Harbor Improvement Report

Maritime Tsunami and Coastal Hazard Mitigation Guidance

For Harbor Engineers and Emergency Managers

Oceanside and Camp Pendleton Harbors – San Diego County

Harbor Improvement Report (HIR) No. 2017-SD-01

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By California Geological Survey
University of Southern California
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Contents

1 Purpose

The California coastline, and especially its ports and harbors, is susceptible to damaging tsunamis from both local and distant tsunami sources. During the tsunamis of 2006 from the Kuril Islands, 2010 from Chile, and 2011 from Japan, California harbors sustained over $100M in total damages (Wilson et al, 2012A). However, harbor improvements and mitigation measures can greatly reduce tsunami damage from future events. A study headed by the U.S. Geological Survey indicated that although a large, distant-source (Alaska) tsunami could cause tens of billions of dollars of damage to coastal ports and harbors, 80-90% of that damage could be reduced by implementing tsunami mitigation and related resilience strategies (Ross et al, 2013). These resilience strategies will not only reduce the direct damage to the harbors but will also improve recovery times significantly.

In addition to local coastal flooding, there are a number of tsunami hazards or conditions which could directly affect boater safety and damage to the harbors and vessels:

- **Strong and unpredictable currents**, especially where there are narrow entrances, narrow openings, and other narrow or shallow parts of harbor
- **Sudden water-level fluctuations** where docks and boats:
  - Hit bottom (grounded) as water level drops
  - Could overtop piles as water level rises
- **Eddies/whirlpools** causing boats to lose control
- **Tsunami bores and amplified waves** resulting in swamping of boats and damage to docks
- **Drag** on vessels inducing break-aways or serious damage to dock structures (floating or fixed)
- **Movement of navigational buoys and single point moorings** could create dangerous conditions for vessels after event
- **Scour, sedimentation, and debris** can affect harbor protection measures and shipping channels
- **Dangerous tsunami conditions can last tens of hours** after first wave arrival
- **Environmental hazards** causing delays in recovery
- **Poor decision-making** by unprepared or inexperienced boating community
- **Lack of maintenance/inspection and rehabilitation**

The California Tsunami Program, comprised of the California Governor's Office of Emergency Services (CalOES) and the California Geological Survey (CGS), the University of Southern California (USC), the California State Lands Commission, and other partners are working with the Federal Emergency Management Agency (FEMA) to help maritime communities mitigate hazards from tsunamis and other coastal impacts. This document summarizes mitigation measures that minimize loss of life and damage from future tsunamis. Portions of this document are written for harbor engineers and managers who can help address permanent harbor improvements, and other portions are written for local emergency managers to help develop Local Hazard Mitigation Plan strategies. The engineering analyses focus on harbor damage related to hazards from strong currents, water-level fluctuations, and debris and sediment movement; although tsunami inundation is also a hazard, it is not a focus of this report. This document can be used to update Local Hazard Mitigation Plans so there is a mechanism to obtain pre-disaster hazard mitigation funding from CalOES and FEMA.

In addition to this document which focuses on permanent mitigation measures, Maritime Tsunami Response Playbook Guidance documents have been created for all at risk ports, harbors, and marinas in California as real-time decision support tools (State of California, 2015; Wilson et al, 2016). These Playbook documents help harbor and port officials prepare, plan, and respond to strong currents and damage from future tsunamis. The response Playbooks can also be used to pre-identify real-time response mitigation measures and determine where infrastructure enhancements should be initiated. Table 1 identifies these response ("soft") mitigation measures as well as a number of permanent ("hard") mitigation measure, some of which are discussed in greater detail in this document.

Table 1 Mitigation Measures for Reducing Impacts in Maritime Communities

Real-time response ("soft") mitigation measures	**Permanent ("hard") mitigation measures**
Reposition ships within harbor	Increase diameter/stiffness of dock piles
Move boats and ships out of harbors	Fortify and armor breakwaters
Remove small boats/assets from water	Inspect/Restore uniform buoyancy for floating docks
Shut down infrastructure before tsunami arrives	Increase flexibility of interconnected docks
Evacuate public/vehicles from water-front areas	Improve floating dock movement along pile guides
Restrict boats from moving during tsunami	Increase height of piles to prevent overtopping
Prevent boats from entering harbor during event	Deepen/Dredge channels near high hazard zones
Secure boat/ship moorings	Move docks/assets away from high hazard zones
Personal flotation devices/vests for harbor staff	Widen harbor entrance to reduce focusing of currents
Remove hazardous materials away from water	Reduce exposure of petroleum/chemical facilities
Remove buoyant assets away from water	Strengthen boat/ship/dock moorings and cleats
Stage emergency equipment outside affected area	Construct flood gates
Activate Mutual Aid System as necessary	Strengthen wharfs to prevent damage from uplift forces
Activate of Incident Command at evacuation sites	Install debris deflection booms to protect docks
Alert key first responders at local level	Inspect/Maintain/Rehabilitate harbor structures
Restrict traffic entering harbor; aid traffic evacuating	Construct breakwaters further away from harbor
Identify/Assign rescue, survey, and salvage personnel	Install Tsunami Warning Signs
Identify boat owners/live-aboards; establish phone tree, or other notification process	Identify equipment/assets (patrol/tug/fire boats, cranes, etc.) to assist response activities

This document is divided into three sections:

1) **Tsunami Impact Report (TIR)** – The TIR is developed by coastal engineering partners with the Tsunami Research Center at USC, and is written for harbor engineers and managers. It includes detailed analyses of the tsunami hazard potential related to current velocity, direction of currents, and their impacts on docks throughout the harbor. This report also includes analysis of debris and sediment movement during a tsunami so that pre-disaster mitigation and planning can reduce impacts to vital docks and harbor infrastructure. Results from these analyses are used to formulate recommended actions.
2) **Recommended Actions** – This section summarizes the mitigation measures which will have the most impact on harbor resilience. It includes information for both harbor engineers, community and harbor planners, and emergency managers. Recommendations include both "soft" and "hard"

mitigation measures, and consider the cross-benefit of specific mitigations that address other coastal hazards like king tides, storm surge, and sea-level rise. Where possible, cost-benefit analyses of these mitigation activities will also be included.

3) **Local Hazard Mitigation Plan (LHMP)** – This section is written for local emergency managers assisting the harbors, with the idea that it can be directly integration into community LHMPs. This section lists harbor-specific mitigation measures and the benefits of those activities so that the harbor can obtain support when pre-disaster mitigation funding becomes available.

In addition to the LHMPs, the information provided within this document can also be used for long-term planning. Part of this planning effort would include: 1) pre-establishing contracts/MOUs for response/recovery (e.g. dredging, riprap); 2) pre-identifying hazardous material (HazMat) source release point locations; and 3) prioritizing future harbor expansion during planning with potential resiliency applications ("shovel ready"). Hazard analyses and mitigation measures identified herein can be incorporated into Local Coastal Plans, General Plan-Safety Elements, and Port Management Plans to reduce exposure of essential facilities and infrastructure to hazards. This information can also be used in pre-disaster recovery planning by identifying where damage occurs and sedimentation and debris will likely accumulate after future tsunamis. **The state, its partners, and FEMA would also like to make it clear that this document is only provided as guidance, and that harbor and community officials are not responsible for its contents nor are they required to follow the recommendations in this document.**

Oceanside and Camp Pendleton harbors are located in central San Diego County (Figure 1). A detailed harbor map for Oceanside Harbor is provided in Figure 2; a harbor map for Camp Pendleton was not available.

