Mitigating the Risk from Coastal Hazards: Strategies & Concepts for Recovery from the December 26, 2004 Tsunami

December, 2005
V1.1

Dedication

This paper is dedicated to the victims and survivors of the December 26, 2004 tsunami, in the hope that coastal communities can be made more resistant to the damage from future natural disasters.

Mitigating the Risk from Coastal Hazards: Strategies & Concepts for Recovery from the December 26, 2004 Tsunami

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Chapter 1 - Introduction

This report presents strategies, concepts and options for the recovery and redevelopment of areas damaged by the December 26, 2004 tsunami. Particular emphasis is placed on the use of scientifically based hazard mitigation measures for siting and construction in conjunction with flexible implementation strategies in the land use and construction process. It is believed that the technically based standards will protect the public to a greater degree from future flooding and wave events, while the flexible strategies will ease and expedite implementation and overall recovery.

From a technical standpoint, methods for dividing the tsunami inundation zone into subzones are introduced. Within the subzones, appropriate multi-hazard mitigation measures are presented. Recurrence interval considerations are discussed, as well as strategies to adjust the construction and siting standards based on the interval. In chapters 3 to 5, concepts and strategies to assist implementation of the technically based standards are presented to assist the short-term and long-term recovery of tsunami stricken areas.

Many of the concepts in this report are derived from the recently published Hawaii Coastal Hazard Mitigation Guidebook (“Guidebook”).[1] In particular, the major concepts developed in the Guidebook that are relevant to the recovery of countries damaged by the Indian Ocean tsunami are: (i) identify overlapping hazard zones (preferably multi-hazard); (ii) divide the development process into stages and craft hazard mitigation measures that are appropriate for that stage of development; (iii) implement measures through a light-handed flexible approach that emphasizes guidance and policy over new regulation; and (iv) recognize the government purpose for regulation of development. Each of these concepts forms the basis of a chapter in this report. In the last chapter, these concepts are applied to the north Sumatra area to demonstrate their applicability to the situation dealing with tsunami inundation.

Significant contributions in this report are provided by the professionals listed on the title page and their work is appropriately cited. Many of these professionals donated their time for the completion of this report and it is hoped that countries will contact these individuals if any follow up work or study is required. It is also hoped that countries can take the information in this report and use it to create their own detailed guidebook that will facilitate implementation of hazard mitigation measures into the recovery and redevelopment of stricken areas. The important relationship between planning information, concepts, strategies, guidance, policy and regulation is discussed in chapter 3.

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[1] Hwang, Dennis J., 2005, “Hawaii Coastal Hazard Mitigation Guidebook,” for Hawaii Department of Land and Natural Resources, State Office of Planning – Coastal Zone Management Program, University of Hawaii Sea Grant College Program and the Pacific Services Center and Coastal Services Center of the National Oceanic & Atmospheric Administration.
http://www.soest.hawaii.edu/SEAGRANT/communication/HCHMG/hchmg.htm

This report is written in a general manner so that the concepts can apply to any country recovering from the tsunami. To the greatest extent possible, specifics for a particular country are not mentioned for several reasons. First, this paper was written on an expedited basis to assist critical rehabilitation and recovery efforts. Neither the time nor resources were available for a detailed guidebook that accounts for the specifics of each country. This is an effort best left to each implementing country, and can be accomplished by overlaying their own cultural, community, political and social needs over the hazard mitigation measures presented in this report. In this manner, each country or region can customize their own recovery plan.

Also, it is not the purpose of this report to make suggestions or recommendations on how the recovery or redevelopment of each country should proceed. Each country is a sovereign nation and should be free to choose the methods that are best suited to their needs. This report, however, provides options, concepts, and strategies that a country could choose to adopt, if deemed appropriate, in the form of guidance that the country develops on their own initiative.

It is a basic tenet of this report that the measures to mitigate damage from waves, erosion or flooding are not country specific, but hazard and force specific. Thus, similar siting or construction concepts can apply to mitigate the damage from a 2 meter (6.6 feet) tsunami wave, no matter what the country.[2] Under this premise, a generalization can be made that once suitable hazard mitigation measures are identified based on anticipated forces, each country can overlay their own specific cultural, social, economic, political, and community needs to shape the recovery efforts in their area.

Utmost respect for the sovereignty and culture of affected countries is planned for in the report. Strategies will be presented to show how local custom and government decisions can be combined with the scientific standards. The measures will be detailed enough to apply to foreseeable redevelopment decisions (e.g., local tsunami, lack of warning time, desires to develop coastal areas, etc.), yet general enough so that they can be applied to affected countries recovering from the tsunami.

It is hoped that this report will provide recovering countries numerous additional options for the recovery from the tsunami. Since the hazard mitigation options will be scientifically based, they will be more protective to citizens, while flexible land use strategies and emphasis on simplified risk factors will make the measures easier to implement and considerably less burdensome.

