COMPREHENSIVE PLANNING IN TSUNAMI PRONE AREAS

Jane Preuss[I]
Presenting Author: Jane Preuss

Summary

A two tier planning approach is needed upon which to base decisions at both the regional and project scales of planning for portions of communities which are located in areas which have been identified as susceptible to tsunamis. Regional scale issues will pertain to the general allocation of land uses and the location of critical facilities and life lines, such as major transportation routes. Decisions are based on a defined susceptibility to tsunamis. At the project scale issues pertain to the arrangement of uses on a specific site. Decisions pertain to interactions between the dynamics of tsunamis and land based variables. At both scales technical research findings are translated into their appropriate land use planning implications.

The Problem

Earthquakes have both primary and secondary impacts. Primary impacts are directly attributable to shaking and result in damages derived from building and/or ground failure. Secondary impacts include fires and tsunamis. The amount of property destruction and number of deaths caused by to these secondary effects, is equally and often more devastating then primary impacts. For example, of the 131 deaths attributable to the 1964 Great Alaska earthquake, 119 were caused by the tsunami. Furthermore, the geographic extent of damage indirectly caused by an earthquake potentially encompasses vast areas which could be vulnerable to a tsunami. Another example from the 1964 Alaska earthquake illustrates this point. Of the total deaths caused by the earthquake, 82 occurred in Alaska while the remaining 37 occurred in Oregon and California. Furthermore, effects of the tsunami were felt as far away as the Palmer Peninsula in Anartica which is 8,500 miles from the epicenter of the earthquake.

For a variety of reasons relating both to historical land use patterns and contemporary development pressures coastal areas tend to be among the most intensively utilized portions of a community. A high percentage of communities in Japan, on the west coast of the United States, and South America, as well as other coastal communities throughout the world, are therefore susceptible to tsunamis. Furthermore, in many cases these areas are relatively "protected" bays, and/or gently sloping shoreline areas which because of their comparatively constricted configuration and/or easy access are potentially subject to the most severe tsunami effects related both to run up heights and wave velocities. Port areas accomodating the Alaska fishing fleet (based in Kodiak, Seward, and many other communities in Alaska) are in the tsunami zone; most of the San Francisco harbor is in the tsunami zone, and numerous residential and resort communities are located along vulnerable coasts in California, Oregon, Alaska, and Hawaii.

(I) Urban Regional Research, Seattle, Washington, U.S.A.

A recent study entitled Land Management Guidelines in Tsunami Hazard Areas (Ref. 1), analyzed comprehensive planning in three case study communities which had experienced relatively recent tsunamis. The study found that none of the communities utilized previously identified vulnerability as the basis for allocation of land uses, as reflected by the finding that in each tsunami hazard zone virtually all land uses are permitted. Only in extreme cases, such as Hilo, Hawaii or Crescent City, California, where regional parks have been developed, has the hazard been a factor in land use planning. In the State of Hawaii all communities participate in the Pacific Tsunami Warning System. Any warning system must, however, be accompanied by an effective and efficient system of evacuation (both vehicular and pedestrian) and public response. In none of the U.S. cities which were investigated by the above mentioned study (including Hilo) was transportation planning correlated with evacuation route planning.

There are three basic wave forms which a tsunami could assume at the shoreline. These forms, which are listed below are a function of factors pertaining to shoreline and nearshore topography.

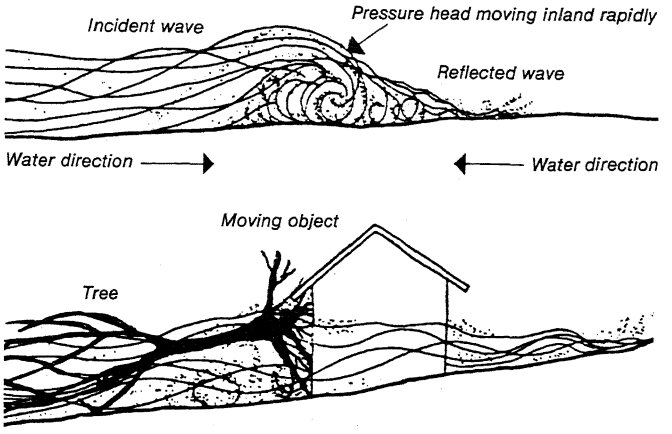
1. Nonbreaking waves that appear as rapidly rising tides. This type of wave formation does not generate surge force.
2. Waves that break far from the shore and become fully developed bores before reaching the shoreline.
3. Waves that break near the shoreline and act as partially developed bores which are not uniform in height.

