I. EXECUTIVE SUMMARY

Damaging tsunamis are rare but potentially catastrophic events that present a danger to the people and economy of California. Over 80 tsunamis have been observed or recorded along the coast of California in the past 150 years, 9 causing minor damage in ports and harbors and 2 with major impacts. Four events caused deaths; the worst occurred in 1964 when 12 people died in California from the tsunami generated by the Great Alaska earthquake. Local earthquakes can produce damaging tsunamis that will provide very little warning time.

On Sunday, December 26, 2004, a strong earthquake of magnitude 9.3 occurred off the coast of northern Sumatra, triggering a giant tsunami that propagated throughout the Indian Ocean Basin, causing massive casualties and destruction. As a result of the Sumatra event and past damaging California tsunamis, the Seismic Safety Commission created a Tsunami Safety Committee to evaluate the state of tsunami readiness in California. This committee held six meetings, took testimony from representatives of local governments and the scientific community. Based on this testimony, the Seismic Safety Commission made the following Findings and Recommendations:

Findings

1 Tsunamis, generated either locally or from events elsewhere in the Pacific Basin, pose a significant threat to life and property in California.

2 Tsunamis present a substantial risk to the economy of the State and Nation, primarily through the impact on our ports.

3 Californians are not adequately educated about tsunamis and the risk they pose; consequently, many are unaware how to respond to natural or official tsunami warnings.

4 The existing tsunami warning system has not achieved all of its objectives for several reasons including problems with communications, agency coordination and protocols.

5 Present building codes and guidelines do not adequately address the impacts of tsunamis on structures. Currently available tsunami inundation maps are not appropriate for code or guideline applications.

6 Federal programs have provided resources to initiate tsunami hazard mapping and mitigation programs. However, more effort and a better understanding of the risk is required to bring the treatment of tsunamis to a level comparable to other State hazards such as earthquakes.

Devastation from the 2004 Sumatran tsunami.

7 The Governor's Office of Emergency Services and many local governments have been proactive in addressing the State's tsunami risk and, since the Sumatran tsunami and the June 14, 2005 tsunami warning in northern California, have renewed interest in improving warning dissemination and other aspects of tsunami planning and preparedness.

Recommendations

The State of California should:

1. Improve education about tsunami issues in the State:

    a. Include multi-language education about tsunami hazards and how to respond to large coastal earthquakes, sudden water level changes and official tsunami warnings in all California schools.

    b. Actively educate coastal populations about tsunami hazard zones, evacuation routes and install signage consistent with other west coast states as soon as possible.

    c. Update State and local earthquake preparedness materials to include tsunami safety. Incorporate tsunamis in safety training for workplaces in inundation zones, especially ports.

    d. Develop multi-language tsunami information and educational materials and make them available to visitors to coastal areas.

2. Work with other coastal states to obtain an external expert review of the NOAA tsunami warning system criteria for issuing and canceling warnings as well as the format and procedures for distribution.

3. Continue to work with federal agencies to develop guidelines for structures to resist both strong ground motion and tsunami wave impact.

4. Support and provide matching funds for tsunami mitigation programs in coastal counties and in OES, including improvements to the communications and emergency response systems. These funds will leverage federal support for tsunami mitigation programs.

5. Support and provide matching funds for the development of improved technologies and methodology to assess the tsunami risk. These new technologies and risk assessments should be used to support better long-term and emergency response planning. Develop probabilistic tsunami hazard maps appropriate for building code and land-use regulations.

II. THE TSUNAMI HAZARD IN CALIFORNIA

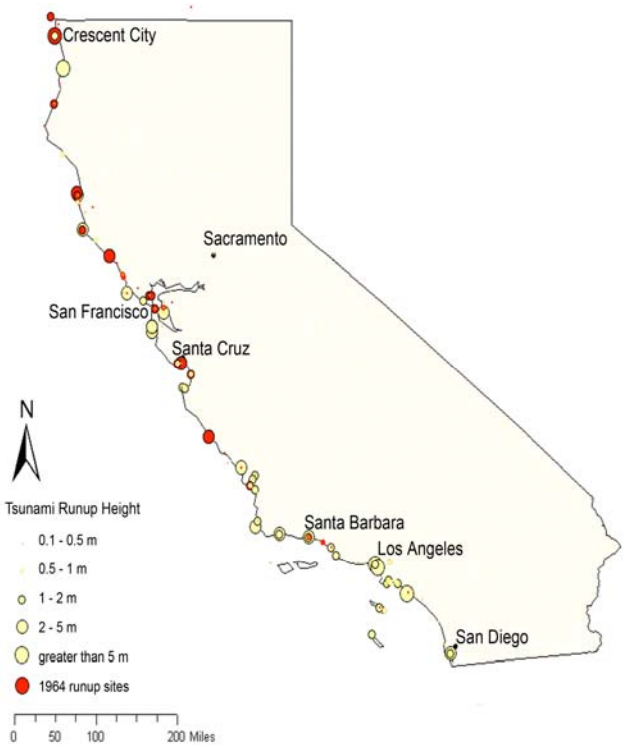
What is a tsunami?

