pile foundations would be similar to those presented in Sections 5.4.1.5 and 5.4.1.8, respectively.

The soil improvement proposed for Option 2 may consist of jet grouting or deep soil mixing. Mitigation measures for the effects of soil improvement would be similar to those presented in Section 5.4.2.1 for Alternative A.

5.4.4 Alternative C

Mitigation for proposed soil improvement effects would be similar to those presented for Alternative A in Section 5.4.2.1. In addition, mitigation measures for the proposed construction effects related to the habitat improvements would be similar to those presented for Alternative A for the habitat bench near Piers 54 and 55 (see Section 5.2.2.3) and similar to Alternative B for the habitat bench near Washington Street Boat Landing (see Section 5.2.3.3).

CHAPTER 6. OPERATIONAL EFFECTS AND MITIGATION

Operational effects are those that will occur during the long term operation of the EBSP. The following sections discuss the operational effects, mitigation, and benefits of the EBSP alternatives.

6.1 NO ACTION ALTERNATIVE

Both federal and Washington State environmental regulations require agencies to evaluate a No Action Alternative to provide baseline information about existing conditions in the project area. For this project, the No Action Alternative is not considered to be a viable alternative because the existing seawall is vulnerable to earthquakes, coastal storm damage, and structural failure due to ongoing deterioration. Three No Action scenarios were considered, as described in Section 1.4.

Under the Minimal Damage scenario, continued deterioration would occur. Historically, sinkholes and other evidence of settlement have occurred behind the seawall. This is likely occurring as material is washed out from below the seawall structure over time as a result of wave-induced erosion. This continued soil erosion could result in settlement of surface roadways, sidewalks, utilities, and other structures adjacent to the seawall. The City and adjacent property owners would need to continue to maintain and repair sinkholes, potholes, and other settlement effects if the seawall is not replaced. As stated in Section 4.5.4, there is a high-potential liquefaction hazard along the downtown Seattle waterfront. The existing seawall would continue to be susceptible to damage caused by ground shaking and liquefaction during an earthquake.

Under the Loss of Functionality scenario, lateral spreading of the ground would occur westward toward Elliott Bay during a seismic event and could cause damage to structures and utilities east of the seawall. The magnitude of the damage that could occur depends on the foundation soils, the condition of existing structures and utilities, and the magnitude and duration of the ground shaking.

The primary effect of the Collapse of the Seawall scenario on the geology and soils environment would be that the Holocene soil and groundwater conditions along the waterfront would be substantially altered. Without the presence of the seawall, groundwater levels would be more sensitive to tidal fluctuations, which could result in flooding of areaways (below grade basements and walkways) along Western Avenue and First Avenue. The action of water from Elliott Bay on the exposed shoreline could result in erosion and loosening of the existing soils. This could lead to ground loss which would reduce foundation support for adjacent railways, utilities, roadways, and structures. Without a seawall in place, the exposed shoreline would slump until the soil is at its natural angle of repose (likely about 20 to 30 degrees from horizontal). This would affect access from Alaskan Way to and from the adjacent piers.

6.2 BUILD ALTERNATIVES

6.2.1 Operational Effects

The geology- and soils-related operational effects of the build alternatives are similar. Most of the effects are due to non-habitat-related project features. The following sections identify the anticipated operational effects of the build alternatives.

6.2.1.1 Utilities

Numerous utilities lie within the footprint of the proposed EBSP alignment. Utilities would need to be relocated temporarily or permanently, or protected in place prior to and during project construction. Abandoned utilities that are not backfilled could become conduits for water, gases, or contamination, which could affect existing or future facilities. If the abandoned utilities are not backfilled, breaks in the pipes or joints could cause erosion of soil around the pipes, which could result in ground settlement.

6.2.1.2 Groundwater

The water table along the EBSP is located at about seven to 15 feet bgs. Groundwater flow could be altered by the presence of soil improvement (Alternatives A and C), drilled shafts (Alternative B), and the structural facing that would form the new face of the seawall (all build alternatives). The existing seawall restricts the flow of groundwater, but water and soil can seep through gaps in the seawall and the seawall depth is shallower than the proposed new seawall. The new seawall would likely restrict groundwater to a greater extent than the existing partially deteriorated seawall.