Figure 1 Location of Oceanside and Camp Pendleton harbors.

Figure 2 Harbor Map for Oceanside Harbor (from http://www.ci.oceanside.ca.us/civicax/filebank/blobdload.aspx?blobid=30979)

2 Tsunami Impact Report

2.1 Introduction

Oceanside Harbor is a municipal harbor located along the Southern California Coast (Figure 1). Oceanside Harbor consists of two main basin known as North Harbor and South Harbor (Figure 2), which each operate a number of commercial and recreational vessels. The harbor also provides some services for Marine Corps Base Camp Pendleton located to the north of the harbor, an area which is partially covered by the hazard analyses.

Historically, Oceanside Harbor has seen very little damage during tsunami events. Strong currents and minor damage were observed in the harbor during the 2010 Chile tsunami (Wilson et al, 2012A). Strong currents also occurred during the 2011 Tohoku tsunami but no damage was observed or reported (Paul Lawrence, personal communication, July 2016).

The purpose of this report is to assess the current state of the harbor's resistance to both past events and probable future tsunami scenarios. To do this a field evaluation was performed on July 15, 2016, to meet with harbor managers, inspect the condition harbor facilities, primarily dock cleats and pile guides. High-resolution numerical modeling was run for five tsunami events (two historic events, and three realistic scenarios). The results of the numerical modeling were combined with a statistical analysis method to estimate the structural capacity of the harbors cleats and pile guides, and to quantify the potential for scour and sedimentation in the harbor. The results of the analysis are presented in the following.

2.2 Numerical Modeling

Hydrodynamic modeling for this study was conducted using the numerical model "Method of Splitting Tsunamis" (MOST) (Titov and Gonzalez 1997; Titov and Synolakis 1998). The model is capable of simulating the full development of the tsunami from wave generation to wave run-up. The model has been extensively validated for a number of global scenarios. Variants of the MOST model have been in constant use for tsunami hazard assessments in California since the mid-1990s (Lynett et al. 2014).

MOST was used to propagate tsunami waves from source to the nearshore region, using a system of nested grids. The outermost grid at 4-arc-minute resolution covers the entire Pacific basin. Three additional grids of increasingly finer resolution were derived from data provided by NOAA's National Centers for Environmental Information specifically for tsunami forecasting and modeling efforts (Grothe et al. 2012). The innermost nearshore grid has a 10-meter resolution and takes boundary input from the previous MOST nested layer. This resolution has been evaluated and found sufficient for capturing tsunami currents inside harbors (Lynett et al. 2014).

A sediment transport model was also coupled with the hydrodynamic model. The erosion and deposition rates were calculated using the empirical formulas given in (Cao et al. 2004). The initiation of the sediment movement is controlled by Shield's Criterion, which sets the speed at which the particles will be picked up from the sea floor and moved by the flow. Based on Shield's Criterion, the threshold current speed ranges between 0.15 m/s (0.3 knots) and 0.2 m/s (0.4 knots) depending on the water depth, for the types of sediment in this location. The sediment model was driven by the hydrodynamic inputs taken from MOST, and then the bathymetry was updated using the erosion and deposition predicted by the sediment transport model. Floating tsunami debris (boats and docks) can cause further damage and also slow down strong currents, facilitating sediment deposition (Wilson et al. 2012B). Here, a Lagrangian particle tracking method was used to identify the likely paths of tsunami debris, coupled with the tsunami currents predicted by MOST. The sediment and debris movement analyses can be used for both pre-tsunami mitigation and post-tsunami recovery assessments. For example, the sediment movement analysis could help harbors determine where additional dredging is needed to help mitigate damage and recovery problems. The damage which could result from the tsunami debris is not analyzed.

MOST was used to evaluate a number of historic and probable scenarios for Oceanside and Camp Pendleton harbors. The following five events (actual historical events and modeled scenarios) were analyzed as part of this study:

- 2010 Magnitude 8.8 Chile Event (Historical)
- Magnitude 9.0 Cascadia Scenario
- 2011 Magnitude 9.0 Japan Event (Historical)
- Magnitude 9.4 Chile North Scenario
- Magnitude 9.2 Eastern Aleutian-Alaska Scenario

2.3 Tsunami Flow Damage

Fragility curves for structural components in small craft harbors are estimated using a Monte Carlo methodology. A Monte Carlo based approach in structural analysis is a probabilistic tool where the governing equations of motion or structural behavior might be well known but the physical properties of the input (i.e. current speed, current direction) and the structural capacities of the components (e.g. cleats, pile guides) might not be. The Monte Carlo approach requires a distribution of each input variable (usually with a rectangular, triangular or Gaussian shaped relationship), and then randomly samples each distribution within the described equations to generate a single computational result. The process repeats hundreds or thousands of times depending on the required accuracy and convergence of the system. A fragility curve is estimated for each component and for each slip within the dock system which is likely to fail during a tsunami. Further details of the analysis can be found in Keen et al. (2017A).

Figure 3 Location of Analysis Zones within Oceanside Harbor

The maximum failure probability from each component in all slips within the dock is then used to define the minimum capacity of the dock system. For the purposes of this report, these failure capacities were calibrated against observed damage (or lack thereof) during the Chile 2010 and Japan 2011 for Oceanside Harbor. The analyses provide failure estimates which are representative of expected damage by dock. The results are expected to be consistent with what would be observed during a post tsunami damage assessment and recorded in a damage report. The results of the analysis for cleats and pile guides are completed for the zones identified in Figure 3 and summarized in the following sections.

2.3.1 Cleats

Damage classifications for cleats were determined by deriving fragility curves for each of the representative docks within the respective damage zones and fitting the derived fragility curves to the curves presented in Keen et al. (2016A). Cleats were classified as Deterioration Class 2 (Minor Existing Deterioration Damage), 12-inch cleat following the methodology presented in Keen et al. (2016B). This classification is based upon observations taken during a visit to Oceanside Harbor on July 15th, 2016 (see example cleats in Figure 4). Results of the analysis are presented in Table 2. Green, yellow and red results refer to low (<10% of cleats are damaged), moderate (10%-90% of cleats are damaged) and high (> 90% of cleats are damaged) levels of expected damage for each tsunami scenario, respectively.

Cleat failure is expected to occur due to shearing and/or bending of the securing bolts. Post-tsunami photographs taken by Mesiti-Miller Engineering Inc. (2011) in Santa Cruz Harbor after the 2011 Tohoku tsunami show sections of the dock where the cleats were ripped from their mountings with only small sections of the bolts remaining. Less commonly noted are indications of lines breaking, possibly because parted sections of lines which remain after the tsunami were removed by the occupants and replaced.