Finally, it is the intent of this report to discuss concepts to assist rapid recovery, where no guidance currently exists. Because this report was written on an expedited basis, it is expected and recommended that many of the sections will be updated or supplemented with appropriate research when it becomes available. Thus, this is the first edition of this report.

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[2] In this report, all measurements are in meters, with conversion to feet in parenthesis.

Chapter 2 – Identification of Overlapping Hazard Zones

After a natural disaster, the first priority is to provide emergency assistance in order to relieve human suffering and prevent the further loss of life. This usually may take from several weeks to several months. Not long after the emergency relief effort is a period of rehabilitation, where basic infrastructure is restored and short-term and long-term planning for recovery begins. The rehabilitation phase may take several months to a couple of years. With the basic infrastructure in place, long-term recovery and redevelopment of a damaged area can begin.

At the time of this report, many countries were in the rehabilitation stage of recovery. One of the most critical decisions in this stage is how to redevelop in the tsunami inundation zone. Many factors must be considered, including economic, social, and political concerns, as well as the implementation of hazard mitigation measures, so that if a similar tsunami happens, the loss to life and property can be reduced to the greatest extent possible.

Initially after the December 26, 2004 tsunami, several countries established fixed setbacks away from the coastline in which redevelopment would be restricted or prohibited. While fixed setbacks are initially attractive because they are easy to establish, they can be controversial as applied and even more importantly, not sufficiently protective or efficient. This is because the level of inundation varies significantly for each coastal section depending on numerous factors such as orientation and configuration of the shoreline, offshore bathymetry, onshore slope, and onshore surface roughness (e.g., natural trees, bushes, etc.) and man made features (seawalls, revetments, buildings, etc.) which reduce run up.

As a hypothetical example, a 300 meter (660 feet) exclusionary setback for a long stretch of coast in which inundation ranges from 50 meters (165 feet) to 1,500 meters (4,950) will be simultaneously over restrictive and not protective enough. At the location inundated 50 meters inland, the setback would be six times more stringent then necessary. This may result in a critical loss of useable and valuable land. For the area inundated 1,500 meters inland, the 300 meter setback would allow redevelopment in a hazardous zone, potentially exposing the public to unnecessary wave and flood risks. As explained above, the extent of inundation for an area is controlled by a certain set of factors specific to a location. If an area has been inundated to a great extent, it likely has a set of variables which make it susceptible to high run up in the future.

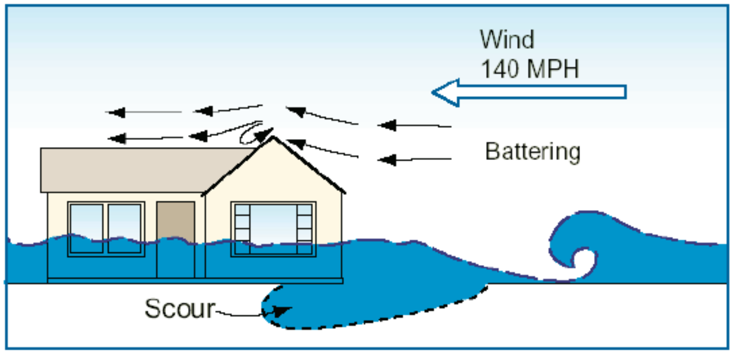
A second reason against the fixed setback is that it may detract from gathering the necessary data to effectively implement hazard mitigation construction measures (how to build) versus hazard mitigation siting measures (where to build). The difference between siting and construction measures will be covered in chapter 3. Both siting and construction measures are important tools in the area of hazard mitigation, but it is considerably less burdensome to implement a construction measure over a siting measure. Put another way, hazard mitigation siting measures are generally the option of last choice, if economics and value of the land are major considerations.

This report proposes that the most protective measure, from a hazard mitigation perspective, is to map the tsunami inundation zone and break it into overlapping hazard sub zones based on wave height (distance between wave crest and trough) or depth of water (distance between water elevation and local ground surface). Appropriate siting and construction measures, as well as recovery strategies, can then be developed for each zone. Examples for Hawaii, and then Sumatra are provided in this chapter and chapter 6. Measures to facilitate implementation are then provided in Chapters 3-5. The end result should be hazard mitigation measures that are simultaneously more protective, while being easier, faster and more economically efficient to implement.