Since groundwater flow is generally westward toward Elliott Bay, the presence of the new wall could cause a higher groundwater level to mound up against the east side of the wall and soil improvement zone. Utilities and other subsurface structures that were previously above the water table east of the walls could be partially submerged and/or experience uplift forces due to buoyancy if groundwater mounding occurs. Areaways and basements east of the EBSP alignment could also experience leakage or partial flooding if groundwater mounding occurs.

Based on subsurface conditions and surface topography, preliminary analyses indicate that a maximum groundwater buildup of approximately three to four feet could occur along the waterfront in the vicinity of Madison Street and Marion Street. Elsewhere, potential buildup would generally be less than one foot. Potential buildup of this magnitude (up to four feet) would be within the existing groundwater fluctuations resulting from tides in Elliott Bay that have been observed in shallow monitoring wells along the waterfront. If final groundwater mounding analyses result in the same estimates, then groundwater mounding would not be a concern for this project.

6.2.1.3 Fills

About 10 to 15 feet of new fill may be placed and compacted above the new seawall structure for all build alternatives to bring the area back up to the current street grade after soil improvement, drilled shafts, and/or anchors are installed. Use of unsuitable fill materials (such as those containing debris and organics), fill placement in wet conditions, or improper fill placement and compaction methods could result in excessive settlement of the fill over time, regardless of the subsurface conditions. This would result in damage to facilities that are supported by the fill (e.g., utilities).

Fills are also proposed to be placed under water on the existing submarine slopes west of the seawall to create new habitat for marine life. Several large fills are planned as part of Alternative B near the Seattle Aquarium and Colman Dock Ferry Terminal. Settlement of the subsurface granular soils would occur as the fills are placed. Over the long term, soft fine-grained soils may continue to settle. Where the fills are located adjacent to existing structures, settlement of the structures could occur due to the fill. For pile-

supported structures, as the fill settles, downdrag loads would be imposed on the piles, which could result in settlement of the structures which they support.

6.2.1.4 Liquefaction-Induced Settlement

Soil improvement using jet grout would be performed adjacent to the seawall as part of Alternatives A and C. Deep soil mixing may also be used in some areas where the timber relieving platform is not present (e.g. gravity walls in Zones 1 and 2). The soil improvement is proposed to mitigate liquefaction around the existing relieving platform and to provide a reinforced soil mass that can be anchored to create a retaining structure. Outside the soil improvement zone, the fill soils below the groundwater table would still liquefy during an earthquake. This could result in differential settlement between the soil improvement zone and the surrounding area. Differential settlement could result in damage to and/or loss of function for utilities, transportation features (e.g., roads), and structures.

For Alternative B, drilled shafts would be used to rebuild the new seawall using a BSP system. Since the soil behind the new wall would not be improved, the fill soils below the groundwater table would liquefy during an earthquake. Since the proposed BSP wall system would be founded in dense glacial deposits, differential settlement between the new seawall and adjacent soils could result in damage to utilities and structures.

6.2.1.5 Soil Improvement

The soil improvement would be installed within the existing relieving platform area, which contains many timber piles. As the soil improvement is installed, the presence of the timber piles may result in zones of soil that are not improved. Because the timber piles will not erode under the action of the jet grouting, they would block improvement to the area behind the pile (termed “shadowing”). This could result in a disconnected soil improvement zone that could lead to instability of the rebuilt seawall system of Alternatives A and C. In areas where deep soil mixing is performed, the presence of piles or other subsurface obstructions may prevent penetration of the mixing blades and result in localized areas that are not improved. Deep soil mixing is not planned for areas where the timber relieving platform is present.

6.3 INDIRECT EFFECTS

No indirect effects related to geology and soils are expected as a result of project operation.

6.4 MITIGATION MEASURES

Mitigation measures for the operational effects identified in Section 6.2.1 are based on site and subsurface information and standard design and construction procedures. Geology- and soils-related effects can generally be mitigated through proper construction and maintenance of the project features.

6.4.1 Exploration and Design Approach

The selected EBSP alternative will be designed by experienced engineers based on the existing site conditions, available subsurface information, and design procedures and criteria approved by the City.

To define the subsurface conditions adequately, subsurface explorations should be performed at 100- to 300-foot intervals along the proposed EBSP alignment. Many of these explorations have already been performed for the AWVSRP. This exploration program partially mitigates the potential for unknown subsurface conditions to affect the earth and groundwater during the operation of the project.

