Appendix I3

Sea Level Rise and Wave Uprush Assessment

NOBLE
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PROJECT MEMORANDUM

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To:	CDM Smith, Dorothy Meyer, Project Manager
From:	Chia-Chi Lu
Date:	August 31, 2015
RE:	Sea Level Rise and Wave Uprush Assessment
Cc:	Jon Moore

In accordance with our professional services agreement, this memorandum addresses a portion of the environmental impact assessment. Specifically, this memorandum provides information related to regional coastal processes, the projected future sea level rise, potential wave uprush and tsunami-induced inundation within the project areas including the development in King Harbor and at Municipal Pier.

1.0 Water Level

Variations in water level along the Southern California shoreline are due principally to astronomical tides, storm surge driven by spatial variation in barometric pressure and wind, and wave setup occurring where waves break and wave energy is dissipated. Tides within the Redondo Beach coastal water area are of the mixed semi-diurnal type. Typically, a lunar day (about 24 hours) consists of two high and two low tides, each of different magnitudes. The lower-low normally follows the higher-high by seven to eight hours; the next higher-high (after the lower-high and higher-low waters) follows in about 17 hours. Tide characteristics along the coast of Redondo Beach are referenced to the Santa Monica tide gauge as shown in **Table 1**. It should be noted that the highest water level of +8.5 feet, MLLW recorded at Santa Monica Pier on November 30, 1982 includes storm surge and wave setup.

Table 1. Tidal Characteristics at Santa Monica Pier

Datum or Level	Santa Monica Pier
Maximum Measured Water Level	8.5
Mean Higher High Water (MHHW)	5.4
Mean High Water (MHW)	4.7
Mean Tide Level (MTL)	2.8
Mean Sea Level (MSL)	2.8
North America Vertical Datum–1988 (NAVD)	0.2
Mean Low Water (MLW)	0.9
Mean Lower Low Water (MLLW)	0.0
Minimum Measured Water Level	-2.9

Notes: The maximum and minimum water levels measured at Santa Monica Pier were on Nov. 30, 1982 and Dec. 17, 1933

1.1 Sea Level Rise Projection

Several notable studies were prepared to predict the increasing rates of future sea level rise (SLR) due to greenhouse gas emission (NRC, 1987, IPCC, 2007 & 2008). The trend of warmer global temperatures will accelerate melting of glaciers, which will consequently release more water into the oceans. In addition, warmer ocean temperatures cause the water to expand, further raising the sea level.

The California Sea-Level Rise Task Force has provided interim guidance on planning for future sea-level rise through the year 2100. Their study was recently updated by the Committee on Sea Level Rise in California, Oregon, and Washington. The recommendations are largely based upon prior research published by Vermeer and Rahmstorf (2009) who forecast future sea level rise by modeling six different global warming scenario groups previously established by the Intergovernmental Panel on Climate Change (IPCC). Their predictions rely upon statistical models that use semi-empirical relationships between past and predicted future global temperature changes. Continuous researches and studies (NRC, 2012 and IPCC, 2014) have provided updated projections of future global sea level rise.

Other summaries of future sea-level rise scenarios have been summarized by the U.S. Army Corps of Engineers. The Corps of Engineers report (USACE, 2013) shows the wide uncertainty in forecasting the future because of issues related to accurately predicting climate change and how it will impact sea level rise over this century. The future sea level rise recommended by the California Ocean Protection Council (COPC, 2013) that was updated in 2013 presents a range of the potential sea level rise as listed in **Table 2**. Using 2015 as the project base year, the projected sea level rises in the 25th, 50th and 75th project years are deduced and shown in **Figure 1** and **Table 3**, respectively. The figure and table also present the mid-level sea level rise by averaging the low and high estimates.

2.0 Wave Climatology

Wave climate in southern California is strongly influence by not only the El Nino-Southern Oscillation (ENSO), which tends to vary on a timescale of 2 to 7 years, but also the Pacific Decadal Oscillation (PDO) that shifts phases on an inter-decadal time scale of 20 to 30 years. In addition, the global warming trend not only results in the acceleration of sea level rise but also may intensify individual storm events. During the PDO warm period as well as the El Nino seasons, impinging storm waves are higher, have a longer wave period and approach from a more westerly direction that increases the storm wave attack potential to the Los Angeles coast (Adam, et al., 2007).