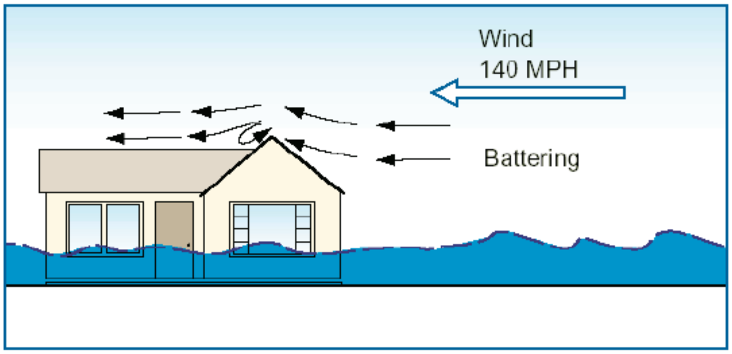
Because of the large area of tsunami inundation zones, it is important that areas inundated be broken into subzones in which different redevelopment strategies can apply. The Hawaii Guidebook divides coastal areas into four overlapping hazard zones: (a) closest to the shoreline is the erosion zone, where structures are exposed to erosion, scour, wave action, flooding and wind forces; (b) farther inland is the wave zone (Federal Emergency Management Agency's ("FEMA") V-VE zones) subject to wave action, flooding and wind; (c) farther inland, structures in the flood zone (A-AE-X zones) are at risk from flood and wind damage; and (d) a zone farthest inland where structures are subject to wind forces (Figure 2-1).

The proposed erosion zone is based on a standard provided in the Guidebook. The key factors are the erosion rate, the life expectancy of proposed structures and a storm erosion buffer and a design buffer. Adjustments are made for errors and accelerated sea-level rise.

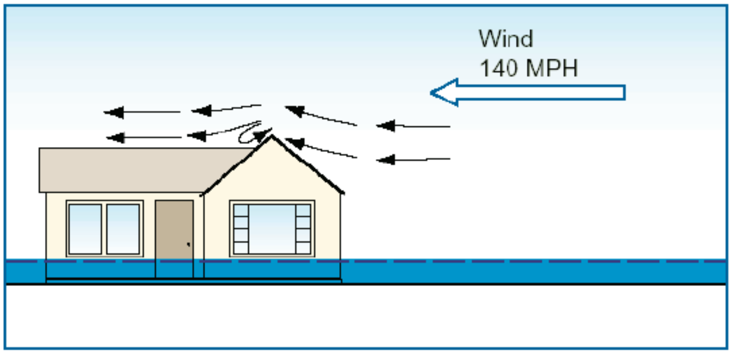
All of the other hazard zones have been determined indirectly by FEMA mapping associated with the National Flood Insurance Program. The boundaries of the hazard zones are based primarily on statistical analysis of the effects of historical tsunamis, although other hazards are also included in the analysis (Section 2.1.2). Between 1819 and the present, there have been 22 destructive tsunamis in Hawaii, both from distant and local sources. Using a combination of historical modeling and inundation data for the ten largest tsunamis, a relationship between the elevation of water and frequency of occurrence was established for sections of the coastline. Water elevations and subsequent runup could then be determined for the 100 and 500-year events, which establish the FEMA V, VE, A, AE and X zones (Figures 2-2 and 2-3).



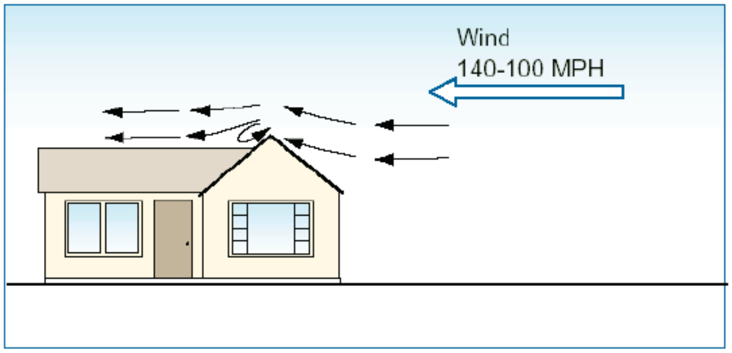
Erosion Zone – Closest to the coast is the erosion zone, subject to erosion, scour, high velocity wave action, flooding and wind. In Hawaii, siting measures are proposed to mitigate damage from these forces.



Wave (V-VE) Zone – Farther inland is the wave zone, subject to high velocity wave action, possibly scour, flooding and wind. In Hawaii, construction measures are proposed to mitigate potential damage.



Flood (A-AE-X) Zone – Even farther inland is the flood zone, (FEMA's A, AE and X zones) subject to wind, flooding and possibly lesser wave action. Construction measures are proposed in this zone.



Inland Zone – Farthest Inland and away from the coast, structures are subject primarily to wind action. Construction measures found in the building codes are used to address inland hazards (e.g., wind, earthquake, etc.).