6.4.2 Utilities

For utilities that are located within the ground disturbance area of the new seawall, relocation of the utilities would likely be required. In some areas, it may be possible to make minor adjustments to the project alignment to avoid effects on existing utilities. Abandoned utilities should be backfilled with cement grout or other suitable backfill materials so that they cannot become conduits for water or gases.

6.4.3 Groundwater

Groundwater monitoring devices have been installed in the study area to evaluate the groundwater levels over time. For final design, groundwater mounding would be evaluated for the new seawall and adjacent soil improvement zones that may restrict groundwater flow. If the magnitude of the groundwater mounding is less than the current measured natural fluctuation of groundwater in the soil, then no mitigation measures would be necessary. If higher mounding is anticipated, then mitigation measures could consist of providing a path for groundwater through the retaining walls or soil improvement zones. This could be achieved by constructing pipes that connect the groundwater flow between the west and east sides of the wall or zone. A backflow preventer or other device should be installed in the pipes to prevent salt water from flowing through the wall from Elliott Bay.

6.4.4 Fills

Suitable structural fill materials would be used to construct the fills. In general, structural fill materials should consist of sand and gravel with a low percentage (less than 30 percent) of fines (silt and clay). The material would be compacted to the compaction criteria required by the City. In wet weather conditions, cleaner (less than five percent fines) structural fill materials may be required.

For the large tidal habitat fills (primarily associated with Alternative B), lighter weight fill materials could be used to minimize the long term settlement and effects on adjacent structures. The size of the fills (height and extent) could be adjusted to reduce loading on adjacent facilities. The fills could also be moved farther away from adjacent facilities to reduce effects. If the settlement from the fill would cause unacceptable loading of adjacent structures, then foundation retrofits could be performed for the adjacent facilities to obtain suitable resistance to the potential downdrag loads.

6.4.5 Liquefaction-Induced Settlement

Differential settlement would primarily occur due to liquefaction behind the new seawall. Utilities that cross both unimproved and improved ground (Alternatives A and C) or pass through the BSP wall (Alternative B) should be replaced or retrofitted to accommodate differential settlement due to liquefaction if it is critical that they be operational after an earthquake. Transportation facilities located

behind the liquefaction zone may also need to be retrofitted to accommodate differential settlement to mitigate the potential for loss of function.

6.4.6 Soil Improvement

Proper construction techniques and monitoring should be performed to confirm that the desired degree of soil improvement is being achieved. Field tests can be performed before and after the improvement to confirm the degree of soil improvement achieved. Core samples can be obtained at various depths/locations and tested for strength. A jet-grouting test section can be performed prior to production jet grouting to check that the degree of soil improvement is being achieved and that shadowing due to the relieving platform timber piles is not resulting in large unimproved soil areas. If necessary, the spacing of the jet-grouting columns can be reduced to mitigate shadowing and unimproved ground areas.

This page intentionally left blank.

CHAPTER 7. REFERENCES

Adams, J. 1996. Great Earthquakes Recorded by Turbidities Off the Oregon-Washington Coast. Pages 147–158 in: Assessing Earthquake Hazards and Reducing Risk in the Pacific Northwest. U.S. Geological Survey Professional Paper 1560. Edited by A.M. Rogers, T.J. Walsh, W.J. Kockelman, and G.R. Priest.

Atwater, B.F. 1987. Evidence for Great Holocene Earthquakes Along the Outer Coast of Washington State. Science 236:942–944.

Atwater, B.F. 1992. Geologic Evidence for Earthquakes During the Past 2,000 Years Along the Copalis River, Southern Coastal Washington. Journal of Geophysical Research 97:1901–1919.

Atwater, B.F., and E. Hemphill-Haley. 1997. Recurrence Intervals for Great Earthquakes of the Past 3,500 Years at Northeastern Willapa Bay, Washington. U.S. Geological Survey Professional Paper 1576.

Atwater, B.F., and A.L. Moore. 1992. A Tsunami About 1,000 Years Ago in Puget Sound, Washington. Science 236:942–944.

Bakun, W.H., R.A. Haugerud, M.G. Hopper, and R.S. Ludwin. 2002. The December 1872 Washington State Earthquake. Bulletin of the Seismological Society of America 92(8):3239–3258.