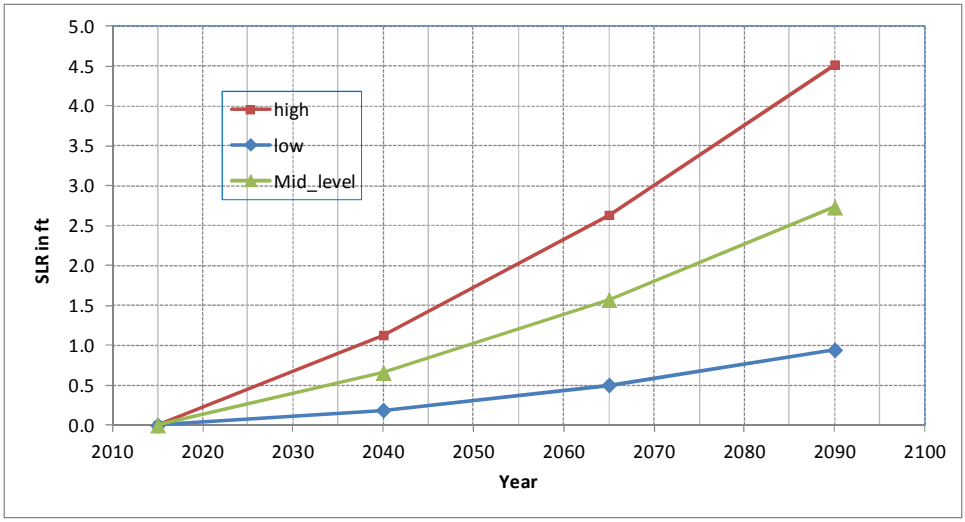


Figure1. Future Sea Level Rise Projection from Year 2015

Table 2. Sea-Level Rise Projection from Year 2000

Time Period	South of Cape Mendocino	
	Low Estimate	High Estimate
2000 to 2030	0.13 feet	0.98 feet
2000 to 2050	0.39 feet	2.00 feet
2000 to 2100	1.38 feet	5.48 feet

Table 3. Derived Sea level Rise at Individual Project Years

Year	Project Year	SLR from 2000		SLR from 2015*		Mid level*
		Low	High	Low	High	Ave.
2015	0	0.04	0.43	0.0	0.0	0.0
2040	25	0.23	1.56	0.2	1.1	0.7
2065	50	0.55	3.07	0.5	2.6	1.6
2090	75	0.99	4.95	0.9	4.5	2.7

**: SLR values rounded out to the first digit*

2.1 Storm Wave Patterns

Wind waves and swells in the Southern California Bight are produced by the following meteorological patterns: i) extratropical cyclone of the northern hemisphere; ii) northwest winds in the outer coastal waters; iii) west to northwest local sea; iv) pre-frontal local sea; v) tropical storm swell; and iv) extratropical cyclone of the southern hemisphere.

Extratropical Cyclone of the Northern Hemisphere

Low pressure centers which develop along the polar front are the source of the predominant wave action along the entire California coast during the winter season. Storm swell is typically generated at some distance from the Los Angeles County coastline in the North Pacific. Most commonly these storms will traverse the mid-Pacific before turning northeastward toward the Gulf of Alaska with swell decaying on the average of 1,500 miles to the coast of Southern California. However, under some meteorological conditions such as during the El Nino seasons, storms can be developed in the low latitude region west of the California coast and move in much closer to the coast; and on a rare occasion these storms may move directly across Southern California, following a northeast, east or southeast trajectory. The severe winter storm occurring in January 1988 is an example of the moving close-by storm, which resulted in significant coastal damage within Southern California.

Northwest Winds in the Outer Coastal Waters

The predominant wave action along the coast area within the Los Angeles shoreline is due to the prevailing northwest winds. This is particularly true during the spring and summer months. Wave heights are usually low, less than 3 feet; but on occasion, with superposition of a strong surface high and an upper level trough, the northwesterlies increase, becoming very strong from about Point Sal to San Nicolas Island. The inner waters of Southern California very often remain unaffected under the influence of the Catalina eddy circulation. Waves traveling at a variance to the mean wind direction reach the nearshore water with periods on the order of 6 to 10 seconds. Moderate winds from the northwest will produce breaker heights of 3 to 6 feet, while strong events can generate heights of 6 to 10 feet.

West to Northwest Local Sea

Local westerly winds can be divided into two types: 1) temperature-induced sea breezes, and 2) gradient winds. The former exhibits a pronounced seasonal and diurnal variation. The strongest sea breezes occur during the late spring and summer months, while the lightest winds are during December and January. The summer sea breezes averaging about 15 knots usually set in during the late morning and peak in the mid-afternoon. In winter months, sea breeze conditions are limited to a few hours during early afternoon with wind speeds on the order of 10 knots. Gradient winds are confined largely to the months of November through May with the peak in March and early April. These typically occur following a frontal passage or with the development of a cold low pressure area over the southwestern United States.

Pre-Frontal Local Sea

The coastal zone within the Los Angeles area is particularly vulnerable under extratropical winter storm conditions prior to frontal passage winds blowing strongly from the southeast along the coast but turning toward the south-southeast to south a short distance offshore. Wind waves, with peak energy averaging between 6 and 8 seconds, reach the shore with minimal loss. Significant wave heights are generally in the range of 3 to 8 feet. Extreme wave heights are rare,

because the fetch and often the duration of these wind waves are short. An example of this rare case is the storm of January 4, 1995, which generated southerly seas of 10 to 12 feet.

Tropical Storm Swell

Tropical cyclones form regularly along the intertropical convergence zone west of Mexico from early July to early October. On the average, about 15 to 20 of them are to be expected each year. Most of the tropical cyclones travel on a westerly track, and swells generated by these storms will have little or no effect on Southern California. A few, however, take a northwest track, thereby lengthening the effective fetch over which swells traveling toward Southern California can be generated. Hurricane Marie, which occurred in August 2014 and was considered to be a Category 5 hurricane, generated swells of 10 to 15 feet along Southern California and caused significant damages to coastal development in Santa Catalina Island.