Multiple observations have found that damage varies significantly along a single coastline from effects of tsunamis exhibiting the same wave height but with the above difference in wave characteristics. This observation was initially documented in relation to the damage to Oahu during the tsunami of April 1, 1946, which was classified according to three categories (Ref. 2). These classifications have remained valid in subsequent tsunami events such as the 1964 Alaska earthquake.

1. The damage from a tsunami does not exceed that which would be expected from an equal tidal inundation without surf. Typical houses are floated from their foundations or merely flooded but moved little; the vegetation is not disturbed to any extent.
2. The damage caused by the tsunami is intermediate between the conditions in categories 1 and 3. Houses are moved some distance and damaged; the ground is somewhat eroded.
3. The damage resulting from the tsunami is disproportionately great when compared with that which would be expected from a tidal inundation of similar height. Evidence of high velocity is everywhere. Buildings are destroyed, reef coral is carried far inland, automobiles are rolled about, escarpments and stripping are produced, and the level regions are invaded by the water for a great distance inland.

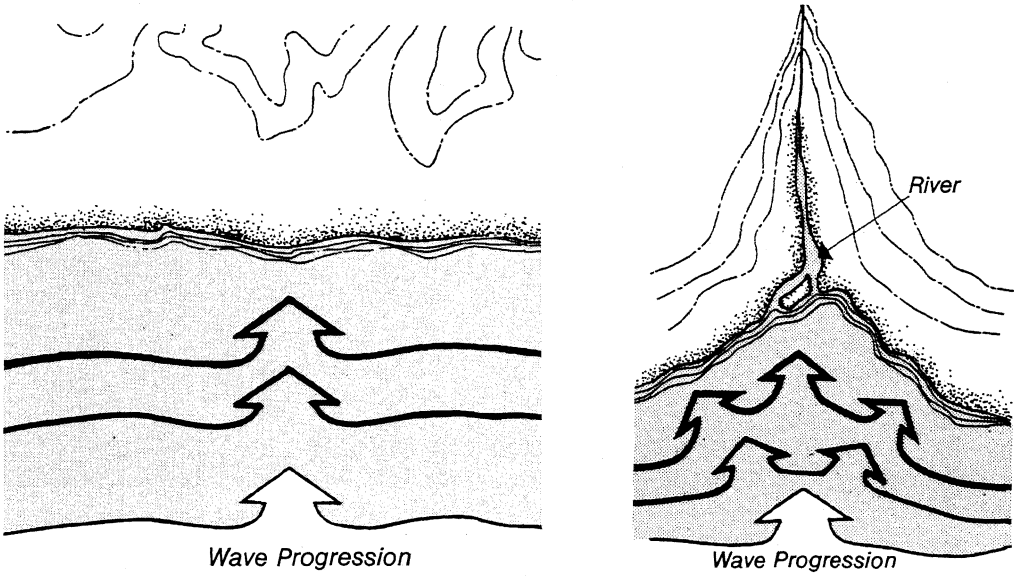
The major effects of the wave are the result of direct impacts of the incident wave and indirect forces affecting both the ocean and inland sides of buildings and structures. Damage inflicted when the wave impacts the coast is caused by the run-up field (inundation heights) and local flow field (velocity of the water). Direct forces are created by the incident wave impacting a structure. Indirect impacts occur as a result of

secondary effects. The direct forces alone or in concert with indirect forces caused the extensive damage which is associated with tsunami.



Wave action has direct effects and indirect effects.