Brocher, T.M., T. Parsons, R.J. Blakely, N.I. Christensen, M.A. Fisher, R.E. Wells, and SHIPS Working Group. 2001. Upper Crustal Structure in Puget Lowland, Washington: Results from the 1998 Seismic Hazards Investigation in Puget Sound. Journal of Geophysical Research 106 (B7, July 10, 2001):13541–13564.

Bucknam, R.C., E. Hemphill-Haley, and E.B. Leopold. 1992. Abrupt Uplift Within the Past 1,700 Years of the Southern Puget Sound, Washington. Science 258:1611–1613.

City of Seattle. 2006. Seattle Municipal Code Chapter 25.09: regulations for environmentally critical areas. Available at: http://clerk.ci.seattle.wa.us/~public/code1.htm.

Clarke, S.H. Jr., and G.A. Carver. 1992. Late Holocene Tectonics and Paleoseismicity, Southern Cascadia Subduction Zone. Science 255:188–192.

Darienzo, M.E., and C.D. Peterson. 1990. Investigation of Coastal Neotectonics and Paleoseismicity of the Southern Cascadia Margin as Recorded in Coastal Marsh Systems. Pages 131–139 in: National Earthquake Hazards Reduction Program, Summaries of Technical Reports. Volume XXXI. U.S. Geological Survey Open File Report 90-680. Edited by M.L. Jacobson.

Darienzo, M.E., and C.D. Peterson. 1995. Magnitude and Frequency of Subduction-Zone Earthquakes at Four Estuaries in Northern Oregon. Journal of Coastal Research 10:850–876.

Grant, W.C. 1989. More Evidence from Tidal-Marsh Stratigraphy for Multiple Late Holocene Subduction Earthquakes Along the Northern Oregon Coast. Geological Society of America, Abstracts With Programs 21(4):86.

Jacoby, G.C., P.L. Williams, and B.M. Buckley. 1992. Tree Ring Correlation Between Prehistoric Landslides and Abrupt Tectonic Events in Seattle, Washington. Science 258:1621–1623.

Johnson, S.Y., S.V. Dadisman, J.R. Childs, and W.D. Stanley. 1999. Active Tectonics of the Seattle Fault and Central Puget Sound, Washington – Implications for Earthquake Hazards. Geological Society of America Bulletin 111(7):1042–1053.

Johnson, S.Y., compiler. 2004. Fault Number 570, Seattle Fault Zone, in Quaternary Fault and Fold Database of the United States. U.S. Geological Survey website. Available at: http://earthquakes.usgs.gov/regional/qfaults. Accessed September 21, 2009.

Karlin, R.E., and S.E.B. Arbella. 1992. Paleoearthquakes in the Puget Sound Region Recorded in Sediments from Lake Washington, USA. Science 258:1617–1620.

Lawson, J.S. 1875. Du Wamish Bay (part of) Washington Territory: U.S. Coast Survey, Register no. 1406, scale 1/10,000.

Malone, S.D., and S.S. Bor. 1979. Attenuation Patterns in the Pacific Northwest Based on Intensity Data and Location of the 1872 North Cascades Earthquake. Bulletin of the Seismological Society of America 69:53–546.

Meyers, R.A., D.G. Smith, H.M. Jol, and C.D. Peterson. 1996. Evidence for Eight Great Earthquake-Subsidence Events Detected With Ground-Penetrating Radar, Willapa Barrier, Washington. Geology 24:99–102.

Nelson, A.R., S.Y. Johnson, S.K. Pezzopane, R.E. Wells, H.M. Kelsey, B.L. Sherrod, R.D. Koehler, R.C. Bucknam, W.T. Laprade, J.W. Cox, and C.F. Narwold. 2000. Postglacial and Late Holocene Earthquakes on the Toe Jam Strand of the Seattle Fault, Bainbridge Island, Washington. Poster, GSA Cordilleran Section Meeting, Vancouver, Canada.

Nelson, A.R., I. Shennan, and A.J. Long. 1996. Identifying Coseismic Subsidence in Tidal-Wetland Stratigraphic Sequences at the Cascadia Subduction Zone of Western North America. Journal of Geophysical Research 101:6115–6135.

PBPower/BJT Associates. 2003. Analysis of Existing Alaskan Way Seawall. Report prepared by PBPower/BJT Associates for WSDOT and City of Seattle, Seattle, Washington. January 2003.