Extratropical Cyclone of the Southern Hemisphere

From the months of April through October, and to a lesser extent the remainder of the year, large South Pacific storm systems traversing the ocean between 40 and 60 degrees south from Australia to South America send swells northward to the west coast of Central and North America. The great circle approaching directions to Southern California range from about 215 degrees for storms near New Zealand to 170 degrees for South American storm systems, respectively. The decay distance ranges from about 4,500 to 7,000 miles. Wave heights in deep water are usually low, on the order of 2 to 3 feet; however, since these waves are nearly monochromatic, their capacity for shoaling is greatly enhanced. Breakers of 6 to 10 feet in the Los Angeles coastal region are not uncommon.

2.2 Storm Wave Characteristics

The nearshore storm wave characteristics at the Municipal Pier were obtained from a 36-year hindcasted deepwater wave climate that was transformed to the nearshore location for various selected storm events. **Table 4** lists the derived annual and other return storm wave conditions (1-, 10-, 25- 50- and 100-year) at a nearshore station (Station 1) in a depth of approximately 30 feet. Due to the presence of Redondo Submarine Canyon, the 100-year return wave is only about 7.2 feet, which is considerably small as compared to return waves along the adjacent coastline regions. Return storm wave heights inside Redondo Beach Harbor (Stations 2 and 3) were obtained from a physical model simulation at US Army Engineer Waterways Experiment Station (WES) under various severe design storm conditions, as also presented in **Table 4**. It is noted that return wave heights at Stations 2 and 3 were respectively derived from different offshore approaching wave angles (260° for Station 2 and 240° for Station 3). **Figure 2** illustrates the respective locations of these three wave conditions.

It is noted that a recent study was performed by the California Climate Change Center (Cayan, et al., 2009) to assess likely winter wave height changes along the California coast under various scenarios of greenhouse gas emission (i.e., sea level rise) in the future. It was concluded that the intensity of future storm events is expected to follow a slightly negative trend within southern California, as the mean cyclone track with a warmer climate tends to move north. Therefore, the

wave conditions hindcasted in the 1979-2001 period would yield more conservative representation of the future wave climate in Southern California.

Table 4. Estimated Return Wave Heights

Locations	Return Wave Heights, Hs (ft)				
	1-Yr	10-Yr	25-Yr	50-Yr	100-Yr
Station 1: Near Multiple Pier[1]	5.1	6.2	6.5	6.8	7.2
Station 2: Mole D Area[2]	2.1	2.3	2.7	2.7	3.9
Station 3: North End of Proposed Lagoon[2]	1.3	1.6	2.0	1.8	3.6

Notes: offshore incoming wave angles are 260° for Station 2 and 240° for Station 3
References:[1] CCSTWS Draft Report, 2010 at a depth of 29.7 feet, MLLW
[2] Bottin and Mize, 1990

Figure 2. Locations of Return Wave Stations

2.3 Tsunamis

Tsunamis are long period waves caused by an underwater disturbance such as volcanic eruptions or earthquakes. Tsunami waves propagate across the deep ocean as very long waves of low amplitude. Tsunami waves can be significantly amplified by shoaling, diffraction, refraction, convergence, and resonance when they reach coastal areas.

No tsunami has ever significantly affected the Los Angeles coast in the past. Although historically tsunamis were originated from coasts of Chile and Alaska, the propagation impacts to Redondo Beach have been of little consequence. Occurrences of the 2011 tsunami in Japan and the 2010 tsunami in Chile only elevated 2 to 3 feet of sea level in Southern California. **Figure 3** shows the elevated and lowered water levels measured at the Santa Monica tide gage resulting from the 2011 tsunami that originated in Japan.

The Tsunami Research Center at the University of Southern California (TRC-USC) has preformed various studies to quantify the potential tsunami events that are generated by local tectonic shift and submarine landslide in Southern California Bight (Borrero, et.al., 2004). Based on these studies, the California Geological Survey and other state agencies have prepared tsunami inundation maps along the California coast to assist local agencies in identifying potential tsunami hazard zones and formulating an emergency plan to minimize the potential impact in the event that a tsunami centering in Southern California occurs. **Figure 4** illustrates the potential inundation map in the Redondo Beach area, which shows the entire project area is within the tsunami-induced inundation limit, provided that the origin of the tsunami is located in the coastal water of Southern California. In light of the moderate impact, respectively induced by the 2010 and 2011 tsunamis in Chile and Japan, to the west coastal region, the USGS is currently conducting extensive studies to reassess the hazards of tsunamis to the west coast region (USGS, 2015).