A tsunami is a series of waves most commonly caused by the deformation of the sea floor during a submarine earthquake. They are also generated by landslides, volcanic eruptions or more rarely by asteroid impact. Tsunamis are extremely long waves with the distance between successive peaks or troughs on the order of 10's to 100's of miles. As the waves enter shallow water, they slow down and rise in height, in the largest cases, by tens of feet. Large tsunamis can cause great loss of life and property damage where they come ashore. Tsunamis are always largest closest to the source region where they may strike the closest coastlines only minutes after the triggering event. The largest tsunamis travel across the ocean with sufficient energy to cause damage thousands of miles away and many hours after the source event occurred. When the coastal area is close to the source region and the first waves to arrive take less than an hour to travel, the tsunami is called a local or near-field tsunami. For travel times of several hours or longer, the tsunami is a distant or far-field tsunami.

Crescent Beach Motel, Crescent City, California damaged by the 1964 tsunami. A core taken from the pond shown by the star. Deposits of sand from the 1964 and 1960 tsunamis marked by the red arrows are much smaller than the 1700 deposit marked by the green arrow.

Does California have tsunamis?

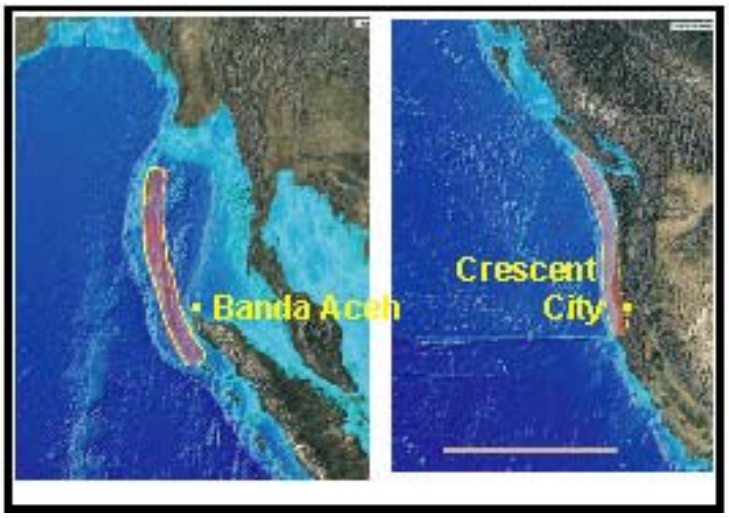
California is at risk from both local and distant tsunamis. Eighty-two possible or confirmed tsunamis have been observed or recorded in California during historic times. Most of these events were small and only detected by tide gages. Eleven were large enough to cause damage and four events caused deaths. Two tsunami events caused major damage. The 1960 Chilean earthquake produced a great tsunami that impacted the entire Pacific basin. Damage was reported in California ports and harbors from San Diego to Crescent City and losses exceeded one million dollars. The worst event was the 1964 tsunami generated by the M 9.2 Alaska earthquake that killed 12 in Northern California and caused over $15 million in damages. The peak wave height was 21 feet in Crescent City and 29 city blocks were inundated. Wave oscillations in San Francisco Bay lasted more than 12 hours causing nearly $200,000 in damages to boats and harbor structures.



What is the greatest risk to California?

The Cascadia subduction zone will produce the State's largest tsunami. The Cascadia subduction zone is similar to the Alaska-Aleutian trench that generated the magnitude 9.2 1964 Alaska earthquake and the Sunda trench in Indonesia that produced the magnitude 9.3 December 2004 Sumatra earthquake. Native American accounts of past Cascadia earthquakes suggest tsunami wave heights on the order of 60 feet, comparable to water levels in Aceh Province Indonesia. Water heights in Japan produced by the 1700 Cascadia earthquake were over 15 feet, comparable to tsunami heights observed on the African coast after the Sumatra earthquake.

The Cascadia subduction zone last ruptured January 26, 1700, creating a tsunami that left markers in the geologic record from Humboldt County, California to Vancouver Island, Canada and is noted in written records in Japan. At least seven ruptures of the Cascadia subduction zone are observed in the geologic record.



Comparison of the December 26, 2004 Sumatra rupture and the estimated rupture of the 1700 Cascadia Subduction zone at the same scale. Scale bar is 700 mi.

Distant and local tsunamis.

Tsunamis that damaged California's coast have come from all around the Pacific basin including South America and Alaska. Nearly two thirds of California's historic tsunami events and all but one damaging event were generated by distant sources.

In addition, local tsunamis can be caused by offshore faults or coastal and submarine landslides and have the potential to cause locally greater wave heights and do pose a threat to the state. The largest historic local-source tsunami on the west coast was caused by the 1927 Point Arguello, California, earthquake that produced waves of about 7 feet in the nearby coastal area.

What government agencies are responsible?

The National Oceanic and Atmospheric Administration (NOAA) has statutory responsibility to provide tsunami warnings, which are disseminated in California through the Governor's Office of Emergency Services. Local jurisdictions have the responsibility for ordering and canceling evacuations.

