SAN FRANCISCO WATERFRONT COASTAL FLOOD STUDY, CA

APPENDIX B.3 – EARTHQUAKE LIFE SAFETY RISK [DRAFT]

JANUARY 2024

USACE TULSA DISTRICT | THE PORT OF SAN FRANCISCO

US Army Corps of Engineers

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Acronyms and Abbreviations

Acronym	Definition
FWOP	Future Without Project
FWP	Future With Project
HAZUS	Hazards United States
MHRA	multi-hazard risk assessment
PDT	Project Delivery Team
TNBP	Total Net Benefits Plan

B.3-1 General Methodology

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

B.3-2 Future Without Project Condition

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

An earthquake can happen at any time, and it is expected that one or more earthquake events will occur during the 100-year period of analysis, therefore it is important to consider the consequence of these events and understand how investment in a coastal storm risk reduction system will alter these consequences when designed to meet the requirements of ER 1110-2-1806 *Earthquake Design and Evaluation for Civil Works Projects* (USACE 2016). Performance of the existing waterfront has been qualitatively

scored for two metrics related to earthquake performance (1) life-safety and (2) resilience.

B.3-2.1 Life-Safety

The life-safety score is a semi-quantitative metric based upon the results of the MHRA, whereby the approximate number of casualties along the Embarcadero were estimated using a customized Hazards United States (HAZUS) approach to represent the seismic hazard to marine structures and associated superstructures. The MHRA results indicate a substantial number of casualties within the bulkhead wharf zone, and people trapped over water when landside portion of the facilities are damaged by a 225-year earthquake, therefore the FWOP condition is assumed to result in a poor outcome, scoring a qualitative rating of 1. Approximate number of casualties and people trapped over water for the FWOP and FWP alternatives are provided in Table B.3-1. Table B.3-2 provides the score assigned to the FWOP and FWP alternatives with 2040 and 2090 actions constructed.

B.3-2.2 Resilience

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

B.3-3 Future With Project Condition

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

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

B.3-3.1 Life-Safety

The life-safety score is again semi-quantitative metric where the difference between casualties in the FWOP condition are compared to the expected casualties in the FWP condition. It is assumed that full replacement of seismically vulnerable wharf substructures, which serve as part of the existing coastal defense system, will have a positive outcome. Alternatives E, F, and G all include ground improvement and replace the existing structures with new pile supported structures or solid fill, therefore result in substantial reductions to the FWOP life-safety hazard. Alternative D also includes ground improvement and replaces the existing structures, but does not construct the replacement until halfway through the study phase therefore only shows an improvement at 2090. The ground improvement included with Alternative C will substantially reduce the lateral spreading and liquefaction hazard acting upon the vulnerable wharf structures but does not fully eliminate the life-safety risk therefore this alternative is assumed to have a neutral outcome (score 3).

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

Embarcadero Zone Earthquake Safety, 225-year Earthquake (Draft)			
Alternative	**Occupancy over Water**	**Bulkhead Zone Casualties**	**Trapped Over Water**
A (FWOP) and B	8810	295	608
C and D	810	224	0
E, F, G	8810	161	0

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

Alternative	Qualitative Metric		Notes
	2040 Actions	2090 Actions	
A – No Action (FWOP)	1 – poor outcome	1 – poor outcome	
B – Non-Structural	1 – poor outcome	1 – poor outcome	No investment in vulnerable structures that reduce earthquake life-safety risk
C – Low Curve	3 – neutral outcome	3 – neutral outcome	Reduce lateral spreading risk with ground improvement, lowered demand on wharf structure

Alternative	Qualitative Metric		Notes
	2040 Actions	2090 Actions	
D – Low Curve Adaptable	3 – neutral outcome	5 – positive outcome	Reduce lateral spread risk with ground improvement, same score as C at 2040; but 2090 investment in vulnerable structures, substantially reduces earthquake life-safety risk.
E – Shoreline	5 – positive outcome	5 – positive outcome	Reduces lateral spread risk with ground improvement and replaces vulnerable wharves with new structures
F – Bayward w/Gates	5 – positive outcome	5 – positive outcome	Replaces vulnerable wharves with solid ground
G - Retreat	5 – positive outcome	5 – positive outcome	Replaces vulnerable wharves with new structures

To roll up the earthquake life-safety metrics for the economics key driver matrices, the score from the 2040 action will be used to best captures the alternative performance related to the initial action.