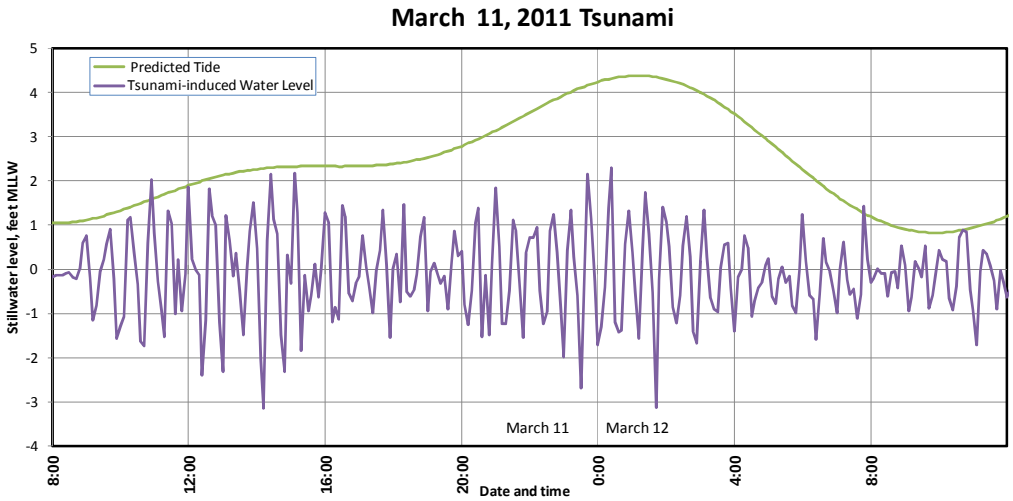
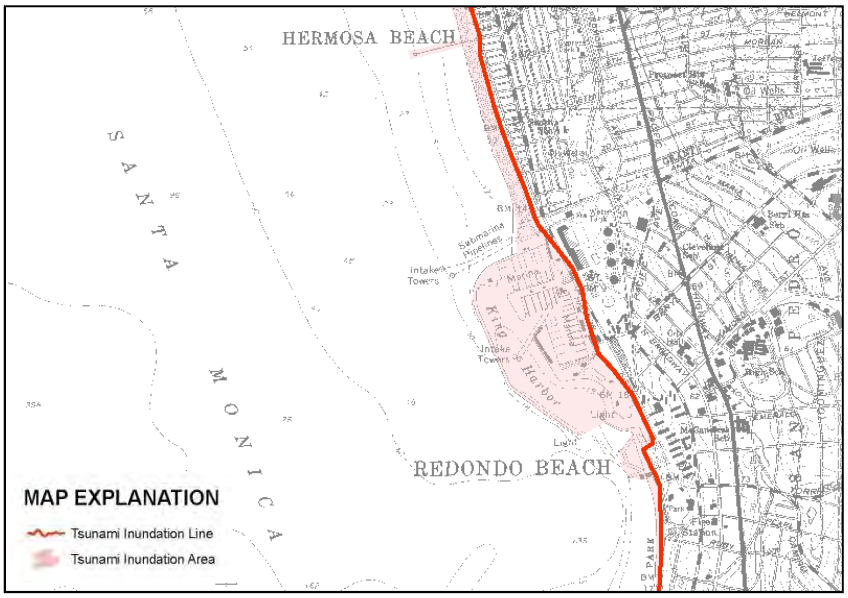


Figure 3. Measured Tsunami-induced Water Level Change at Santa Monica Gage



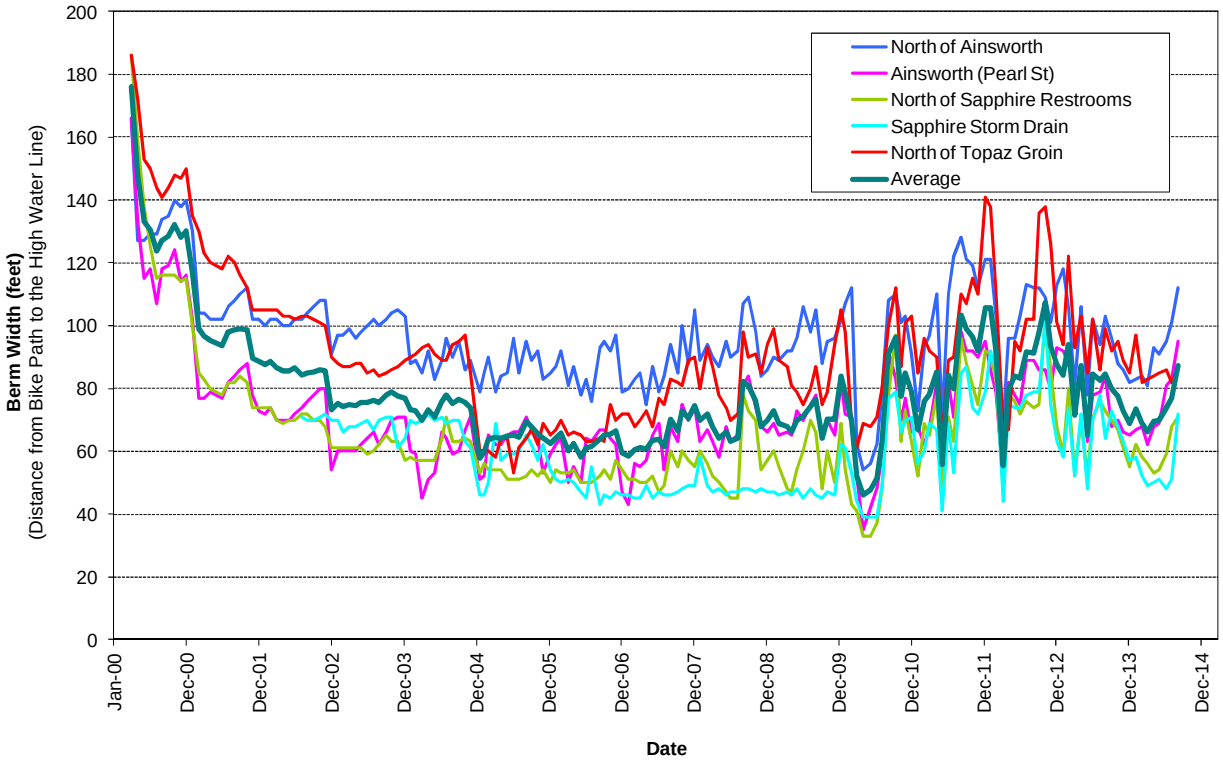
Source: California Emergency Management Agency, 2009