Peterson, C.D., and M.E. Darienzo. 1996. Discrimination of Climatic, Oceanic, and Tectonic Mechanisms of Cyclic Marsh Burial, Alsea Bay, Oregon. Pages 115–146 in: Assessing Earthquake Hazards and Reducing Risk in the Pacific Northwest. U.S. Geological Survey Professional Paper 1560. Edited by A.M. Rogers, T.J. Walsh, W.J. Kockelman, and G.R. Priest.

Pratt, T.L., S.Y. Johnson, C.J. Potter, et al.. 1997. Seismic-Reflection Images Beneath Puget Sound, Western Washington State. Journal of Geophysical Research 102:469–490.

Rogers, A.M., Walsh, T.J., Kockelman, W.J., and Priest, G.R. 1996. Earthquake hazards in the Pacific Northwest - an overview, in Rogers, A. M.; Walsh, T. J.; Kockelman, W. J.; and Priest, G. R., Assessing earthquake hazards and reducing risk in the Pacific Northwest: U.S. Geological Survey Professional Paper P 1560, v. 1, p. 1-70.

Satake, K., K. Shimazaki, Y. Tsuji, and K. Ueda. 1996. Time and Size of a Giant Earthquake in Cascadia Inferred from Japanese Tsunami Records of January 1700. Nature 378(18):246–249.

Schuster, R.L., R.L. Laiger, and P.T. Pringle. 1992. Prehistoric Rock Avalanches in the Olympic Mountains, Washington. Science 258:1620–1621.

SDOT (Seattle Department of Transportation). 2010. Elliott Bay Seawall Project Geology and Soils Methodology Technical Memorandum. Submitted by Tetra Tech, Inc. Prepared by Shannon & Wilson. Seattle, Washington. December.

SDOT. 2012a. Elliott Bay Seawall Project Noise and Vibration Discipline Report. Submitted by Tetra Tech, Inc. Prepared by LPES.

SDOT. 2012b. Elliott Bay Seawall Project Water Resources Discipline Report. Prepared by Herrera Environmental Consultants. Seattle, Washington.

SDOT. 2012c. Elliott Bay Seawall Project Fish, Wildlife, and Vegetation Discipline Report. Prepared by Tetra Tech, Inc. Seattle, Washington.

SDOT. 2012d. Elliott Bay Seawall Project Contaminated Materials Discipline Report. Submitted by Tetra Tech, Inc. Prepared by Floyd|Snider. Seattle, Washington.

Shannon & Wilson (Shannon & Wilson, Inc.). 2002. Geotechnical and Environmental Data Report, SR 99: Alaskan Way Viaduct Project, Seattle, Washington. Report prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-09490, for Washington State Department of Transportation and City of Seattle, Seattle, Washington. August. 5 volumes.

Shannon & Wilson. 2003. Geotechnical Analysis for Alaskan Way Seawall, SR 99: Alaskan Way Viaduct Project, Seattle, Washington. Report prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-09490-550, for Washington State Department of Transportation and City of Seattle, Seattle, Washington. January.

Shannon & Wilson. 2004. Seismic Ground Motion Study Report, SR-99: Alaskan Way Viaduct Project, Seattle, Washington. Report prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-09490-929. 2 volumes. Prepared for Washington State Department of Transportation, Federal Highway Administration, and City of Seattle, Seattle, Washington. October.

Shannon & Wilson. 2005. Geotechnical and Environmental Data Report, SR 99: Alaskan Way Viaduct Project, Seattle, Washington. Report prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-09490-710. 7 volumes. Prepared for Washington State Department of Transportation and City of Seattle, Seattle, Washington. August.

Shannon & Wilson. 2006. Utility Geoprobe Report, Geotechnical and Environmental Data, SR-99: Alaskan Way Viaduct and Seawall Replacement Project, Seattle, Washington. Report prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-20447-010. Prepared for Washington State Department of Transportation and City of Seattle, Seattle, Washington. April.

Shannon & Wilson. 2007a. Geotechnical and Environmental Data Report, Electrical Utility Explorations, SR-99: Alaskan Way Viaduct and Seawall Replacement Project. Report prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-20447-012, for WSDOT, Seattle, Washington. April.