Figure 4 Representative Cleats from Oceanside Harbor

Results of the cleat analysis indicate that Oceanside Harbors is most vulnerable to the Magnitude 9.2 Eastern Aleutian-Alaska Scenario. The modeling indicates that Zones 1-6 have a moderate level of vulnerability (see Figure 3 for a delineation of Zones). The second most damaging event would be the Magnitude 9.4 Chile North Scenario. In terms of all scenarios/historical events, Zone 1 would be most vulnerable to the modeled tsunami events with all five events suggesting a moderate level of vulnerability. The next most vulnerable area would be Zone 5.

Table 2 Cleat Damage Estimate (By Tsunami Event/Zone) for Oceanside Harbor

Zone	Case ID				
	Alaska	Cascadia	Chile 2010	Chile North	Japan 2011
1	Moderate	Moderate	Moderate	Moderate	Moderate
2	Moderate	Low	Low	Low	Low
3	Moderate	Low	Low	Low	Low
4	Moderate	Low	Moderate	Moderate	Low
5	Moderate	Low	Moderate	Moderate	Moderate
6	Moderate	Low	Low	Moderate	Low
7	Low	Low	Low	Low	Low
8	Low	Low	Low	Low	Low
9	Low	Low	Low	Low	Low

2.3.2 Pile Guides

Damage classifications for pile guides were determined by deriving fragility curves for each of the representative docks within the respective damage zones and fitting the derived fragility curves to the curves presented in Keen et al. (2016). Pile Guides were classified as Deterioration Class 1 (No Existing Deterioration Damage), 9/16-inch hoop type pile guides following the methodology presented in Keen et al. (2016B). This classification is based upon observations taken during a visit to Oceanside Harbor on July 15th, 2016 (see examples in Figure 5). Results of the analysis are presented in Table 3. Green, yellow and red results refer to low (<10% of pile guides are damaged), moderate (10%-90% of pile guides are damaged) and high (>90% of pile guides are damaged) levels of expected damage for each tsunami scenarios, respectively (Note: There are no red levels of expected damage for this harbor).

Incidents of pile guide failure have been documented by Dengler et al (2009) in Crescent City Harbor during a post-tsunami damage assessment of the 2006 Kuril event. Dengler et al (2009) attribute pile guide failure to the strong currents pinning the pile guides against the pilings and the guides being unable to adjust to the rising water level which leads to failure. Post-tsunami photographs by Mesiti-Miller Engineering Inc. (2011) support a second tension failure mechanism where tension from the pile guides pulling against the piles lead to the guides being torn from their mounting in the dock. Photos show areas along the floating dock where the pile guides are disconnected from the dock without any evidence of whalers (or other dock components) being crushed.

 

Figure 5 Representative Pile Guides from Oceanside Harbor

Like the cleat analysis, results of the pile guide analysis indicate that Oceanside Harbor is most vulnerable to the Magnitude 9.2 Eastern Aleutian-Alaska Scenario. The modeling indicates that Zone 1-6 have a moderate level of vulnerability. After the Aleutian-Alaska Scenario, the results indicate that the next most damaging event would be the Magnitude 9.4 Chile North Scenario. In terms of all scenarios and actual historical events, Zone 1 would be most vulnerable to the modeled tsunami events with four of the five suggesting a moderate vulnerability. The next most vulnerable area would be Zone 5.

Table 3: Pile Guide Damage Estimate (By Tsunami Event/ Zone) for Oceanside Harbor

Zone	Case ID				
	Alaska	Cascadia	Chile 2010	Chile North	Japan 2011
1	Moderate	Moderate	Low	Moderate	Moderate
2	Moderate	Low	Low	Low	Low
3	Moderate	Low	Low	Low	Low
4	Moderate	Low	Low	Low	Low
5	Moderate	Low	Low	Moderate	Low
6	Moderate	Low	Low	Low	Low
7	Low	Low	Low	Low	Low
8	Low	Low	Low	Low	Low
9	Low	Low	Low	Low	Low

2.4 Scour, Sedimentation and Debris Motion

Bathymetric changes of the harbor basin were predicted for each tsunami scenario, and are shown in Figure 6. No significant scour or sedimentation problems were reported in Oceanside Harbor after the 2011 Japan and the 2010 Chile tsunamis. And calibrating with actual events, the model results do not predict a substantial amount of sediment movement related to these two sources. Simulations show that both tsunamis deposited sediment of up to 0.5 meters (1.6 feet) along the entrance channel, and the depth changes inside the harbor remained less than 0.2 meters (0.7 foot). The primary scour areas of sediment were at breakwater heads.

Scour and deposition predictions from the other scenarios show that the Cascadia scenario does not appear to substantially transport sediment; this case shows maximum depth changes of 0.5 meters (1.6 feet) around the breakwaters with most areas experiencing changes of 0.1 meter (0.3 foot) or less. The Chile North scenario yields scour and deposition that are, in general, similar in pattern to the 2011 Japan and 2010 Chile events, but greater in depth. The Chile North scenario predicts a higher shoaling of one meter (3.3 feet) along the entrance starting from the inside of the east jetty, and also creates a deposition region at the southern half of the North Harbor. The Alaska scenario produces the greatest sediment movement. More than 2 meters (6.6 feet) of deposition is estimated throughout the South Harbor and the southern half of the North Harbor. The scour areas are the same as with other events, as erosion greater than 2 meters (6.6 feet) is found around the jetties.

Table 4 Volumes of sediment eroded or deposited in and out of the harbor (Note that 1 m^3 = 1.3 cubic yards = 35.5 ft^3)

Sed. Transport Amount / Tsunami Source	Net Volumetric Change (m^3)		
	North Harbor	South Harbor	Entrance
Japan 2011 event	3,500	110	-13,500
Chile 2010 event	1,850	-285	-7,340
Alaska-Aleutians scenario	700	36,670	-153,000
Chile North scenario	8,510	-1,330	-24,800
Cascadia scenario	60	-30	710

Table 4 provides volumetric estimates of sediment transport predicted by analyses for each tsunami scenario/event for the harbor sections shown in Figure 7. In the North Harbor area, net deposition is predicted for all cases, with the highest amount of 8,500 m^3 due to the Chile North scenario. In the South Harbor, a net deposition of 36,670 m^3 was estimated from the Alaska scenario, whereas minimal changes were expected from other cases. All sources tend to scour the entrance channel, except the Cascadia case. The Alaska scenario is expected to erode 153,000 m^3 of materials from the channel, followed by the Chile North scenario and the 2011 Japan cases, which remove 24,800 m^3 and 13,500 m^3 of sediment respectively.