FINDING: **Tsunamis, generated either locally or from events elsewhere in the Pacific Basin, pose a significant threat to life and property in California.**

The California Geological Survey has statutory authority to conduct tsunami inundation mapping, contingent on State funding that has not yet been appropriated. The Governor's Office of Emergency Services (OES) has contracted with the University of Southern California for preliminary tsunami inundation mapping with funding from NOAA through the National Tsunami Hazard Mitigation Program (Program). This Program supports tsunami hazard mitigation in the states of California, Oregon, Washington, Alaska and Hawaii. The State of California has representation on the program steering committee by a representative from the Governor's Office of Emergency Services (OES) and a representative from the California Geological Survey (CGS). Coordination with the other four western states and the National Tsunami Hazard Mitigation Program is essential to the success of the Program.

III. THE NATURE OF THE TSUNAMI RISK IN CALIFORNIA

Casualties.

As the 2004 Sumatran tsunami amply demonstrated, a large tsunami poses a major risk to human life, primarily from flooding and debris impact. Evacuation is possible and can save many lives if carried out properly. However, a poorly coordinated evacuation can actually put people in harm's way. Moreover, the short time frame between event and tsunami for local events requires that the local population be aware enough of the appropriate action to evacuate without official notification.

Of the five Pacific states, California has the largest population exposed to tsunami risk. NOAA has estimated that more than one million people in California live within coastal areas vulnerable to tsunami inundation (the rushing in of the water causing flooding and battering by debris). That number does not include one million or more visitors to California's beaches on any given summer day.

Financial losses.

Tsunamis cause damage to man-made structures in several ways, primarily from water currents and the impact of water-borne debris. The incoming waves cause flooding and push vessels into land-based structures. The withdrawing waves causes vessels and boats to hit bottom and damages power plants and other facilities that use sea water for cooling. The strong currents scour foundation material from under structures and carry debris. Debris carried by the water batters people and property, and is responsible for much of the damage from tsunamis. Secondary effects, such as fire and the release of hazardous materials, can escalate the disaster to a greater catastrophe. These effects are difficult to predict.

The exposure of our built environment to possible tsunami damage varies dramatically along the California coast. The flooding produced by the tsunamis depends strongly on local topography. Some areas, such as Crescent City, California have experienced large run-up, whereas other areas have yielded relatively minor impacts. In general, lower areas have always been more vulnerable. The codes that produce buildings resistant to earthquakes do not, in general, address the forces likely to arise from tsunamis. Many structures are designed to resist forces directed towards the structure; however, once water enters the structure and draw-down occurs outside of the structure, walls may collapse or deflect outward, causing serious damage.

Aerial photographs of Banda Aceh, Indonesia, before and after the 2004 tsunami.

Seaports.

Our ports face the greatest exposure for catastrophic losses. The Ports of Los Angeles and Long Beach are the first and second busiest seaports in all the United States. Together these California State-owned but city-managed seaport complexes handle 14 million units of containers annually, which make them the third busiest port in the world. Combined they handle approximately $240 billion worth and 250 million metric tons of cargo, generate $10 billion worth of yearly taxes, and are responsible for approximately $100 billion in direct and indirect business annual sales, and directly and indirectly generate some 600,000 and 2.5 million jobs throughout our State and nation, respectively. Other economically important ports in

California subject to tsunami damage include those in Oakland, Richmond and San Diego.

There is substantial development of apparently well engineered and "permanent" port infrastructure designed only for earthquake forces. They are located largely along the water's edge at the two ports and include the pile supported reinforced concrete wharves, rubble mound retaining structures, and ship-to-shore container cranes. There are also a multitude of potentially loose infrastructure and objects that can become buoyant and/or free floating in the event of flooding from a significant tsunami. These include the millions of tons of open stored dry and break bulk products; mobile equipment, vehicles, railroad infrastructure and tools; approximately 10,000 8,400 pound empty 40-foot containers; about 60 huge simultaneously berthed ocean-going ships; and thousands of smaller pleasure craft and harbor boats. These vessels are secured to their docks by sets of mooring lines that provide security for "normal" ship mooring forces, and not for the tremendous vertical buoyant and hydrodynamic forces that can be induced by major tsunamis.

FINDING: **Tsunamis present a substantial risk to the economy of the State and Nation, primarily through the impact on our ports.**

The ports' docks and terminals operate at a surface level that is, in general, only 9 feet above the mean high seawater level. A 15-foot (or greater) tsunami, for example, arriving at the Inner Harbor would therefore overtop the wharf decks and inundate much of the 7500-acre landside port operations. Without adequate warning, this would cause considerable human casualties, operational disruption, port damage, and economic impact. Based on the ports' own data, a two-month shut down of the two ports would result in a overall total economic loss of $60 billion. In addition to this, there are approximately 8,000 total outdoor personnel on any given port operational day. Unless safely evacuated, these workers can face injury and loss of life directly from drowning, or indirectly by water borne collision into water-borne debris.

The port of Valdez, AK after the tsunami of March 27, 1964.