Shannon & Wilson. 2007b. Geotechnical and Environmental Data and Dewatering Feasibility Report, Central Section, SR-99: Alaskan Way Viaduct and Seawall Replacement Project. 2 volumes. Report prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-20608-004. Prepared for Washington State Department of Transportation, Seattle, Washington. April.

Shannon & Wilson. 2007c. Geotechnical and Environmental Data Report, Phase 1 Archeological Explorations, SR 99: Alaskan Way Viaduct and Seawall Replacement Project, Seattle, Washington. Report prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-20710-011, for WSDOT and City of Seattle, Seattle, Washington. October.

Shannon & Wilson. 2007d. Geotechnical and Environmental Data Report, Utilidor Explorations, SR 99: Alaskan Way Viaduct and Seawall Replacement Program, Seattle, Washington. Report prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-20501-070. Prepared for WSDOT and City of Seattle, Seattle, Washington. December.

Shannon & Wilson. 2009. Seismic Ground Motion Study Supplement, 1,000-Year Ground Motion, SR 99: Alaskan Way Viaduct and Seawall Replacement Program, Seattle, Washington. Report prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-20840-044. Prepared for WSDOT and City of Seattle, Seattle, Washington. May.

Shannon & Wilson. 2010a. Geotechnical and Environmental Data Report, SR 99 Bored Tunnel Alternative Design-Build Project, Alaskan Way Viaduct and Seawall Replacement Program, Seattle, Washington. 2 volumes. Report prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-20840-075. Prepared for Washington State Department of Transportation, Seattle, Washington. May.

Shannon & Wilson. 2010b. Interim Letter CT-6, Geological Characterization, SR 99 Bored Tunnel Alternative Design-Build Project, Alaskan Way Viaduct and Seawall Replacement Program, Seattle, Washington. Report prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-20840-002. Prepared for Washington State Department of Transportation, Seattle, Washington. June.

Shannon & Wilson. 2011. Elliott Bay Seawall Project Geotechnical Data Summary Report. Prepared by Shannon & Wilson, Inc., Seattle, Washington, 21-1-21374-262. Prepared for City of Seattle, Seattle, Washington. January.

Shennan, I., A.J. Long, M.M. Rutherford, F.M. Green, J.E. Innes, J.M. Lloyd, Y. Zong, and K.J. Walker. 1996. Tidal Marsh Stratigraphy, Sea-level Change and Large Earthquakes, 1: A 5,000 Year Record in Washington, USA. Quaternary Science Reviews 15:1023–1059.

USACE (United States Army Corps of Engineers). 1995. Engineering and design: design of coastal revetments, seawalls, and bulkheads: U.S. Army Corps of Engineers Engineer Manual 1110-2-1614, 1 v. Available at: http://140.194.76.129/publications/eng-manuals/.

USACE. 2008. Coastal engineering manual: U.S. Army Corps of Engineers Engineer Manual 1110-2-1100, 5 v. Available at: http://140.194.76.129/publications/eng-manuals/.

Walsh, T.J., V.V. Titov, A.J. Venturato, O. Mofjeld, and F.I. Gonzalez. 2003. Tsunami Hazard Map of the Elliott Bay Area, Seattle, Washington: Modeled Tsunami Inundation from a Seattle Fault Earthquake. Scale 1:50,000. Washington State Division of Geology and Earth Resources Open File Report 2003-14.

WSDOT (Washington State Department of Transportation). 2010. Environmental Procedures Manual. M 31-11. Olympia, Washington. October.

WSDOT. 2011. Geotechnical Design Manual. M 46-03. Olympia, Washington. April.

Wells, R.E., C.S. Weaver, and R.J. Blakeley. 1998. Fore-Arc Migration in Cascadia and Its Neotectonic Significance. Geology 26(8):759–762.

Wilson, B.W., and A.F. Torum. 1972. Effects of the Tsunamis – An Engineering Study. 1972. Pages 361–523 in: The Great Alaska Earthquake of 1964: Oceanography and Coastal Engineering. National Research Council Committee on the Alaska Earthquake.

Yount, J.C., G.R. Dembroff, and G.M. Barats. 1985. Map Showing Depth to Bedrock in the Seattle 30' x 60' Quadrangle, Washington. Scale 1:100,000. U.S. Geological Survey Miscellaneous Field Studies Map MF-1692.