Whether or not the waves break and to what extent they break seems to determine the category of damage. A non-breaking wave presumably causes damage of the type in the first category, light-breaking waves cause damage of the second type, and waves that break the most violently cause damage similar to that described in the third category. The types of protective measures taken by a community must in so far as possible reflect the projected characteristics of tsunamis in the particular portion of a coastal area.



Coastal configuration influences wave progression.

To date most U.S. communities have responded to the tsunami hazard in one of two ways. One is to ignore the hazard from a planning standpoint. The other, used primarily by communities which participate in the U.S. Flood Insurance Program, is to require buildings to be elevated a specified number of feet above grade. This later approach, however, is not based on refined understanding of water/land interactions nor are the standards correlated with susceptibility as related to probable warning time and evacuation possibilities. Past studies have repeatedly noted the need for improvements in the warning system. For example, "part of the limitation of the effectiveness of the tsunami warning system at the time of the Alaska earthquake was the lack of clearly defined hazard zones or evacuation areas (Ref. 3). Accordingly, the warning system is constantly being improved in terms of identifying where a tsunami will impact and in shortening the time between detection and warning. In addition, however, criteria must be prepared which relate the above categories of potential damage to standards which can guide development within susceptible areas. It is therefore essential that interrelationships between land use planning, evacuation route planning and the warning system be refined and improved.

An integrated planning process is therefore needed which is designed to minimize susceptibility to tsunami inflicted damage, yet realistically accommodate demands for coastal related development--which is often a critical component of a community's economic base. Heightened public awareness of tsunami danger, regional plans, project scale planning criteria, together with an effective decision making framework (disaster prevention system) are all integral components of this multi-faceted system which must be designed to minimize damage and facilitate evacuation.

The dilemma of developing a prescriptive planning approach for tsunami prone areas is that the range of variables associated with the dynamics of tsunami waves as they potentially impact a specific section of the coast are vast. Furthermore, a large number of uncertainities can still not be predicted, e.g. behavior based on nonlinearity of the tsunami; the breaking edge; wave current interactions; etc. It should, however, be noted that because the wave slows down as it enters shallow water most communities will have at least a short time for warning and evacuation. Thus, it is critical that any planning approach be thoroughly integrated with a warning and decision making framework pertaining to evacuation.

Proposed Planning Framework

A two tier planning approach is needed upon which to base decisions at both the regional and project scales of planning for portions of communities which are located in areas which have been identified as susceptible to tsunamis. Regional scale issues will pertain to the general allocation of land uses and the location of critical facilities and life lines, such as major transportation routes. Decisions are based on susceptibility to tsunamis. At the project scale issues pertain to the arrangement of uses on a specific site. Decisions pertain to interactions between the dynamics of tsunamis and land based variables. At both scales technical research findings are translated into the appropriate land use planning implications.

Research papers presented at a the U.S.-Japan Tsunami Workshop, sponsored by the U.S.-Japan Cooperative Program for Natural Resources in May 1983, indicate that many of the critical variables, e.g. implications of the shape of the tsunami front on dry land and shallow water, effects of obstructions on land, effectiveness of tsunami forests in relation to different magnitudes of tsunamis, etc. have been considered by recent tsunami investigations conducted in Japan. Despite the significant progress which has been made with respect to understanding tsunami behavior, it is, however, an underlying assumption that, because of tsunamis' unpredictability and high degree of nonlinearity, all planning will be based on a high level of uncertainity. The proposed planning approach must therefore be flexible and must consider the potential multi-purpose attributes of land use planning considerations, e.g. evacuation and transportation efficiency.

Technical insights into tsunami behavior near shore and on land must be utilized as the basis for developing a regional planning and administrative framework which can integrate the diverse activities relating to economic, land use and response/evacuation planning. This methodology would utilize and apply an improved understanding of the relationships between run-up heights and wave behavior to refine the basis for land use planning/regulation and decision making. Proposed planning responses would be applicable for areas susceptible to both local and distantly generated tsunamis. Subsequently more definitive site planning criteria can be prepared.