B.3-3.2 Resilience

The resilience score is again a semi-quantitative metric where the difference between damage and disruption in the FWOP condition is compared to the expected damage and disruption for each of the FWP alternatives. Alternatives that replace vulnerable structures with new facilities are expected to substantially reduce damage and disruption following an earthquake, thereby score higher from the lens of earthquake resilience. As can be seen in Table B.3-3, when bulkhead wharf structures are fully or partially replaced by engineered fill, the expected earthquake damage is very minor, while the pile supported wharf has a range of minor to very minor damage, significantly reduced from the FWOP condition. Similarly, when ground improvements are employed below major transportation corridors such as the Embarcadero, the roadway damages are expected to be reduced as seen in Table B.3-4, thus providing a post-event emergency response corridor as another measure of added earthquake resilience. These metrics focus heavily on the conditions in the Northern Waterfront (Reaches 1 and 2) and are not expected to differ substantially in the Southern Waterfront, except for the disaster response functions fulfilled at deep draft vessel berths such as Pier 94/96 or replicated at Pier 80. The maritime metrics described in *Sub-Appendix E.2: Other Social Effects Report*, quantify this maritime function, therefore this qualitative scoring has not been modified to consider differences between alternatives in the Southern Waterfront.

Table B.3-5 includes the scores assigned to the FWOP and FWP alternatives with both the 2040 and 2090 actions constructed.

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

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

Table B.3-4: Embarcadero Roadway Damage Rating

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

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

Alternative	Qualitative Metric		Notes
	2040 Actions	2090 Actions	
A – No Action (FWOP)	1 – poor outcome	1 – poor outcome	
B – Non-Structural	1 – poor outcome	1 – poor outcome	No investment in vulnerable structures that reduces earthquake resilience
C – Low Curve	3 – neutral outcome	3 – neutral outcome	No investment in vulnerable structures.
D – Low Curve Adaptable	3 – neutral outcome	5 – positive outcome	2090 investment in vulnerable structures, does not mitigate near term earthquake life-safety risk.
E – Shoreline	5 – positive outcome	5 – positive outcome	Replaces vulnerable wharves with new structures, but does not address full roadway risk
F – Bayward w/Gates	5 – positive outcome	5 – positive outcome	Replaces vulnerable wharves with solid ground, but does not address full roadway risk
G - Retreat	5 – positive outcome	5 – positive outcome	Replaces vulnerable wharves with new structures and addresses full roadway risk

To roll up the earthquake resilience metrics for the economic key driver matrices, the score from the 2040 action will be used since it best captures the alternative performance related to the initial action.

B.3-4 Future Without Project and Future With Project Alternative Maps

The impact of seismic ground improvement in all structural alternatives and wharf replacement in Alternatives E, F, G and D (2090) is demonstrated with a series of color-coded maps, which have been included as Attachment B.3-1. The color-coded maps depict the expected level of damage that would occur during a 225-year return period earthquake, similar to the 1906 earthquake that shaped San Francisco. Using professional judgment individual polygons for wharves, piers and roadway segments are modified to reflect the expected performance of that asset when the first actions Alternative E, F or G is built to U.S. Army Corps of Engineers seismic performance standards.

B.3-5 References

U.S. Army Corps of Engineers (USACE). 2016. ER 1110-2-1806 *Earthquake Design and Evaluation for Civil Works Projects*. May 31.

Attachment B.3-1

Future Without Project and Future With Project (Alternatives E, F, and G First Action)

225-year Earthquake Damage Maps