Figure 4. Tsunami Inundation Map for Emergency Planning

2.4 Coastal Processes

The project site is situated within a tiny shoreline reach extending from the King Harbor on the north to the terminal groin at Topaz Street (Topaz Groin) in the south. This short shoreline section has been a chronically narrow sandy beach and is strongly influenced by the effects of the Topaz groin and the Redondo Submarine Canyon located immediately offshore. It has been observed that steady sand losses to the canyon occur, resulting in shoreline recession over this short segment.

A beach nourishment project using dredged sand from Marina del Rey was conducted in 2000 during which placed approximately 300,000 cy of sand on the beach between the Topaz Groin and Redondo Municipal Pier. However, a significant volume of the beach fill was substantially lost into the submarine canyon within a short time after the 2000 beach nourishment. The average berm was reduced from the original width of 190 feet to approximately 60 feet by 2005; and the remaining beach subsequently appears to be somewhat stable after 2005. Another cycle of beach nourishment for the same shoreline reach was conducted in 2012 when 75,000 cy of clean sand was placed directly on the beach. An additional 85,000 cy of sand was deposited in an offshore storage site for future renourishing use. **Figure 5** illustrates the measured berm widths at various referenced locations between 2000 and 2014. It is indicative that due to the presence of the submarine canyon the capacity of beach sands within this shoreline reach is limited and can only accommodate a width of about 60 to 70 feet.



Source: Data from Los Angeles Department of Beaches and Harbors

Figure 5. Measured Berm Widths at Redondo Beach

3.0 Wave Uprush Assessment

To formulate an adaptation strategy and ensure adequate protection for the proposed coastal development, the wave uprush assessment is herein based on the high estimate of future sea level rise that was recommended by the COPC. This translates to the potential sea level rise of 1.1 feet at Year 2040 and 2.6 feet at Year 2065 (i.e., 25 and 50 years from the present day).

3.1 Municipal Pier

The proposed boardwalk immediately landward of the Municipal Pier provides a continuous corridor for pedestrians to reach the harbor development from the pier area. The elevation of the finished floor that is proposed is at 23 feet, MLLW on the northern end and tapers down to 20 feet, MLLW to the southern limit. Personal communications with City personal indicate that wave uprush overtops the northern segment of the protective revetment/wall annually, while wave runups rarely reach higher than the existing protective revetment in the southern reach. A wave uprush analysis was therefore performed along the existing shore protective device to validate field observations in the past. Three cross-shore transactions defined as the North, Middle and South profiles were selected from the combined topographic survey in 2014 and nearshore wading survey within the pier limit in 2015. The approximately locations of these three transects and deduced cross-shore profiles are shown in **Figure 6**.

