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TECHNICAL INFORMATION RESOURCES ON TSUNAMIS WITH A SECTION ON LANDSLIDE GENERATED WAVES

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INTRODUCTION

This conference is on Technical Information Resources for Coastal Studies. I will consider the subject of tsunamis in general, followed by a separate section on water waves generated by a landslide or other mass movement (debris avalanche, rockfall), either submerged or into the ocean, a bay, lake, or reservoir. In searching the technical literature, it should be recalled that the water waves now most commonly known as tsunamis, in the past were also called tidal waves or seismic sea waves.

A great amount of technical information on tsunamis is available in journals, books, reports, newspapers, and websites. After the Sumatra-Andaman Islands Earthquake and the accompanying Indian Ocean Tsunami of 26 December 2004, I updated my list of **tsunami information sources** (increased to about 3,500), and made them available in a 115 page report. I continued to update the list, and modify the presentation in two subsequent reports. The three reports are in print and electronic format.

Much is known about tsunamis (generation, transmission, runup, and effects), and how to mitigate for them. Often, however, there has been insufficient implementation of coastal policy, procedures, and works; and maintenance and upgrading. Much is known about what to do (or not to do), and how to assess tsunami hazard and risk. We would always like to know more. But, decisions must be made, and implemented. This can be done, and must be done, although it may be difficult. Mitigation works and procedures may affect the quality of daily life (inconvenience/convenience), and efficiency of use of the waterfront. They involve choices, tradeoffs, risk, and adjustment, either explicitly or implicitly. They may be costly. Often little or nothing is done - but it has been done in some places, with details available in some of the technical information sources.

DEFINITIONS OF RISK, ADJUSTMENT, MITIGATION

Risk, adjustment, and mitigation are defined as follows, as used in this presentation

Risk - "The probability of harmful consequences or expected losses (death and injury, losses of property and livelihood, economic disruption, or environmental damage resulting from interactions between natural or human-induced hazards and vulnerable conditions."

(From National Science and Technology Council, Dec. 2005, p. 23)

Adjustment - "The word 'adjustment,' as used here, is not meant to imply complete avoidance of risk. Some degree of risk must be acceptable, for economic reasons. Furthermore, because of the infrequent occurrence of tsunamis, information regarding their possible impact locations and runup heights is very scanty, and it must be assumed that no reasonable action can take into account all possible risk. For some locations the decision might be to make no adjustment whatever."

(From Ayre, Robert S., with Dennis S. Mileti, and Patricia B. Trainer, 1975, P. 104)

I recommend that this definition be modified by adding the term **and convenience in daily life** after the words **economic reasons** in the second sentence.

Mitigation - "Mitigation involves sustained actions taken to reduce or eliminate the long-term risk to human life and property based on tsunami risk assessments. this includes planning and zoning to manage development in areas particularly at risk for tsunami, embracing tsunami resistant construction, and protecting critical facilities and infrastructure."

(From National Science and Technology Council, Dec. 2005, p. 1)

THREE TSUNAMI INFORMATION SOURCES REPORTS, UCB

As mentioned in the Introduction, I have prepared three reports on tsunami information sources. They are available in print and in electronic format. The sources are listed in the following categories:

Articles, papers, reports, by author(s)
Bibliographies
Books, monographs, pamphlets
Catalogs of events
Collections
Journals, newsletters
Maps
Organizations
Proceedings, symposia, workshops
Videos, photographs

The three reports are:

Tsunami Information Sources (Robert L. Wiegel, University of California, Berkeley,CA, UCB/HEL 2005-1, 14 December 2005, 115 pages). Available in printed format, and on a diskette. It is available in electronic format at the Water Resources Center Archives (WRCA), University of California, Berkeley, CA 74720-1718
http://www.lib.berkeley.edu/WRCA/tsunamis.html
and in *Science of Tsunami Hazards* (the International Journal of The Tsunami Society), Vol. 24, No. 2, 2006, pp 58-171 at
http://www.sthjournal.org/sth6.htm

Following publication of the above report, additional sources were listed in two subsequent reports, Part 2 and Part 3. Also, sources given in all three reports on the following subjects were listed separately as well, in Sections C and D, to help investigators.

Section C. Planning and engineering design for tsunami mitigation/protection; adjustment to the hazards; damage to structures and infrastructure.

Section D. Tsunami propagation nearshore; induced oscillations; runup/inundation (flooding) and drawdown.