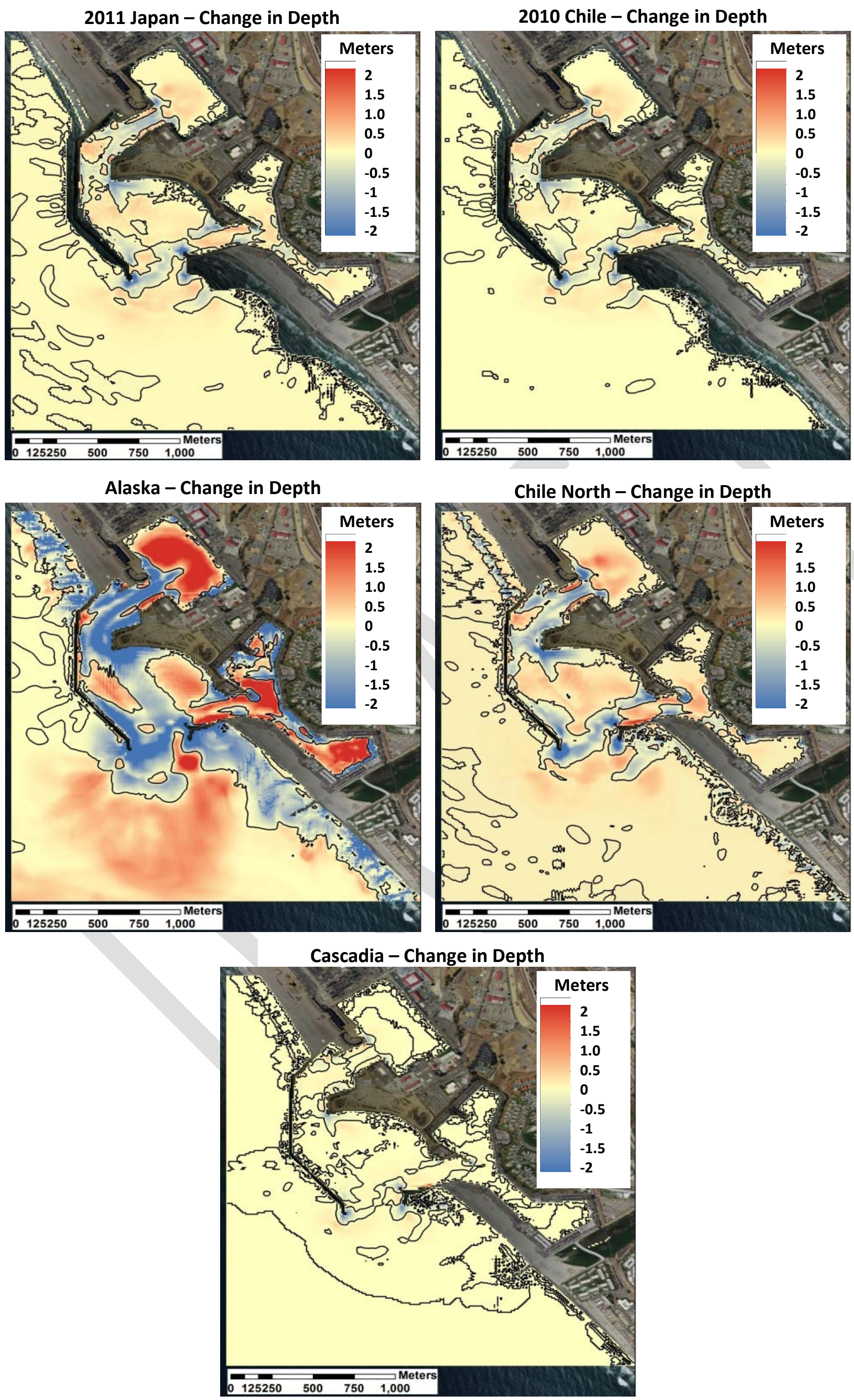

Figure 6 Seafloor elevation changes due to tsunami sediment transport, where areas of blue indicate scour and areas of red indicate sedimentation. The magnitude of the elevation changes is given by the color bar.

Figure 7 Harbor sections that were used to calculate the volumetric estimates

Tsunami debris transport for Oceanside Harbor was computed for each tsunami scenario as well. Figures 8 to 10 provide a summary of the potential transport of debris. Before the arrival of the tsunami, 600 “tracer” particles were placed throughout the harbor. These particles were divided in to five groups according to their location in the harbor, and each of the groups are plotted with a different color. The particles begin to move with the flow when current speeds exceed 3 knots, and therefore these particles are meant to approximately represent damage-related debris. The tracer motion results are driven only by the tsunami currents; tidal current and/or wind affects have been neglected.

The results of debris transport analysis that are shown in Figures 8 and 9 indicate that the 2011 Japan, 2010 Chile events and the Chile North scenario create similar patterns of debris transport in Oceanside Harbor. These tsunamis are able to move only the particles placed at the entrance of the Harbor as well as those in the channel. These particles tend to leave the harbor, flushed out by the tsunami currents. On the other hand, the Alaska tsunami moves the majority of the particles, which makes it the most critical scenario in terms of debris transport for Oceanside Harbor. Compared to the other cases, the Alaska tsunami moves particles from a larger area, which extends to the back of both South and North Harbors as shown in Figure 10. Most of these particles are flushed out of the harbor, and tend to spread equally to the north and south of the harbor entrance. Lastly, Cascadia scenario does not cause any significant debris transport here.