Considerations Addressed at the Regional Level

Regional plan(s) would contain detailed criteria for land use allocations; general building locations as well as density and intensity of land use patterns; for open spaces; and for the location of supporting life lines in relation to a delineated evacuation zone and evacuation routes. The possible locations of tsunami defense works (engineering/structural solutions) could also be identified on these plans. At a minimum, the criteria for major defense works could be refined in terms of multi-purpose function, e.g. protection of fishing fleet, etc.

Intra-regional location patterns play an important a role in the economic character of any region with respect to the nature and scope of probable impacts in tsunami hazard areas. In general, the uses which occupy the waterfront and low level portions of a regional have the highest susceptibility to damage, however, these uses vary depending upon a multitude of factors including but not limited to size and profile of the resident population base, primary residents, second home retirees, access to a transportation system and thus a large market for product distribution, the availability of a major water-based resource (e.g., a major fishery), the importance of tourism as an economic stimulant in the region, and the historical land uses of the resident population base. Furthermore, at the regional scale of equal importance in assessing impacts, but often overlooked, are the relationship between primary impact economic activities with other industries and economic functions within and outside the region. Needless to say, the salient issues will be determined by the diverse characteristics of the specific tsunami-prone hazard area, however, typical examples of questions which must be addressed (in Alaska)

include: Where do the King Crab fisherman's supplies come from? Where is boat overhaul work performed? Where is the product marketed? Where do employees of seaside restaurants and tourist attractions spend their income? How many jobs are supported within and outside the local economy by a world-class salmon fishery and processing operation? What is the nature of employment (e.g. high pay, blue collar, low skill, etc.) in the primary impact industries and the linked industries inside and outside the region?

Project Scale Issues

Once an administrative decision has been made to permit development in an identified tsunami hazard zone the potential tsunami impacts pertaining to the varying characteristics of the wave interactions with specific characteristics of the site must be addressed.

Project scale planning (hereafter referred to as site planning) is concerned with the organization and arrangement of uses on a specified piece of property. At the project scale, planning requirements associated with use of the property must be correlated with requirements associated with the unique environmental characteristics of the site. It is at the site planning scale that land planning issues are addressed which reflect interactions between the tsunami wave and land.

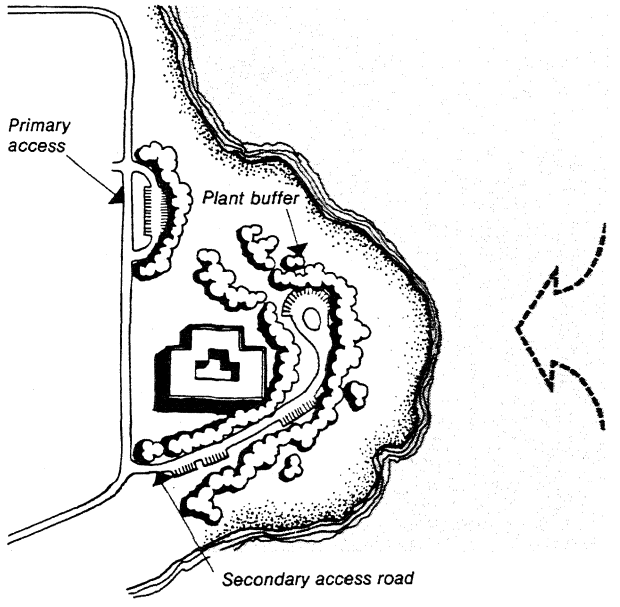
Site planning integrates the built with the natural environment to accommodate a range of activities on a defined piece of property. The planning framework at this scale applies standards and performance criteria for a specified use of an individual site with a well defined set of unique characteristics. Site planning is concerned with the location, use and configuration of three primary elements. The site planning process must consider the role of each element in relation to the tsunami hazard. These roles are listed below, although in no case will any element fulfill all potential functions. Selection of the precise response mechanisms utilized for any site must be determined in relation to the unique characteristics of each site in relation to the specific demands of the proposed use.