Tsunami Information Sources: Part 2 (Robert L. Wiegel, University of California, Berkeley,CA, UCB/HEL 2006-1, 18 April 2006, 36 pp). Available in printed format, and on a diskette. It is available in electronic format at the WRCA
http://www.lib.berkeley.edu/WRCA/tsunamis.html
and in *Science of Tsunami Hazards* (the International Journal of the Tsunami Society), Vol. 25, No. 2, 2006, pp 67-125

Tsunami Information Sources: Part 3 (Robert L. Wiegel, University of California, Berkeley,CA, UCB/HEL 2006-3, 18 December 2006, 23 pp). Available in printed format at the WRCA, University of California, Berkeley, CA, 94720-1718, and on a diskette. It is available in electronic format at the WRCA
http://www/lib.berkeley.edu/WRCA/tsunamis.html

Much is known about damage to structures and infrastructure by tsunamis, and to injury and loss of life (public safety), on land and in harbors; including secondary damage such as oil spill, spread, and fire. How does one plan, engineer, construct new, retrofit old, and manage for protection/mitigation in regard to tsunami hazards, and how does one adjust to the hazards? What is the relative importance of zoning/land-management, open-space, elevation, tsunami-resistant structures, defense structures (breakwaters, seawalls, dikes, gates, forests/groves, drainage canals); aesthetics, convenience/inconvenience to people, public education? The knowledge of these subjects is widely scattered, and from the several thousand tsunami information sources listed in the first report, and in Parts 2 and 3, I have listed in Section C of Parts 2 and 3 several hundred sources on these subjects.

Closely associated with the above subjects are tsunami propagation nearshore (such as edge waves, Mach-reflection/Mach-stem, wave trapping, refraction/diffraction, wave focusing, wave scattering, bay and harbor oscillations); and the runup of tsunamis onto shore (and drawdown/ receding floodwater). Runup may occur as a fast rising tide, or a surge, or a bore. In addition to information on inundation/flooding, the subject runup and drawdown includes flow characteristics of the water; and the resulting scouring and sediment movement. It includes transport of wreckage, other debris, boats, automobiles, and other floating objects, including buildings which are not adequately attached to their foundations and floated away. Several hundred sources on these subjects are listed in Category D of Parts 2 and 3.

I have been developing a list of technical sources for the subject of water waves generated by a rapid mass movement, either submerged or into the ocean, a bay, lake, or reservoir. The mass movement may be a landslide, rockfall, debris avalanche, slump, rigid body. <u>This is work in progress. A list of about 350 references is appended</u>.

Distributed throughout reports, monographs, papers, newspaper articles, etc. are comments, data, and recommendations for designing for tsunami hazards. Building codes have been developed for some areas; they vary in detail of what they recommend. What can be done by local planners, policy makers, and coastal engineers and geologists? Where can they start? I recommend the following publication. This monograph is concise, illustrated with sketches and photos, and written to be easily understood. Reading it is the first step in learning what to "mine" from the technical information resources.

DESIGNING FOR TSUNAMIS; SEVEN PRINCIPLES FOR PLANNING AND DESIGNING FOR TSUNAMI HAZARDS

Designing for Tsunamis: Seven Principles for Planning and Designing for Tsunami Hazards, prepared for the U.S. National Tsunami Hazard Mitigation Program (**NTHMP** - NOAA, USGS, FEMA, NSF, Alaska, California, Hawaii, Oregon, and Washington), March 2001, 60 pp

[For more details, see the companion report: *Designing for Tsunamis: Background Papers*, March 2001.]

The **Seven Principles** are:

1. Know your community's tsunami risk: hazard, vulnerability, and exposure

2. Avoid new development in tsunami run-up areas to minimize future tsunami losses

3. Locate and configure new development that occurs in tsunami run-up areas to minimize future tsunami losses

4. Design and construct new buildings to minimize tsunami damage

5. Protect existing development from tsunami losses through redevelopment, retrofit, and land reuse plans and projects

6. Take special precautions in locating and designing infrastructure and critical facilities to minimize tsunami damage

7. Plan for evacuation

As an example of what is recommended, refer to Principle 4. Details about this principle are in a chart on page 35 of the monograph. Some of the effects or design solutions listed are: evaluate bearing capacity of soil in a saturated condition; hydrostatic forces; buoyancy (flotation or uplift forces caused by buoyancy); design for dynamic water forces on walls and building elements; design for breaking wave forces; design for debris impact; design for scour and erosion of the soil around foundations and piles; design waterfront walls and bulkheads to resist saturated soils without water in front; provide adequate drainage. Valuable *technical information resources* on loads and design are in reports by Dames and Moore (1980), FEMA (2000), Matlock, Reese, and Matlock (1962), Matsutomi and Shuto (1995), Structural Engineers Association of Hawaii (1972), Wilson and Torum (1968), Yeh, Robertson and Preuss (2005).