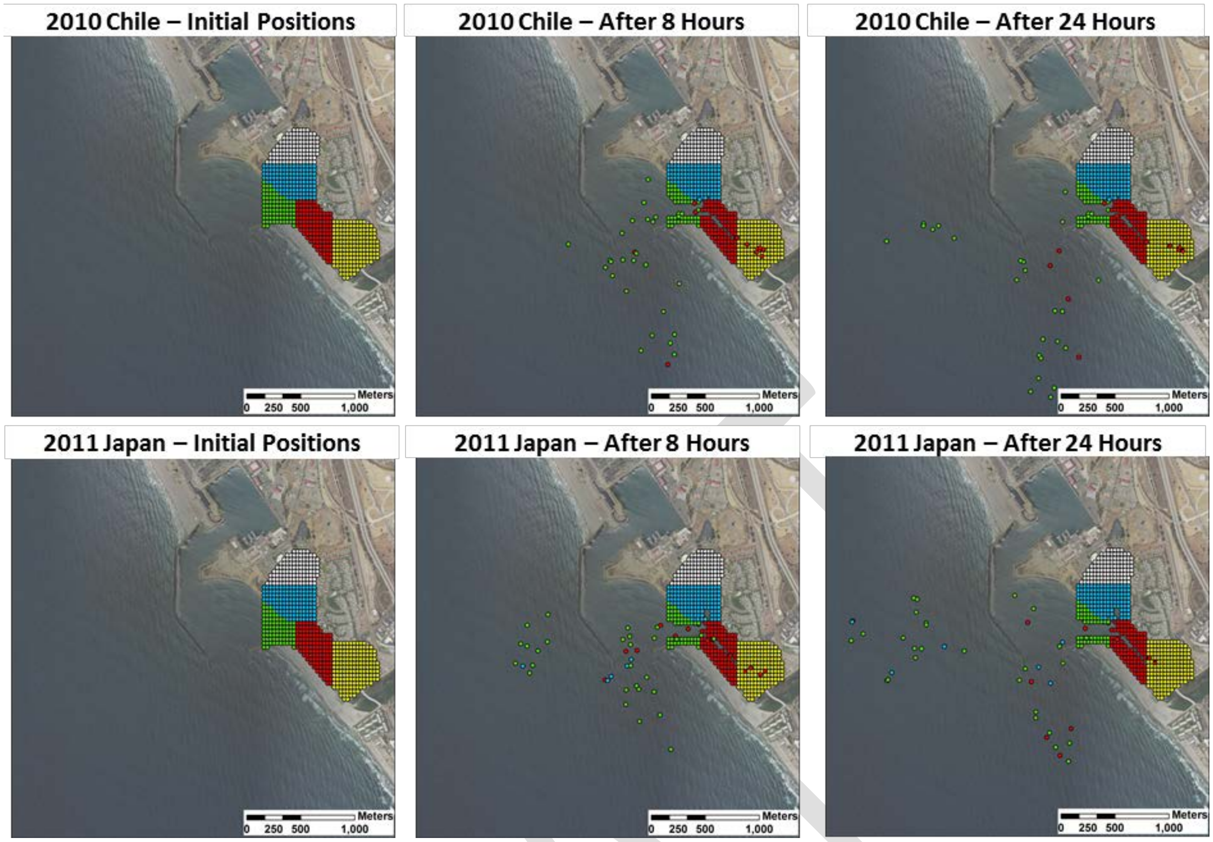

Figure 8 Debris transport potential for each scenario (different rows) and for three different times: pre-tsunami (left column), after 8 hours of tsunami activity (center column), and after 24 hours of tsunami activity (right column) for 2011 Japan and 2010 Chile tsunamis.

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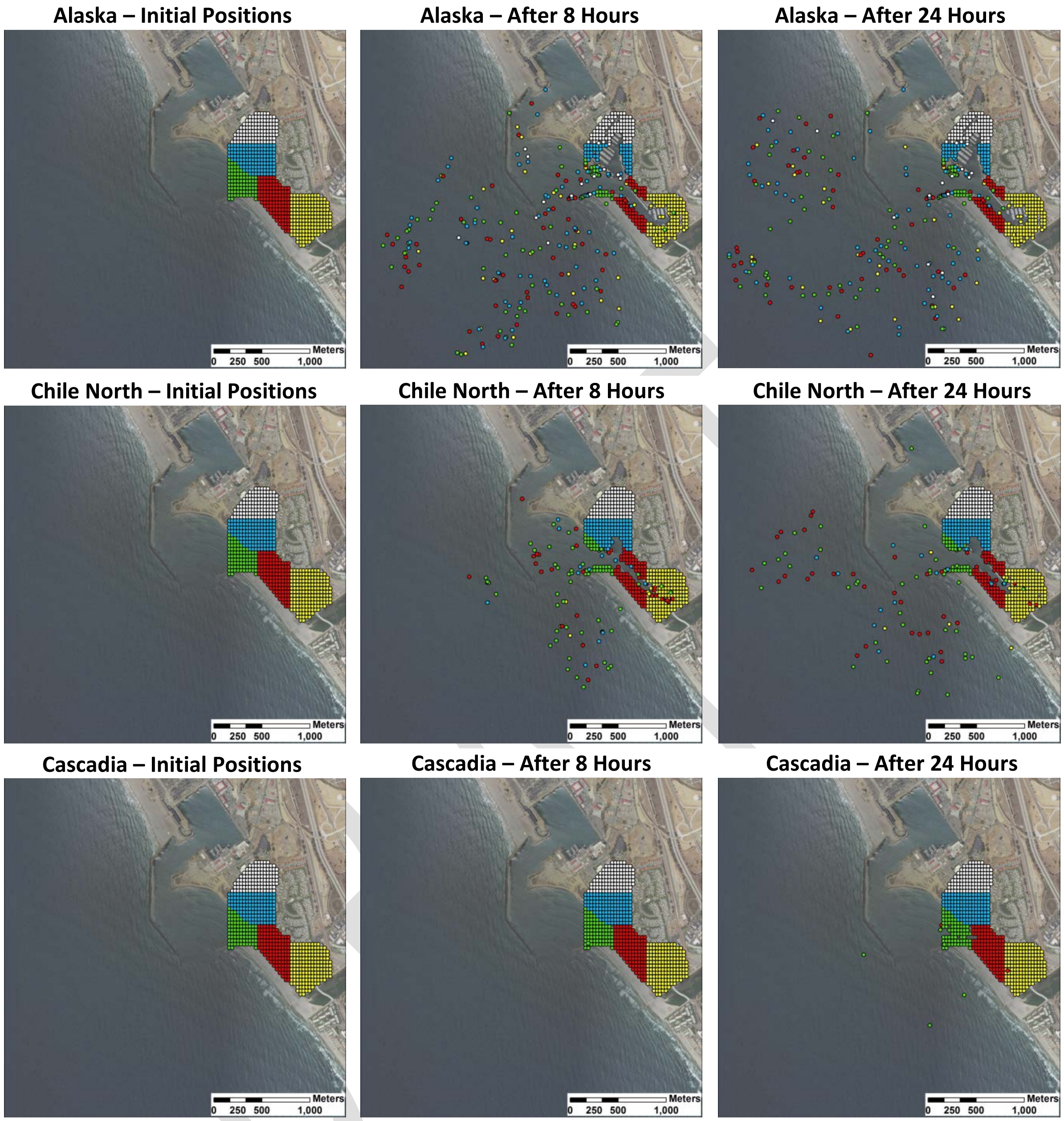

Figure 9 Debris transport potential for each scenario (different rows) and for three different times: pre-tsunami (left column), after 8 hours of tsunami activity (center column), and after 24 hours of tsunami activity (right column) for Alaska, Chile North, and Cascadia Scenarios.