Buildings and Structures
- o Protection (buffering) of inland structures
- o Creation of friction impacting water velocity

Circulation
- o Vehicular evacuation and post disaster access
- o Pedestrian evacuation

Open Space/Landscaping
- o Protective Buffer
- o Creation of friction
- o Protection against erosion

Present approaches to land management practices impose relatively uniform standards within the entire inundation area. The same tsunami wave may, however, differ from one point on shore to another both in terms of wave height and velocity. Accordingly, a flexible approach to land management is needed which can utilize a range of tools to address the refined levels of susceptibility within the inundation zone. Prototype site planning criteria were prepared by the previously mentioned study conducted by Urban Regional Research to illustrate utilization of tsunami sensitive design objectives and performance standards as the basis for preparation of responsive site plans. The plans illustrate ways in which each element of the site plan must be analyzed such that objectives pertaining to wave force, water level and general safety are addressed. The prototype site plans respond to the variable nature of the tsunami hazard by varying the three key site plan elements (buildings and structures; circulation networks; and open spaces) in relation to the site and use characteristics (Ref. 4). These criteria were concerned with location, function and configuration of the three primary variables.



Site Plan Elements: buildings, circulation and open space.

Conclusions: Administrative Framework

In the United States land use regulations are promulgated at the local level. Disaster prevention planning pertaining to warning and evacuation and other types of response efforts tends, however, to be promulgated at the Federal or State level. In addition to a traditional land use component the planning framework must in order to ensure implementation of the plan propose a complementary tsunami disaster prevention/administrative system including but not limited to recommendations pertaining to pedestrian and vehicular evacuation route identification and maintenance; land

use allocations; structural criteria; and open spaces. The decision making process needs to be modified in order to explicitly evaluate the costs and benefits of decisions which are made at both the regional scale and the project scale. The evaluation structure will explicitly identify the costs and benefits of both regional plans and site plan solutions by analyzing the impacts of decisions from three perspectives: hazard mitigation, economic impacts, and socio-cultural impacts. At the regional scale the evaluation framework would primarily address the impacts of decisions pertaining to the allocation of uses. At the project scale the evaluation would address the implications of various site plan solutions. In addition, development of any property within the hazard zone requires not only coordination of many agencies but even more significantly they require public and private cooperation. Some uses such as those which generate economic returns to the community (provide jobs) will tend to result in an economic analysis warranting a higher level of public support/spending; while those which do not generate revenues will probably reflect an analysis resulting in private expenditures. The analysis must be made explicit for any long term policy decision which affects development in the hazard zone. Implementation considerations for tsunami hazard zones must include but not necessarily be limited to the following elements:

- o An administrative/management system which defines an integrated system of priorities for the Federal, State and local levels of government.
- o Define administrative considerations for multiple functions of land uses/building types: transportation systems (coordination of transportation, route planning with evacuation zone delineation and route planning; open spaces (criteria for government land acquisition and alternative uses).
- o Define Local Agency criteria, which can be used for site plan review at the project scale.
- o Define operational characteristics of tsunami protective planning, including criteria for coordinating and planning operations and maintenance of warning and infrastructure networks on both regional and local levels; building inspections; insurance eligibility criteria, etc.
- o Define implications relating to capital improvements (standards and priorities) for protective measures.
- o Establish a system for data base management to ensure availability for all jurisdictions within a susceptible region.

Ref. 1 - Urban Regional Research, 1982, National Science Foundation
Ref. 2 - Wilson, B.W. and A. Torum; 1972; "Effects of the Tsunamis: An Engineering Study"; in The Great Alaska Earthquake of 1964: Oceanography and Coastal Engineering; National Academy of Sciences; pages 361-526
Ref. 3 - Cox; 1972; National Academy of Sciences

Research upon which this paper is based was funded by The National Science Foundation grant numbers PFR-7823884 and CEE-8112630.

I would like to acknowledge the assistance of Roy Ellis economist with Urban Regional Research on this paper.