TSUNAMI HAZARDS IN CALIFORNIA

Information on tsunami hazards in California is in a number of papers and reports. Four are: *Evaluating Tsunami Potential* by McCulloch (1985); *Tsunami Inundation Model Study of Eureka and Crescent City, California* by Bernard, Mader, Curtis, and Satake (1994); *Evaluating the Tsunami Risk in California* by Synolakis, McCarthy, Titov, and Borrero (1997); *Inundation Maps for the State of California*, by Eisner, Borrero, and Synolakis (2001). Lists of tsunamis in California are in: *Tsunamis Affecting the West Coast of the United States, 1806-1992*, by Lander, Lockridge, and Kozuch (1993); *Evaluating Tsunami Potential,* by McCulloch (1985); *Tsunamis and Their Occurrence Along the San Diego County Coast*, by Joy (1968; for years 1769-1968, including remarks).

Probability predictions of tsunamis from farfield sources (teletsunamis) are in three reports prepared for the Federal Insurance Administration (FIA) by the U.S. Army Corps of Engineers, Waterways Experiment Station; two by Houston and Garcia, (1974; 1978), and one by Houston (1980). Predicted 100-year and 500-year elevations ("runups") are shown on a series of plates. The authors say (1978, p. 7):

"A 100-year runup is one that is equaled or exceeded with an average frequency of once every 100 years; a 500-year runup has a corresponding definition. Runup values in this report are referenced to mean sea level (msl) datum."

[Note. As commented by Synolakis, et al. (1997, p.

1,229): "The computational boundary was a vertical wall at the shoreline, i.e., there were no inundation computations. Houston (1980) noted that the runup elevations, i.e., the elevation of the maximum inland penetration of the tsunami may not equal shoreline elevations at locations where dunes prevent flooding, or if the land is flat, where inland flooding maybe extensive." Other pertinent comments are made.]

During the past decade or so, studies have been made of a major co-seismic tsunami that was generated along the Cascadia Subduction Zone in the year 1700 (e.g., Atwater, 1987; Atwater, Musumi-Rokkaku, Satake, et al., 2005; Satake, Shimazaki, et al., 1996). This

[Note. In a study of sedimentation rates in Bolinas Lagoon, Marin County, California, cores were taken and analyzed, including studies of pollen, and dating (Byrnes and Reidy, 2006, p. 29). A layer of sand was found at all of the "short core sites," above the peaty clay. The date was not inconsistent with that of the Cascadia Subduction Zone earthquake and tsunami in the year 1700, but they state that "more radiocarbon dates are needed to resolve the issue." It is likely that the sand is from overwash from the beach. Perhaps it is similar to the findings from sediment cores in Tillamook Bay, Oregon by Komar and Styllas (2006, p. 15). A sand layer was probably overwash from the beach by the Cascadia Subduction Zone earthquake and tsunami of the year 1700, and other overwash and breaching events made possible by subsidence of the spit.]

In regard to the preparation of tsunami inundation maps for emergency preparedness and evacuation planning, Eisner, Borrero, and Synolakis (2001) made the following comments. [Note. Richard K. Eisner was Regional Administrator of the California Governor's Office of Emergency Services (OES), Coastal Region.]

"As early as 1997, California's Coastal Regional Administrator of the Governor's Office of Emergency Services (OES), through a series of workshops and publications, informed local governments and emergency agencies of the plans to address tsunami hazards and presented the NTHMP (sic National Tsunami Hazard Mitigation Program). OES solicited input as to the levels of hazards to be represented on the maps, as the short length of the historic record did not permit a comprehensive probabilistic hazard assessment. As early as 1997, it was decided that the maps would include worst case scenarios to be identified further in the mapping process..."

They caution (p. 67): "These maps are only to be used for emergency preparedness and evacuation planning." Several examples of inundation maps are in the paper:

paleotsunami, and the occurrence of a small tsunami generated by the Cape Mendocino earthquake on 25 April 1992, triggered the use of scenarios for California of possible future tsunamis hypothesized to be generated at the southern Cascadia Subduction Zone, a "near-field event" (e.g., *Tsunami Inundation Model study of Eureka and Crescent City, California*, by Bernard, Mader, Curtis, Satake 1994). Eisner, Borrero, and Synolakis (2001, p. 76) wrote that the Cape Mendocino tsunami "was a wake up call that led to the immediate development of inundation maps for Humboldt Bay (sic, and Crescent City)."

