MEMORANDUM

October 8, 2015

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

FROM: Monique Moyer
Executive Director

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

DIRECTOR'S RECOMMEDATION: Information Only - No Action Required

---

Executive Summary

This is an informational item on the progress of the Earthquake Vulnerability Study of the Northern Waterfront Seawall, a component of the overall effort to improve resiliency of the waterfront by quantifying risks, prioritizing actions, and executing improvement projects. The Northern Waterfront Seawall ("Seawall") stabilizes four miles of historic waterfront stretching continuously from Fisherman's Wharf to Mission Creek[1]. The Earthquake Study[2] is a high level engineering study that will assess earthquake vulnerability, predict damage and economic impacts from a range of earthquake events, develop conceptual mitigation alternatives, and make recommendations for further action and/or study. The information is vital for the Waterfront Land Use Plan Update[3] and to inform Port and City efforts to respond to climate change and sea level rise.

Significant progress has been made to date including a comprehensive review of existing information, developing a 3-D representation of geotechnical conditions, developing structural models of select bulkhead walls and wharves, generating site specific representations of earthquake ground shaking hazards, and gathering economic information on assets within the zone of influence. Initial results are being generated and will then be peer reviewed. Draft of results and recommendations are expected to be released by the end of this year.

[1] September 24, 2013 Port Commission presentation and staff report:
[2] July 7, 2014, and October 28, 2014 Port Commission presentations and staff reports:
[3] September 22, 2015 Port Commission presentation and staff report:

Strategic Objective

This effort complies with the Port's strategic objective to lead the City's efforts to address infrastructure and seawall resiliency to earthquake, sea level rise and natural hazards. As such, the Port is developing and implementing a seawall plan that will maintain viability of Port's operations, increase protection of the Port's and City's assets, and enhance life safety in the face of degradation, flooding, earthquakes, climate change, and security hazards.

Background

The Northern Waterfront Seawall is one of San Francisco's most important and historic pieces of infrastructure. Constructed over 40 years beginning in 1878, the seawall transformed an irregular tidal marsh shoreline into a curving maritime friendly waterfront that was instrumental to the economic development of the City and remains so today. Stretching four miles from Fisherman's Wharf in the north to Mission Creek in the south, the seawall also made possible the creation of hundreds of acres of what now is some of the most valuable land in the world. Today, the seawall anchors the northern waterfront, silently providing support to historic bulkhead wharves and buildings, protecting the shoreline against tides and storms, and holding back the filled lands containing vital Port and City infrastructure including The Embarcadero Promenade and Roadway, MUNI Light Rail lines, and key utilities serving large areas of the City including Treasure Island. Every day thousands of people enter and leave the City by crossing over the seawall to access ferries and cruise ships, or by traveling under the seawall on BART trains. Thousands of visitors and residents walk, run, bike, or skate over the top of the seawall on their way to work, to a ballgame, to shop, to dine, or to experience the serene beauty of the Bay. It's easy to let yourself believe that the seawall has always been there and always will be.

In the 1850s, when San Francisco began transforming into a booming City, the northern waterfront along the Bay looked nothing like it does today. The typical condition of the waterfront was that of a broad tidal marsh similar to what one can see today at Richardson Bay north of Sausalito. Downtown was known as Yerba Buena Cove, a shallow cove extending to the vicinity of the now iconic Transamerica Pyramid. The City street grid extended through this area and water lots were sold to private interests who began filling them haphazardly and constructing timber wharves to get to deeper water where ships could berth. Order was brought to this chaotic scene by the Board of State Harbor Commissioners, which took control of the tidal lands in 1863, and began building a seawall in 1867 located at the edge of the mapped street grid. This zig zag wall was abandoned less than two years later when the corners began filling with silt. In 1873, Thomas J. Arnold proposed a curved seawall that would work with tidal currents to limit silting. It was located several hundred feet beyond the City street grid where construction would not impact the functioning of the City. This location allowed creation of a wide landside thoroughfare by filling the land behind the wall. In 1877 legislation was enacted to establish a new waterfront line and commence engineering plans for a seawall to run from Jones Street on the north to China Basin in the south, a distance of approximately 4 miles. Behind this seawall, filling created hundreds of acres of new land over the former tidal areas.

The seawall was created by dredging a trench through the mud, approximately 100 feet wide and 20 feet deep, filling with rock and rubble to create a pyramid shaped dike 40 feet tall, capping with a short timber pile bulkhead wall and timber wharf extending 50 to 60 feet out to deeper water beyond the toe of the dike, and filling the area landside to create a minimum 200 foot wide thoroughfare. Additional lands behind the wall were filled over time, often with rubble, debris, and dredged sand. The seawall was divided into eighteen sections of approximately 1,000-foot lengths to be constructed as funds became available. Construction commenced in September 1878 with section A in the north and by 1905, a total of 12 sections were completed largely consistent with the original design (sections A, 1, 2, 3, 4, 5, 6, 7, 8b, B, 8a, and 13). The remaining sections south of the Ferry Building were completed between 1909 and 1915 using a modified design where the rock dike was topped with a concrete bulkhead wall and wharf supported on concrete piles (sections 8, 9, 10, 11, 11a, and 12). As the seawall and bulkheads were completed, finger piers were constructed extending from the bulkhead wharves. The piers were originally of timber construction until 1909 at which point reinforced concrete and steel was used for new piers and as well as to replace all of the original timber piers, bulkhead wharves, and bulkhead walls apart from the Ferry Building. Today, there are more than 40 different combinations of rock dike, bulkhead wall, and bulkhead wharf that constitute the seawall.