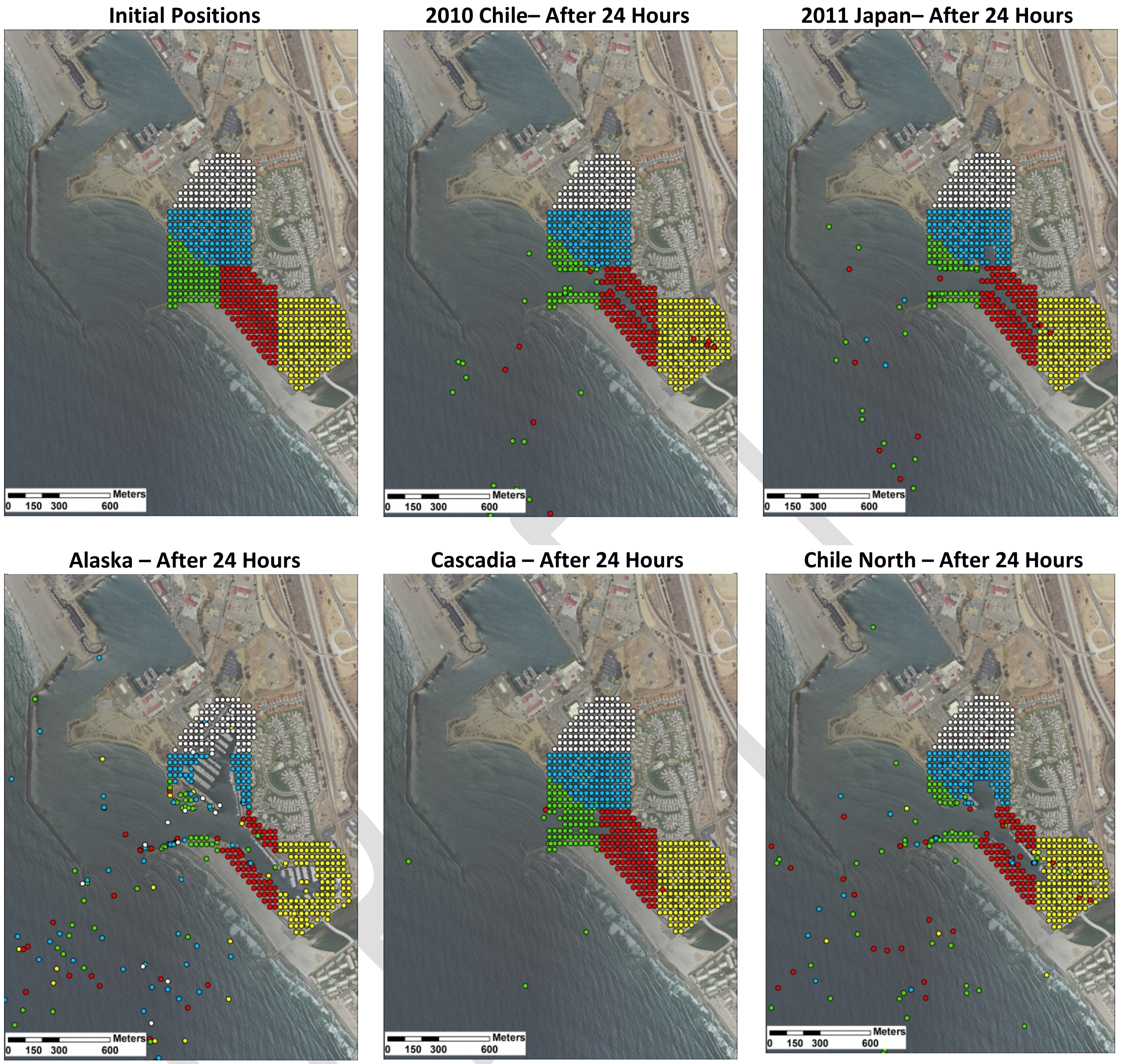

Figure 10 Distribution of debris particles in the vicinity of the harbor after 24 hours. Top left image shows the initial positions of the tracer particles.

2.5 Conclusions

The purpose of this report was to assess the vulnerability of Oceanside harbor to historical events and probable future scenarios. To achieve this, high resolution numerical modeling was run for five tsunami events (two historic events, and three realistic scenarios). The results of the numerical modeling were combined with a statistical method to estimate the structural vulnerability of cleats and pile guides, as well as to understand the potential for scour, sedimentation, and debris transport.

Like the cleat analysis, results of the pile guide analysis indicate that Oceanside Harbor is most vulnerable to the Magnitude 9.2 Eastern Aleutian-Alaska Scenario. The modeling indicates that Zones 1-6 have a moderate level of vulnerability. After the Aleutian-Alaska Scenario, the results indicate that the next most damaging event would be the Magnitude 9.4 Chile North Scenario. In terms of all scenarios, Zone 1 would be most vulnerable to the modeled tsunami events with four of the five scenarios suggesting a moderate level of vulnerably. The next most vulnerable area would be Zone 5.

Sediment and debris transport analyses indicate that the Oceanside harbor not likely to experience problems related to these processes. Among all the tsunamis considered in this study, only the Alaska scenario creates meaningful changes in the bottom topography due to sediment transport, which is approximately 1 meter (3.3 feet) of deposition in the harbor basin, in addition to the 1 meter (3.3 feet) of scour expected around the jetty tip. Numerous debris particles originating near the entrance and center of the harbor are generated within the first 8 hours of the Alaska tsunami. These particles are carried towards west through the Harbor Channel and out into the open ocean.

3 Recommended Actions

3.1 Overview

The following section summarizes the recommended tsunami hazard mitigation activities for the harbor, including both response activities and permanent measures. A brief discussion of other coastal hazards and other susceptible harbor facilities is provided as background to help demonstrate how recommended actions are comprehensive. The potential benefit-cost of mitigation measures will also be considered where appropriate.

3.2 Non-Tsunami Hazards

Other non-tsunami hazards are briefly discussed in this section. Where these hazards are similar to tsunamis, harbor improvements will be more beneficial by addressing multiple hazards.

3.2.1 Extreme Tides

Extreme tides, also known as spring or King tides, occur during special alignments between the earth, moon, and sun. These alignments can increase the elevation of ocean water column by 2-4 feet beyond average tidal levels in California. Sea level anomalies, such as those due to strong El Nino events, can cause prolonged 1-2 feet additional increases in water levels. These extreme water levels can cause localized flooding in low-lying areas and push wind-generated, breaking waves inland. Unlike tsunamis, high-velocity surges do not occur, but they are similar to tsunamis in that water levels can be significantly increased within harbors. Any structural improvements which raise the pile heights or elevate fixed piers will help mitigate this hazard.

3.2.2 Storm and Swell Events

Most harbors are protected from daily wind waves by breakwaters. Similar to tsunamis, waves and surges from large coastal storms can travel beyond breakwaters and travel into harbor and port entrances. Storm surge, the change in water level caused by strong winds and pressure gradients, can behave very similar to tides. Surges often are characterized by a relatively gradual change in the water level and weak currents, relative to tsunami events. Wind waves associated with storms or large distant swell events can lead to increased wave heights inside a harbor. Structures and infrastructure near harbor entrances can be susceptible to excessive wave action from these storms. Critical facilities located on or near the water in these areas should be moved, raised or reinforced. Additionally, long period wave events can cause seiching, or sloshing, in harbors through a process called harbor resonance. The character of these sloshing events is very harbor specific, but does exhibit behavior that can be similar to a tsunami, with rapidly changing water levels and strong currents in channels.

3.2.3 Sea-Level Rise

In 2015, the California Coastal Commission (CCC) developed guidance for addressing potential sea-level rise due to climate change (California Coastal Commission, 2015). For southern and central California, the CCC referenced a National Academy of Science report from 2012 projecting sea-level rise of: 1) 2-to-12 inches by the year 2030; 2) 5-to-24 inches by 2050; and 3) 17-to-66 inches by 2100. Harbor facilities are typically updated every 30-40 years, so any new structures or infrastructure improvements should consider the 2050 threshold which is a 24-inch (2-foot) rise in ocean water levels.