Santa Barbara, Marina del Rey, San Francisco (Golden Gate south to Lake Merced).

In the section of my comments that follows, I mention discussions in *Civil Engineering* (mid-2005) about the Ports of Long Beach and Los Angeles, and the possibility of a severe tsunami in the future, from a hypothesized nearby underwater landslide generated tsunami. One area of agreement of the writers was the need to estimate the hazard risk in probabilistic terms. This is difficult for several reasons. One reason is that although present underwater mapping of previous slides has improved, little is known about underwater slide speeds, hence, the size of the resulting tsunami. [Details of estimating quantitatively for the Palos Verdes debris avalanche is in a paper by Locat, Lee, Locat, Imran (2004).] Another problem is the timing; when did an event occur? The date for the **Palos Verdes debris avalanche** has been estimated from carbon dating of samples from cores, to be about 7,500 years ago (Normark, McGann, and Sliter (2004). As already mentioned, earlier studies of tsunami risk were for tsunamis generated in the far-field by co-seismic underwater tectonic displacements (e.g. Houston and Garcia, 1974, 1978; Houston, 1980). These are sets of two different tsunami populations. How should the probability distributions of two different "populations" be treated?

PALOS VERDES PENINSULA AND VICINITY, CALIFORNIA; PORTS OF LONG BEACH AND LOS ANGELES

There have been discussions recently in *Civil Engineering* about the possibility (what probability?) of damage to the Ports of Long Beach and Los Angeles, California, by a hypothesized locally generated tsunami, with substantial disagreement, as well as some agreement (Borrero, Cho, Moore II, Richardson, and Synolakis, 2005; Thiessen and Gioiello, 2005; Sterling, Edge, Calhoun, et al., 2005; Synolakis, Moore II, Borrero, et al., 2005). And, in the report of the California Seismic

Safety Commission, *The Tsunami Threat to California: Findings and Recommendations on Tsunami Hazards and Risks*, one of the findings is (2005, p. 1, with details on p. 6):

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

[Note. This report is based on the work of the Commission's Tsunami Safety Ad Hoc Committee, which held 6 meetings and took testimony from representatives of local governments and the scientific community in California during 2005).]

Borrero, Cho, Moore II, Richardson and Synolakis (2005), and Synolakis, Moore II, Borrero and Richardson (2005) write about several locally generated tsunamis offshore southern California. They write about tsunamis generated by submarine landslides, and the importance of this mechanism to southern California. [Note. Submarine landslides may be triggered by earthquakes, or other mechanisms.] The authors discuss how a locally generated tsunami might affect adversely the ports of Long Beach and Los Angeles. Owing in part to this, I have prepared a list of references (about 350) for tsunamis generated by rapid mass movements, either submerged, or into, the ocean, a bay, lake, or reservoir. This includes papers and reports on fluid mechanics, theory, numerical modeling, physical modeling, characteristics of mass movements, paleo-events, and the little information I have found on speeds of such movements in nature. This list is appended hereto.

In a few of the technical sources it has been mentioned that underwater slides of accumulations of sediment at submarine canyons may be triggered by earthquakes. One case in which this might have been expected is at Newport Submarine Canyon by the 10 March 1933 Long Beach earthquake. The earthquake epicenter was on the Newport-Englewood fault zone, near Newport Submarine Canyon. No tsunami was recorded (Barrows, 1974; Hauksson and Gross, 1991). [Note. The location of the foreshock - main shock - aftershock sequence was relocated by Hauksson and Gross, to be onshore rather than offshore.]

I have not had sufficient time to write as much as I want to about this region. Some information on undersea slope instability and the potential for submarine landslide-generated tsunamis in this area are in the paper by Clarke, Greene and Kennedy (1985) and in the abstract of a paper by Greene, Maher, and Paull (2000). Responses of bays and harbors (oscillations) to tsunamis are important; as are tsunami spectral characteristics, and spectral characteristicsof the California Borderland basins and bays. Refraction is important. Several papers on these subjects are listed in the References: Houston (1977), Jen (1969), Miller, Munk and Snodgrass (1962), Raichlen (1972; 1979), Snodgrass, Munk and Miller (1962) Wilson (1971). There has been substantial subsidence of the Long Beach Port area and contiguous land owing to oil and gas withdrawal; what might the long term effects of this (e.g., U.S. Army Corps of Engineers, Los Angeles District, 2002). What about the long term effects of sea level rise? The ocean floor landslide generated tsunami that is discussed in the papers by Locat, Lee, Locat and Imran (2004) and by Normark, McGann, and Sliter (2004) was 7500 years ago. The sea level was many tens of feet lower then, and the shore a considerable distance seaward of where it is now. Terrestrial deposits from a tsunami that occurred 7500 years ago would be under water now.