Earthquake Vulnerability Study Scope and Objectives

Filled lands and waterfront structures throughout the world have experienced considerable damage in earthquakes. Hazards include liquefiable soils, soft soils, lateral spreading and settlement, and amplified ground shaking. Both the 1906 San Francisco and 1989 Loma Prieta earthquakes caused damage along the waterfront including permanent movement of the filled lands adjacent to the seawall. Of today's remaining structures, only the Ferry Building and slightly over one half of the rock dike experienced the 1906 earthquake. In 1992, an engineering consultant working for the San Francisco Department of Public Works studied the waterfront to assess performance of the Auxiliary Water Supply System and developed maps showing the potential of up to 2 feet of earthquake induced lateral spreading along portions of the waterfront. Recent projects including the Pier 43 Bay Trail Link and the Brannan Street Wharf have noted the potential for significant lateral spreading and movement of the seawall necessitating special detailing of the piles to accommodate the movement. In 2014, the City of San Francisco Lifelines Council released a report outlining a plan for improving earthquake resilience and included the seawall as a vital piece of infrastructure.

Given the substantial effort required to perform a detailed analysis of four miles of historic waterfront constructed and altered over 135 years, the approach chosen was to develop an advanced screening level methodology based on the wealth of available existing information. The scope of the Earthquake Vulnerability Study includes:

1. Study of Existing Information: Detailed review of existing record drawings, geotechnical reports and borings, condition surveys, earthquake damage reports, and other engineering reports.

2. Zone of Influence: Establishment of the likely zone of influence of the seawall upon bayside structures and the upland areas of filled land for purposes of predicting damage associated with seawall performance.
3. Subsurface Mapping: Development of detailed geotechnical maps showing fill thickness, bay mud thickness, and depth to bedrock, and other important information for predicting earthquake behavior of the waterfront.
4. Subset Study: Selection of eight (8) representative seawall sections for detailed engineering analysis and use of engineering judgment to extrapolate results to other areas.
5. Site Specific Earthquake Hazard : Engineering analysis to generate site specific earthquake ground shaking hazards using the current best estimate probabilistic fault rupture scenarios.
6. Lateral Spreading: Engineering analysis to quantify lateral spreading and settlement and depicting with maps illustrating the variation within the zone of influence for various earthquake hazard levels.
7. Bulkhead Wall Performance: Engineering analysis to quantify the stability of selected bulkhead walls for various earthquake hazard levels.
8. Bulkhead Wharf Performance: Engineering analysis to quantify performance of selected bulkhead wharves for life safety and collapse under various earthquake hazard levels. Bulkhead buildings are not analyzed, but considered in the analysis and identified in the results of the supporting wharves.
9. Utility Mapping and Performance: Mapping of utilities within the seawall zone of influence and seeking assistance and cooperation from utility agencies to assess impacts due to lateral spreading and settlement. This is an important consideration in overall economic impacts and prioritization of mitigations.
10. Flood Hazard: Engineering analysis to quantify the extent of post-earthquake flood hazard associated with seawall damage and settlement of land behind the seawall.
11. Economic Impact: High level economic analysis to quantify the economic impacts associated with predicted seawall performance.
12. Possible Mitigations: Engineering design to develop a range of conceptual level mitigation and improvement measures, quantify costs, benefits and impacts.
13. Prioritization: Development of a ranking scheme and generation of recommendations for prioritizing mitigation measures and/or additional detailed study necessary to inform policy and priorities. Include life safety, economic impacts to Port and City, post disaster recovery role, benefit/cost.

Initial Findings

The expected zone of influence of the seawall is shown in Exhibit A. The zone of influence includes the bulkhead buildings and extends landward several blocks beyond The Embarcadero roadway.

Geotechnical maps have been completed and are attached as Exhibit B. The maps show a significant variation in young bay mud thickness and bedrock depths along the waterfront, both of which are key variables impacting earthquake shaking levels and seawall response.

Representative seawall sections have been selected and detailed ground and structure profiles generated, see Exhibit C. All sections indicate the rock fill dike sits upon poor soils, usually young bay mud, but in some cases sand. The artificial fill forming the land behind the seawall is typically liquefiable at low levels of earthquake ground shaking. The young bay mud underlying the rock dike is prone to degradation and strength loss during earthquake ground shaking and may contribute significantly to lateral spreading. The potential spreading will be quantified by the detailed slope stability analysis of the selected sections and engineering judgement used to extend the results throughout the zone of influence.