3.3 Other Harbor Facilities and Consideration

There are a number of recommendations that can be generally applied to small craft marinas subject to tsunami currents/run-up and related coastal hazards:

- Guide piles for floating docks should exceed the highest postulated run-up from tsunamis with a safety factor of 3-5 feet or more, including consideration for Mean High High Water (MHHW), and should have an additional load factor (horizontal capacity) of 1.25 for design, so that these piles will remain in place following any tsunami event. Having these piles in place will make re-construction easier and quicker, to restore operations/income in a minimum amount of time. Pile heights at this level will also help address the issue of long-term sea-level rise which will improve the functionality and resilience of the harbor.
- Differential heave motion between floating dock segments during tsunamis can cause jamming of these segments as they move up and own within the pile guides Freeboard of the floating docks should be designed according to available standards, but in general should be no less than 16 inches in unloaded conditions and 12 inches in loaded conditions. Changes in the freeboard along and across the docks should minimized in order to reduce the possibility that the dock will jam when subjected to the sudden large variation in high/low water levels. Having these minimum differential floatation values will reduce the possibility that the dock would jam when subjected to the sudden large variation in high/low water levels.
- Dock gangways are a common failure point for extreme low or high water levels. Gangways for docks should consider the minimum water depth associated with the maximum tsunami, or at least be capable of remaining operational if the wave trough reaches the mudline. This will reduce the potential for failure during tsunamis and make docks more resilient with long-term sea-level rise.
- Degraded mooring lines and dock rope may have less strength than the cleats they are tied to. In these cases, boats may be pulled from slips early in the event. Line strength and condition should be specified such that they have at least an equal capacity to the cleats.
- An implemented, comprehensive inspection program, is highly recommended; significant damage can be attributed to marine degradation and lack of any consistent inspection/implementation plan. Harbors which maintain up-to-date inspection records will help identify problem areas and improve their chances of receiving post-disaster recovery funds. The state tsunami program can provide guidance for pre- and post-tsunami inspections.
- As the Tsunami Impact Report (Section 2) indicates, large tsunamis can cause over two meters (6.6 feet) of sediment deposition within the interior harbor basins. Consistent dredging at harbor entrances and within channels can reduce scour in these areas during tsunamis, and therefore, reduce sediment input into harbor basins. Dredging under and around floating docks where shallow conditions already exist will reduce the potential for grounding of large-keel vessels.
- Environmental issues can cause long delays in the post-tsunami recovery process. These include sediment and debris removal, spills from fuel and sewage lines, and leaks from damaged vessel fuel tanks. Limiting the amount of debris and sedimentation and reducing the exposure of infrastructure and vessel damage can significantly help mitigate these issues. Having pre-disaster plans and agreements in-place with engineering, dredging, and debris removal companies will reduce contracting conflicts and improve short-term recovery efforts.

3.4 Response "Soft" Mitigation Measures

For local/near-source tsunamis, dangerous surges and flooding can arrive within 10 minutes and immediate evacuation from beaches and harbors is recommended. However, when a tsunami is generated by a distant source across the Pacific Ocean, harbor personnel have the time perform specific response activities which can greatly reduce the impact of the tsunami before it arrives. Some of these activities are listed in Table 1, and include: 1) removing people from vessels, docks, and waterfront areas; 2) repositioning vessels or other assets to safe locations inside or outside of the harbor; and 3) shutting down fuel, sewage, and electrical infrastructure. The state tsunami program has provided tsunami response Playbooks which the harbors can use to clearly define these activities for different size tsunami events. On-going education of boat owners regarding the hazards discussed above can also reduce the exposure of people and vessels from future tsunamis.

Based on the Tsunami Impact Report for Oceanside and Camp Pendleton harbors, the following additional, specific response activities should be considered (Zones are identified on Figure 3):

- Evacuations of boaters and other people on or near the water should be expected during large Warning-level tsunamis originating from Alaska or Chile.
- A clearly defined plan for recommending if and where vessel repositioning, in harbor or offshore, should occur will reduce exposure of people and vessels from tsunami hazards. In the case of offshore repositioning, boaters should be aware that a return to harbor may be delayed, and should have supplies to remain offshore for a day or longer.
- Based on the cleat damage potential analysis, mooring lines for vessels docked in Zone 1 and 5 should be checked prior to the arrival of the tsunami.
- Based on the pile guide damage potential analysis, pile guides for docks within Zone 1 should be checked and possibly cleaned prior to the arrival of the tsunami.
- Based on the damage potential and debris movement analyses, large vessels in Zones 1, 4, 5, and 6 may possibly be moved to safer areas within the harbors (Zones 7, 8, and 9). This is especially true for large tsunamis originating from Alaska or Chile.
- Full GIS Infrastructure Assessment: identify locations of hazmat sources (fuel pumps, sewage/fuel/water lines, tanks, temporary storage, other), electrical lines, buildings by use, docks by condition, vessel berths by type/size of vessel anticipated to be located there. Prioritize each asset by hazard level/zone association.

3.5 Permanent "Hard" Mitigation Measures

The long-term resilience of harbors during and after extreme coastal events, like tsunamis, will depend on the ability of structures/infrastructure to resist damage and the capability of harbors to become functional after the event. The ability to resist damage is a function of reducing the exposure to hazardous conditions (demand) as well as the maintaining/upgrading the structures/infrastructure (capacity) within the harbors.

Based on the Tsunami Impact Report for Oceanside and Camp Pendleton harbors, the following additional, specific permanent mitigation measures should be considered (Zones are identified on Figure 3; the official harbor map, Figure 2, is also referenced):

- The docks housing fuel and pump-out stations (Figure 8) should be reinforced to prevent damage from strong currents or debris impact. Possible pipeline/tank failures can create serious pollution issues.

- Based on the cleat and pile guide analysis, cleats and pile guides in Zones 1 and 5 should be inspected/maintained and replaced where they appear to be damaged or deteriorating.
- General improvement of floating dock decks, per prioritized assessment. For example, adding strength capacity, through stronger cleats, pile guides, and lines, would be beneficial in high hazard zones.

3.6 Engineering Guidance

Maritime engineers have many resources available for constructing structures and infrastructure within harbors and ports. These engineers typically have a significant amount of experience and know what references should be used for harbor improvement projects. The following section provides a brief summary of some primary references which can be utilized for harbor design or rehabilitation.

ASCE Manual for Planning and Design of Small Craft Harbors (2012): This reference provides general guidelines and planning for small craft marinas. Design guidance is provided for breakwaters and floating and fixed docks with recommendations for maximum wave heights and wave periods. Methods to calculate wind and current forces on small vessels is also provided.

City of Newport Beach Building Code (2014): From the Newport Beach Building Code, guide piles and floating docks shall be designed for a 1 foot/second current, and pile heights should be at least +12 feet above MLLW if in a protected area, and +13 feet above MLLW near the harbor entrance. The current velocity seems low, but in a protected area, this may be acceptable.

Cleats shall be designed to accommodate all loads appropriate for their location, and at least 2 cleats on each side of a finger are required. Through-bolts shall be used. In general, this code is fairly complete, with limitations on differential floatation of the docks. This is important to the tsunami load case, as it will reduce the possibility of the floating dock being jammed when subject to high/low water levels.

Layout and Design Guidelines for Marine Berthing Facilities (California Department of Boating and Waterways, 2005): The commentary of this reference suggests that guide pile heights can be up to 6 to 8 feet above mean high tide, to accommodate storm surges. No concrete guidance is given for tsunami heights, but as a first step, 6 to 8 feet may be a good guideline. This guide does provide the pros and cons of various types of guide piles. Pontoon and floatation specifications are also complete and provide recommendations for the design of floating docks. Extreme tidal variations along California's coast are estimated to be between 10 to 14 feet, without any consideration of a tsunami.