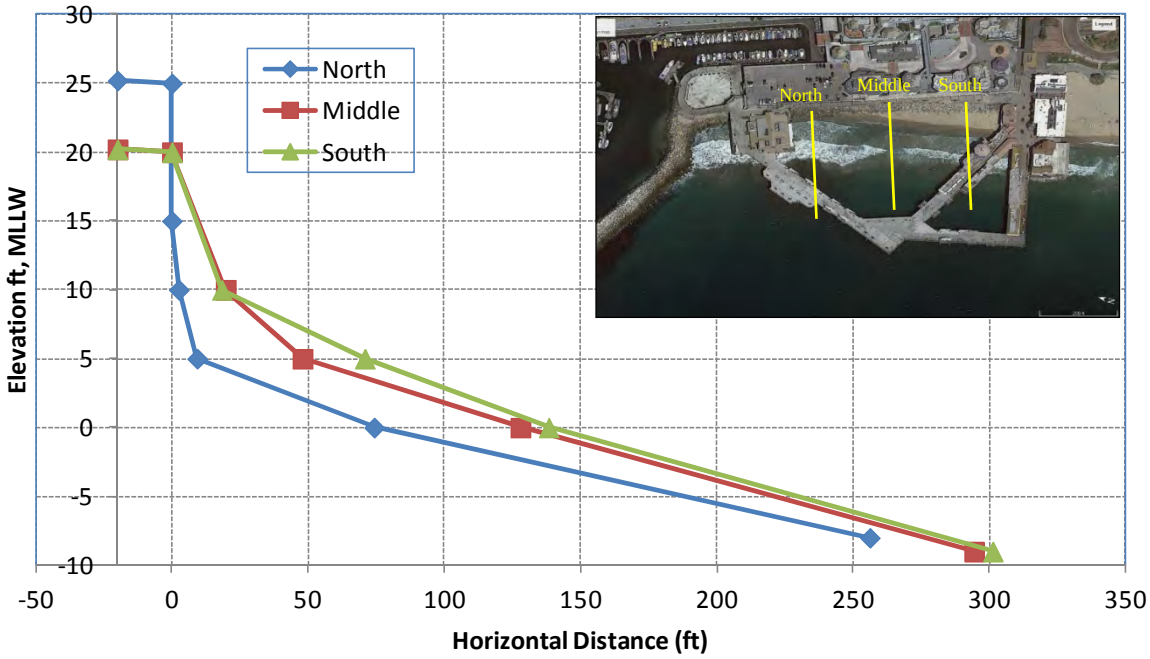


Figure 6. Transect Locations and profiles along the Municipal Pier

The estimated return wave runups for 1-year, 10-year, 25-year, 50-year and 100-year are respectively presented in **Table 5**. The computed results in general validate field observations that existing walkway at an elevation of +25 feet, MLLW in the northern segment is vulnerable to wave overtopping as the wave runup elevation reaches to approximately +25 feet, MLLW even under the annually-occurring wave condition. The wave uprush elevations in the middle and southern segments are generally below the finished slab elevation at +20 feet, MLLW for the existing and proposed boardwalk. The much higher wave uprush in the northern segment is primarily attributed to the shoreline that adjusts its orientation in relation to the approaching storm waves and the steeper upper section of the shore protective device. **Figure 7** illustrates the wave approaching direction and the resulting shoreline orientation reduces the beach buffer fronting the shore protective revetment in the northern segment. It should be noted that the computed wave runup elevation (for example, +25.3 feet, MLLW in **Table 5**) higher than the boardwalk elevation at +25 feet, MLLW indicates the induced inundation depth of at least 0.3 feet flowing across the boardwalk toward the landward end. Field observations indicate that the wave-overtopping height transitioning from the protective wall to the boardwalk would be much higher as evident from the photographs shown in **Figure 8**. The overtopped water will result in various degrees of inundation depth across the walkway as also shown in the figure.

Table 5. Estimated Return Wave Runups under Existing Condition

Return Year	Significant Wave Height (Hs in ft)	North	Middle	South
		Wave Runup Elevation ft, MLLW		
1-yr	5.1	24.8	18.0	16.5
10-yr	6.2	25.2	18.9	17.3
25-yr	6.5	25.3	19.2	17.6
50-yr	6.7	25.3	19.2	18.0
100-yr	7.2	25.3	19.4	18.2

Note: Wave period=15 sec

Figure 7. Wave Pattern Approaching at Municipal Pier

Additional analysis was performed to assess the potential impact resulting from future sea level rise in order to formulate an adaptation plan for the proposed coastal development. To ensure the adequacy of the adaption plan, the high value of future sea level rise that was recommended by COPC was applied. **Table 6** presents the computed wave runup elevations (WREs) at these three locations under the future sea level rise conditions. Various degrees of inundation depth resulting from the overtopped water range from a thin sheet flow layer (0.1 foot) to a depth of approximately one foot. It is noted again that the wave overtopping height transitioning from the protective wall or revetment to the boardwalk would be much higher.

Faria Beach, Ventura County, 1983

Mission Beach, San Diego, 1988

Sources: Photos from USGS and Shore & Beach

Figure 8. Illustration of Wave Overtopping and Subsequent Inundation

Table 6. Estimated Future Return Wave Runups Under Different SLR Projections

Return Year	Hs (ft)	2040			2065			2090		
		North	Middle	South	North	Middle	South	North	Middle	South
		Wave Runup Elevation(WRE) ft, MLLW								
		High SLR Projection								
1-yr	5.1	23.6	20.1	20.1	24.2	20.4	20.3	24.5	20.7	20.6
10-yr	6.2	23.7	20.1	20.1	24.2	20.5	20.3	24.7	20.9	20.7
25-yr	6.5	23.6	20.2	20.1	23.9	20.5	20.4	24.8	20.9	20.8
50-yr	6.7	23.7	20.2	20.1	24.2	20.5	20.4	24.8	20.9	20.8
100-yr	7.2	23.7	20.2	20.1	24.2	20.5	20.4	24.8	20.9	20.8
		Low SLR Projection								
1-yr	5.1	23.4	18.7	17.1	23.6	20.1	19.1	23.8	20.2	20.0
10-yr	6.2	23.4	19.5	18.1	23.6	20.1	19.1	23.8	20.1	20.1
25-yr	6.5	23.4	19.9	18.5	23.5	20.1	19.4	23.7	20.1	20.0
50-yr	6.7	23.4	19.8	18.5	23.5	20.1	19.7	23.6	20.2	20.1
100-yr	7.2	23.4	19.9	18.6	23.5	20.1	19.6	23.6	20.2	20.0