This paragraph is an example of one type of technical information available in the tsunami information sources. In regard to port and harbor facilities, it is important to keep them maintained properly. William Herron comments on the performance difference in the Long Beach - Los Angeles ports, between the 1960 Chile and the 1964 Alaskan tsunamis (USACE, Los Angles District, 1986, p. 6-60). Herron said that the characteristics of the tsunamis were important; but he also said that the rehabilitation of facilities after the 1960 tsunami made them better prepared to withstand the 1964 tsunami.

[Note. Just after I completed my **handout** for the CSBPA Conference, I received a copy of the following report: *Tsunami Hazard Assessment for the Ports of Long Beach and Los Angeles. Final Report*, which had been prepared for the Port of Long Beach and the Port of Los Angeles by Moffatt & Nichol, Long Beach, CA, M&N File: 4839-169, April 2007, 91 pp. I have added this short note about it to my handout. The report has a review of historical tsunamis that impacted the two ports; these were from distant sources (Chile, Alaska). The report identifies and evaluates the likelihood of potential local tsunami sources. Scenarios were developed, and numerical (hydrodynamic)models used to generate and propagate hypothesized tsunamis from these sources to, and into, the ports. Seven potential tsunami sources were modelled: four local tectonic scenarios, two local submarine landslide scenarios, and one distant source scenario (Cascadia Subduction Zone). Potential impacts to the ports from the scenario tsunamis were described. They say (pp 1-2):

"The study expands on the previous work in that it includes more details regarding local maximum water levels, current speeds, arrival times, and overtopping rates at selected locations.... The likelihood of the occurrence of these potential sources is also discussed to place the results in the proper perspective for the design of coastal structures."

One of their conclusions is (p. 84): "Based on the seismicity, geodetics and geology, a large locally generated tsunami from either local seismic activity or a local submarine landslide would likely not occur more than once every 10,000 years."]

TRADEOFF EXAMPLE: SEAWALL - FOR YOU TO THINK ABOUT

I want to leave you with something to do. It is in regard to one type of tradeoff; the use of seawalls. What can you find in the technical information resources about the effectiveness and design of seawalls to protect against a tsunami? What has been the experience with seawalls during tsunamis? What is the present opinion about the value of seawalls for protection from tsunamis? Have the risks and values been quantified? If so, elaborate. If not, can you do so?

In Hawaii, in California, and perhaps elsewhere, it is difficult or nearly impossible to obtain a permit to build a new seawall (e.g., Eversole and Norcross-Nu'u, 2006). Experience in the Indian Ocean (Sumatra) tsunami of 26 December 2004 has demonstrated the usefulness of seawalls for protection from the tsunami, even where they were overtopped (e.g., BBC News, 2005); Strand and Masek, 2005). Shepard, Macdonald and Cox (1950, pp 443, 458, 466, photos in plates 12a and 30a) comment on the value of the strongly built concrete seawall at the Puu Maile Hospital in Hilo, HI, during the 1 April 1946 tsunami, where the wave rose about 20 feet, flooding over the wall. They say: "The wall itself was undamaged, and buildings sheltered by it were undisturbed except for minor damage by flooding." Seawalls have been used in Japan for many decades (e.g. Horikawa, 1960; Togashi, 1981; Miyoshi, 1983; Kawaguchi, Itoh, and Takeuchi, 1995). There are probably other places that they should be used. They must be well designed, constructed, and maintained; they should be long (what should be the elevation of the crest [top]?); they are usually expensive.

A word of caution. Horikawa and Shuto (1983) say the following about the need for a tsunami warning system, and the preparation and education for emergency response. This is important to a community in regard to both risk and accommodation.

"It is quite dangerous to believe that the violent attack of tsunami can be completely prevented by man-made structures. based on past experience evacuation to a safe area and before tsunami attack is the best recourse for the inhabitants. It is incorrect to depend too much on the functioning of coastal defense structures."

However, in some regions, the tsunami generating source is so close that almost no time is available for evacuation. In some areas, both tsunami and direct earthquake effects (shaking, subsidence/uplift, ground-breaking [fissures], liquefaction, landslides) occur nearly simultaneously.

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APPENDIX

WATER WAVES GENERATED BY MASS MOVEMENTS (LANDSLIDES, DEBRIS AVALANCHES, ROCKFALLS, SLUMPS, RIGID BODIES), IN OR INTO A BODY OF WATER

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