Small Craft Berthing Facilities Design (UFC, 2009): This recent Uniform Facilities Criteria (UFC) reference provides guidance for floating and fixed docks for small craft marinas. First, it is recommended that larger vessels are placed at the entrance to the marina. Although seemingly a universal good idea, larger vessels with deeper drafts may be able to exit a marina faster than smaller vessels, but this recommendation may not be recommended for marinas subject to high tsunami currents. Usually the highest velocities/eddies are associated with marina entrances.

The UFC also suggests that if waves are higher than 2 feet, a fixed dock is preferred; however, if the tidal variation is greater than 3 feet, a floating configuration is recommended. And if the current is greater than 3 feet/second (1.8 knots), then it should be "considered in the design." The following paragraph is extracted from this UFC:

Hurricanes (Typhoons), Flood Flows and Tsunamis. *Hurricanes, flood flows and tsunamis are similar in that each can produce dramatic water level rises and destructive waves and currents. If the pier or dock cannot reasonably be designed to withstand such extreme conditions, the berthing system must be relocated to a more protected site, or the consequences of catastrophic failure accepted.*

4 Local Hazard Mitigation Plan Section

The primary purpose of this report is to provide guidance to harbor and port managers about where permanent mitigation measures can be implemented to reduce the impacts from tsunamis and other coastal hazards. This section is formatted to be directly included in the Local Hazard Mitigation Plan (LHMP) for coastal communities or counties. The LHMP process makes communities eligible for pre- and post-disaster funding from FEMA and CalOES. Inclusion of this section in the LHMP will make it easier for harbors to qualify for this grant process or other grants or loans to help fund reinforcement or replacement of structures or infrastructure susceptible to tsunamis. Having said that, harbor managers and local community emergency managers should review and discuss each of these recommendations and determine if they are appropriate for inclusion in community LHMP. For more information about this process, visit the following websites:

http://www.fema.gov/hazard-mitigation-assistance

http://www.caloes.ca.gov/for-governments-tribal/plan-prepare/hazard-mitigation-planning

Table 5 lists, describes, and ranks specific mitigation measures that address tsunamis and other coastal hazards. In order to more easily integrate this information into the LHMP, the format of the table was slightly modified from the example provided in the FEMA "*Local Mitigation Planning Handbook*" (2013):

Table 5 Hazard Mitigation Plan for Oceanside Harbor

Description of Mitigation Activity	Prioritization (High, Medium, Low) and Timeframe	Hazards Addressed	Responsible Agency	(B/C) Benefits-Costs (TF) Technical Feasibility
Develop and share educational materials with boating community (recreational and commercial) that identify the hazards and provide sensible response actions for extreme events like tsunamis.	High Short term - Ongoing	All coastal hazards		B/C: Sustained mitigation outreach program has minimal cost, especially with the educational resources (brochures, guidance, Playbooks) provided by the State and the National Weather Service (NWS). TF: This low cost activity can be combined with recurring outreach opportunities at meetings where hazard specific information can be presented in small increments.
Develop a harbor response plan, using tsunami response Playbooks or other format, which outlines specific response activities for extreme events of different sizes like tsunamis. Close coordination with community emergency managers will be required.	High Short term	All coastal hazards		B/C: Developing or updating harbor response plans has a minimal cost, especially with the resources, like the Playbooks, provided by the State and the NWS. TF: This relatively low cost activity can be completed with the help of the local community emergency manager as well as the State and NWS.
Reinforce fuel dock and dock with the pump-out station. Delays in recovery efforts may occur if there is	High Short term	Tsunamis		B/C: The cost of reinforcement is minimal compared to that of long-term recovery. If this infrastructure becomes damaged and environmental spills occur, the harbor could be

infrastructure damage and spills occur.				closed while water and sediment decontamination and removal takes place. TF: Dock reinforcement and infrastructure hardening would take an engineering analysis but there are mitigation measures available.
Reduce the exposure of or remove liquid and solid chemical containers from waterfront areas.	High Long term	All hazards		B/C: Removing or relocating environmental hazards away from the water will reduce the potential for contamination during extreme events. Removal and monitoring of chemicals is an inexpensive endeavor with large benefit. TF: Removal, relocation, and monitoring chemicals is a simple process.
Conduct a comprehensive harbor-wide inspection program on a semi-annual basis.	High Long term	All coastal hazards		B/C: Inspections are vital to maintain a safe and functional harbor. If done routinely, they can identify weak points in the harbor that need maintenance and will help immensely with post-tsunami recovery funding. Inspections are relatively inexpensive. TF: Engineers for the harbor can complete inspections easily and in a minimum amount of time. Guidance for inspection protocol can be provided by the state tsunami program upon request.
Install dock pile extenders on piles less than ____ feet.	Medium Short term	Tsunamis; Potential long-term sea-level rise		B/C: Pile extensions may be costly but they may be required to address sea-level rise in the long term in order to keep the harbor functional. TF: Although feasible, installing pile extenders will take time and likely shut down the docks being worked on for a period of time.
Maintain and/or replace old cleats and mooring lines in Zones 1 and 5.	Medium Short term	Tsunamis		B/C: Cleat and mooring line failures are common during moderate to large tsunamis, but the cost of replacing these features is relatively minor. TF: Replacing cleats and mooring lines is a simple process.
Maintain and/or replace old dock pile guides in Zone 1.	Medium Short term	Tsunamis; Extreme tides		B/C: Dock pile guides are a common point of failure during tsunamis where strong surges and moderate water-level fluctuations occur. The cost of replacing pile guides is minor to moderate. TF: Replacing all or part of the pile guides is a simple process.
GIS Infrastructure Assessment: identify locations of hazmat sources (fuel pumps, sewage/fuel/water lines, tanks, temporary storage, other), electrical lines, buildings by use, docks by condition, vessel berths by type/size of vessel anticipated to be located there. Prioritize each asset by hazard level/zone association. Identify any naturally protected and/or sensitive habitat areas.	Medium Long term	Tsunamis		B/C: Knowledge of what assets are within various hazard levels, with ability to prioritize addressing resiliency. Cost of staff to perform analysis. TF: Would require some technical capability using a GIS analyst at the harbor or city, state, or other. GIS specialists can analyze and map data to support the planning process and communicate information, such as the locations of assets at risk in threat- or hazard-prone areas and estimates of damage for a particular disaster scenario. Public works/engineering staff can help identify current or projected problems for the community's infrastructure that can be addressed through capital improvements supported by the mitigation plan.

Increase sediment dredging at the breakwater entrance and within the channel leading to the Camp Pendleton Harbor. This will reduce the amount of sediment available to be deposited in harbors during high-energy events.	Low Long term	Tsunamis		B/C: Deepening entrance channels can reduce the sediment available for deposition within the harbor basins, however additional and increased dredging can be a costly endeavor. TF: Dredging activities take significant planning and permitting, however it is feasible to increase dredging if the harbor desires.

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