Note: Wave period=15 sec

3.2 Mole D and Seaside Lagoon

The proposed top elevations of the pedestrian walkway along Mole D and the perimeter of the seaside lagoon are respectively at +17 and +13 feet, MLLW, as illustrated in **Figure 9**. The two representative cross sections along these two development areas are based on Psomas' topographic survey in 2012 and City's hydrographic survey in 2014 and further supplemented by an additional survey in 2015 from Nearshore and Wetland Surveys. The estimated return wave

runups for 1-year, 10-year, 25-year, 50-year and 100-year under the without-SLR condition (i.e., present day in 2015) are presented in **Table 7**.

Along the harbor perimeter of Mole D, the wave runup elevation is either below or at the finish slab elevation at +17 feet, MLLW under the existing oceanographic conditions. Field validation via personal communications with the City personnel indicates that wave overtopping at Mole D has not been observed since the modification of outer breakwaters that was completed in 1990. On the other hand, incoming waves under severe storm events (e.g., 50 and 100- year return storms) can overtop the proposed walkway with a proposed crest elevation of +13 feet, MLLW along the west perimeter of Seaside Lagoon, which results in an inundation depth as deep as one foot. It is noted again that the wave overtopping height transitioning from the protective revetment to the walkway would be much higher than +13 feet, MLLW.

Wave uprush was also estimated at Mole D and Seaside Lagoon under the future high SLR scenario. **Table 8** presents the computed wave runup elevations for various return wave conditions. The results indicate that there exists potential wave overtopping under severe wave climate (i.e., 50- and 100-yr waves). The inundation depth resulting from wave overtopping can be approximately one foot in depth at Mole D and exceeding one foot in depth across the walkway perimeter of the Seaside Lagoon. At the transition zone between the protective revetment and the walkway, the wave uprush will be higher than the estimated elevations at the walkway.

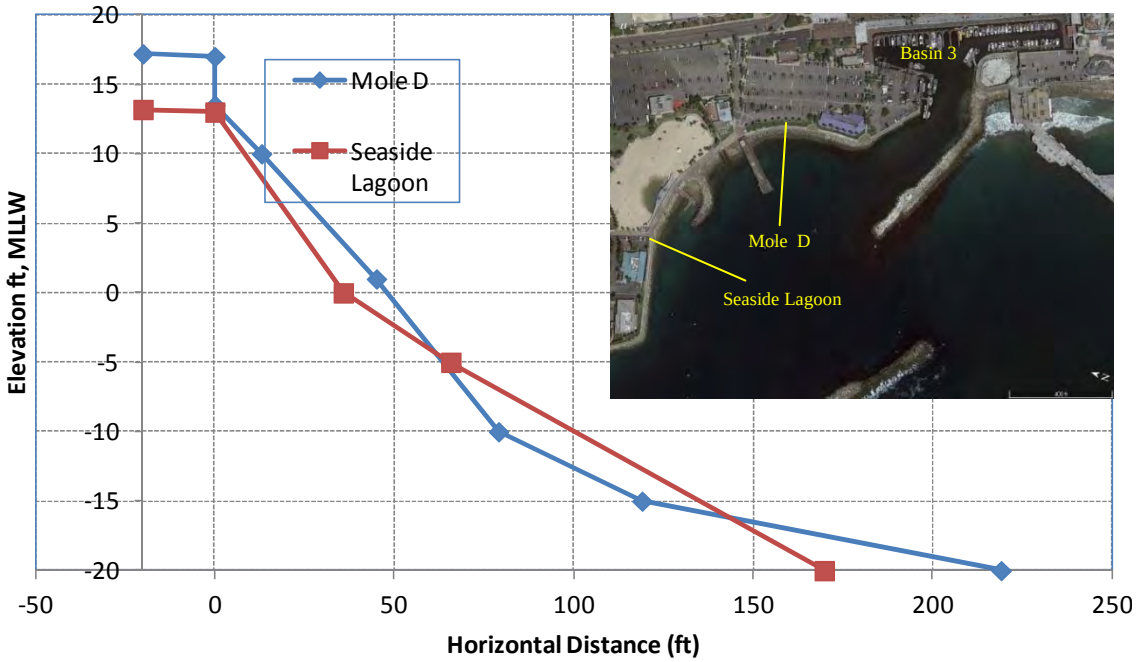


Figure 9. Representative Transect Locations and Profiles at Mole D and Seaside Lagoon

Table 7. Estimated Return Wave Runups Under Existing Conditions

Return Year	Mole D		Seaside Lagoon	
	Hs (ft)	WRE ft, MLLW	Hs (ft)	WRE ft, MLLW
1-yr	2.1	11.9	1.3	9.7
10-yr	2.3	12.4	1.6	10.2
25-yr	2.7	13.2	2.0	11.0
50-yr	2.7	13.2	1.8	10.7
100-yr	3.9	17.0	3.6	13.7