Earthquake ground shaking predictions have been generated at select return periods from 200 years to what is considered a Maximum Considered Earthquake. A return period is an estimate of the average frequency (in years) that a site will sustain ground-shaking of a given intensity or greater. It is the inverse of the annual probability. For example, for a 100 year return period, there would be a 1% probability of this event being exceeded in any given year. Observations from prior earthquakes are being used to calibrate models and justify predictions of behavior and damage. Below are typical observations from prior earthquakes. A common seismograph recording of both earthquakes is included in Exhibit D as a comparison.

1906 San Francisco Earthquake. The California earthquake of April 18, 1906 occurred at 5:12 a.m. with an inferred epicenter approximately 2 miles off the coast of San Francisco and resulted in a 296-mile long rupture along the San Andreas fault from San Juan Bautista in the south to Cape Mendocino in the north. It is estimated to have had a moment magnitude of 7.8. The duration of shaking in San Francisco was about one minute.

In the districts along the waterfront in the areas of “filled” or “made” land, the damage was severe where the pavements were buckled, arched and fissured, brick and frame houses were damaged extensively or destroyed, portions of streets were moved laterally several feet, sewer and water mains were broken, and streetcar tracks were bent into wavelike forms (Lawson, 1908). Near the Ferry Building, the Lawson report[4] indicates that the streets sank as much as 2 feet, probably more, and that the surface of the ground was deformed into waves and small open fissures were formed, especially close to the wharves. Buildings along the water side generally slumped seaward, in some cases as much as 2 feet. The report goes on to say that the damage was greatest close to the water’s edge, growing less as the solid land was approached, gradually at first, then more rapidly.

[4] Lawson, A.C., chairman, 1908, The California Earthquake of April 18, 1906: Report of the State Earthquake Investigation Commission: Carnegie Institution of Washington Publication 87, 2 vols.

1989 Loma Prieta Earthquake. The Loma Prieta Earthquake occurred on October 17, 1989 at 5:04 pm in which San Francisco experienced the highest intensity earthquake shaking since the 1906 Earthquake. It was a much smaller seismic event than the 1906 Earthquake though, as the moment magnitude of the Loma Prieta Earthquake was approximately 6.9 and the epicenter was 60 miles south-southeast of San Francisco in the Santa Cruz Mountains. The earthquake occurred over a 30-mile long segment of the San Andreas fault, and coincided with the southernmost segment of the 1906 Earthquake rupture surface. The duration of the shaking was approximately 8 to 15 seconds.

Despite the relatively low levels of shaking and short duration, soil liquefaction affected sites in the City and County of San Francisco. Most of the reported damage occurred in the Marina District, though lesser damage was noted at Pier 45, Piers 27 and 29, along The Embarcadero between Fisherman's Wharf to the area north of the Bay Bridge, and at the Ferry Plaza[5]. Effects of soil liquefaction included settlement, pavement cracking and sand boils. The SEAOC report indicates that the seawall along The Embarcadero to the Bay Bridge was damaged throughout much of its length. In several places, the wall experienced horizontal cracking or opening of horizontal construction joints on the exposed face. The report also indicates that the soil at the base of the seawall on the bayward side settled and spread laterally due to liquefaction and the retained soils liquefied leading to settlement of paving and other improvements. The USGS report (Holzer, 1998) also reports evidence of liquefaction and lateral spread along the waterfront with settlement of up to 3 to 8 inches in some areas next to the piers as well as in the financial district.

LBE Role/Opportunities

This study is being performed by a team of engineering consultants led by a joint venture of the firms GHD and Geotechnical Consultants, Inc. (GTC). GTC is an LBE firm and is responsible for 40% of the prime consultant's work scope. The team includes the following LBE certified firms as subconsultants: Land Economics Consultants, LLC (LBE-OBE); Ansari Structural Engineers (LBE-MBE); Saylor Consulting Group (LBE-WBE); Rollo & Ridley (LBE-OBE); and Telamon Engineering (LBE-WBE). GHD/GTC JV is on target to meet or exceed the 25% LBE goal set by the Contract Monitoring Division for this contract.

Climate Action

This study will adhere to the latest guidelines and science related to climate change and sea level rise. Proposed retrofit alternatives will fully consider sea level rise and other climate change impacts in the Cost/Benefit analysis.

[5] Seed et al., 1990; Structural Engineers Association Of California, 1991

Funding

The study is funded by Port capital allocated in the FY 2014-15 Capital Budget. Additional funding to advance the seawall program is allocated in the FY 2015-16 Capital Budget.

Next Steps

In the coming weeks, draft results will be reviewed by Port staff and members of the Seawall Technical Advisory Committee (a committee of representatives from City Agencies). After initial review, information will be peer reviewed by a separate engineering consultant team using the As-Needed Engineering Contract. Thereafter, an updated draft of analysis results and recommendations will be reviewed. Port staff expects to present results and recommendations to the Port Commission in early 2016.

Prepared by: Steven Reel, Project Manager, Engineering

For: Eunejune Kim, Chief Harbor Engineer

Exhibits:

A. Seawall Zone of Influence
B. Geotechnical Maps
C. Seawall Sections
D. Seismograph of 1906 and 1989 Earthquakes