Note: Wave period=15 sec

Table 8. Estimated Future Return Wave Runups Under Different SLR Projections

Return Year	2040		2065		2090	
	Wave Runup Elevation (ft, MLLW)					
	Mole D	Seaside Lagoon	Mole D	Seaside Lagoon	Mole D	Seaside Lagoon
	High SLR Projection					
1-yr	13.1	10.8	15.5	12.3	17.3	13.4
10-yr	13.7	11.3	16.3	12.8	17.5	13.6
25-yr	15.2	12.1	17.3	13.5	17.6	13.7
50-yr	15.2	11.8	17.3	13.4	17.6	13.7
100-yr	17.3	13.9	17.5	14.0	17.8	14.4
	Low SLR Projection					
1-yr	12.1	9.8	12.5	10.2	13.0	10.6
10-yr	12.5	10.4	13.0	10.7	13.4	11.2
25-yr	13.4	11.2	14.0	11.5	15.0	11.9
50-yr	13.4	10.8	14.0	11.2	15.0	11.6
100-yr	17.1	13.8	17.2	13.8	17.3	13.9

Note: Wave period=15 sec

3.3 Basin 3

The existing crest elevation of the bulkhead surrounding Basin 3 is at approximately +7.5 feet, MLLW. Inundation along the accessway atop the bulkhead during extreme high tides has been documented in the past. Since the proposed coastal development does not elevate the existing bulkhead, occasional flooding along the accessway atop the bulkhead during the extreme high tide conditions is to be expected. Furthermore, more frequent inundation and associated nuisance from the flooding events will occur due to future sea level rise, particularly if the projected high sea level rise is materialized due to the greenhouse gas emission in the future. Inundation will be confined to the immediate accessway behind the bulkhead. The proposed main access road (Pacific Ave) at an elevation of +12 feet, MLLW will not be susceptible to tide-induced flooding.

4.0 Sea Level Rise Adaptation and Tsunami Risk Preparation

4.1 Sea Level Rise Adaptation

The State's recommended guidelines when compared to other forecast scenarios suggest that the COPC's guidelines may be conservative given the current level of understanding of the phenomenon. This uncertainty raises valid questions about what constitutes reasonable planning criteria for the proposed coastal development. The wave uprush assessment under future SLR conditions, presented in Section 3, was based on the high end of the COPC's recommendation (see **Table 2**), which may or may not occur in the future. An adaptation plan needs to be formulated to provide additional coastal inundation protection, should the projected high SLR indeed occur in the future via a continuous field validation of sea level rise in the upcoming years.

4.1.1 Present Day

Wave runup calculations and field observations indicate that wave overtopping does occur within the northern segment along the existing walkway of the pier. The top elevation of the boardwalk for the proposed coastal development is at +23 feet, MLLW, which is even lower than the elevation of the existing walkway. Therefore, an additional protective measure should be planned to minimize the storm-induced wave overtopping that results in boardwalk inundation. A four-foot high recurved splash wall anchored at the seaward edge of the boardwalk is therefore applicable to redirect the up-rushed water back toward the ocean and significantly reduce potential inundation under the existing oceanographic conditions. Other boardwalk segments along the pier, and the pedestrian walkway along the perimeter of Mole D and the Seaside Lagoon would not be susceptible to storm wave attack that induces the uprush water reaching the crest of the pier boardwalk and pedestrian walkway, respectively.

4.1.2 Future Years

It is uncertain whether the actual sea level rise trend in the future will follow the low or high projection that was recommended by the COPC. The wave uprush analysis performed herein indicates that wave overtopping along the boardwalk of the Municipal Pier and the perimeter of Mole D and the Seaside Lagoon will occur if the high SLR is observed in the future. Therefore, an adaptation plan needs to be implemented to provide additional shore protection in the event that the future high SLR rise does occur.

The adaptation plan consists of two elements: 1) continuously monitor NOAA's tide measurements at the Santa Monica gage and the recorded SLR trend as well as pertinent literatures that update the SLR trend, and 2) design a supplemental structure feature, such as a recurved splash wall, to raise the height of the currently proposed protective device, but not to be built at the present day. If the future sea level rise shows an accelerating trend, the construction of such a structure may then be implemented at an appropriate time in the future.

4.2 Tsunami Risk Preparation

The potential inundation map in the Redondo Beach area (see **Figure 4**), which was issued by the California Governor's Office of Emergency Service (CalOES), shows the entire project area is within the tsunami-induced inundation limit, provided that the origin of the tsunami is located in the coastal water of Southern California. Since no subduction zone (a fault where one continental plate slides under another in an earthquake) exists in the coastal waters of Southern California, a local earthquake event that produces underwater disturbance capable of generating a tsunami within this coastal region is highly unlikely. Nevertheless, the issued tsunami inundation map does assist the City of Redondo Beach in formulating an emergency plan to minimize the potential impact in the event that a tsunami centering in Southern California occurs. The presently proposed coastal development should fully incorporate all City's emergency plan in case that a localized earthquake-induced tsunami in the region occurs. *(http://www.redondo.org/depts/fire/_emergency_preparedness_.asp)*

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