Figure 2-1 - Overlapping Hazard Zones – from Hawaii Coastal Hazard Mitigation Guidebook, adapted from Texas Coastal and Marine Council 1976 and FEMA CCM. Note that the hazard zones overlap (e.g., wind or earthquake forces may be felt in all four zones).

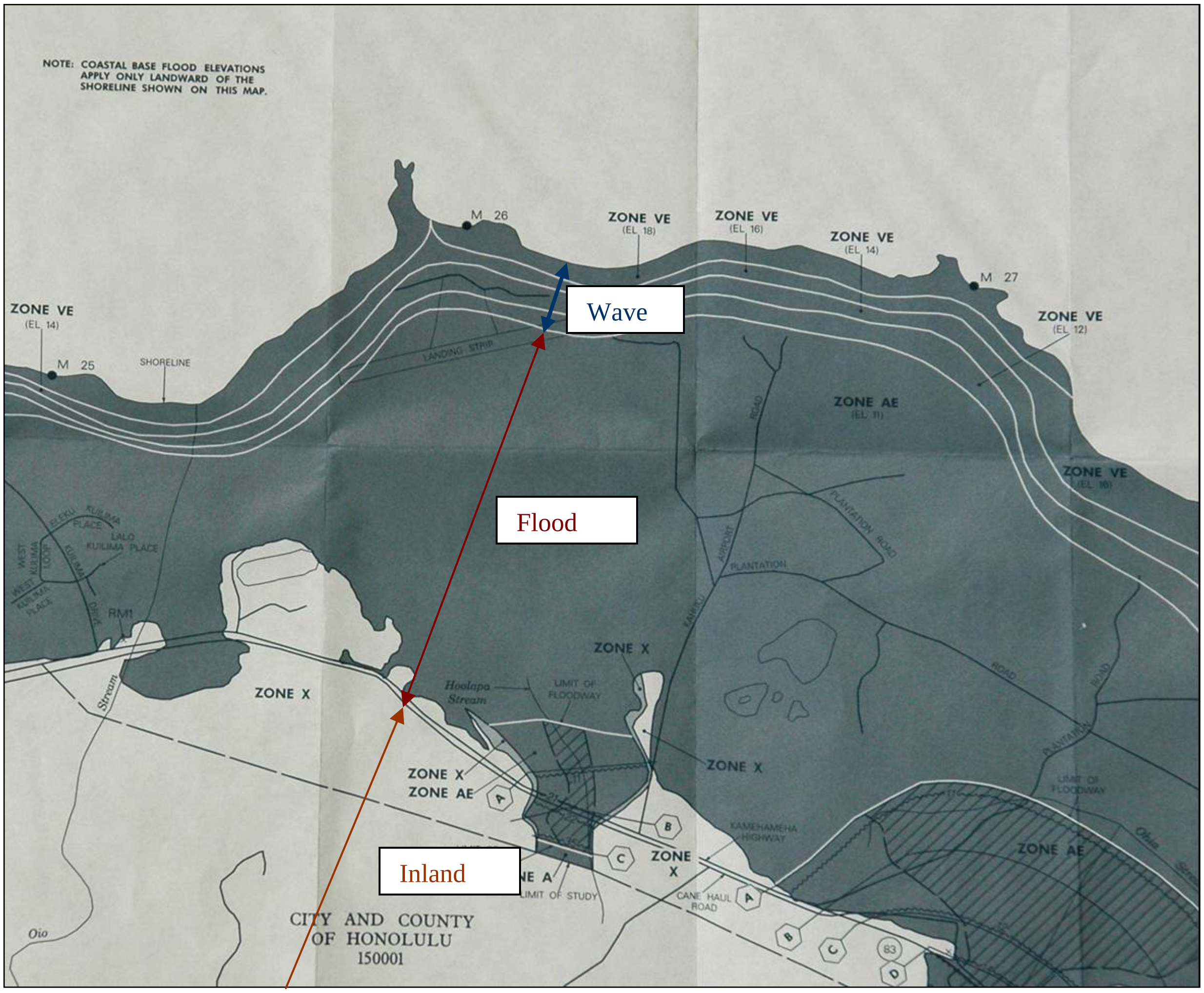


Figure 2-2 - FEMA Flood Insurance Rate Map for Kahuku on the north shore of Oahu. The proposed wave, flood and inland zones are determined by the boundaries of the V, VE, A, AE and X zones on the Flood Insurance Rate Maps. Historical tsunami inundation data was used to determine the boundaries for these zones (See Figure 2-3). Note the flood zones are on the order of several thousand feet inland.

Figure 2-3 - Kahuku, north shore of Oahu. Coral debris and sand washed inland from the 1946 tsunami. Events such as these form the basis of the flood and wave zonation seen on the flood insurance rate maps (Figure 2-2). Inundation from the 1946 tsunami extended several thousand feet inland at this location. Photo Courtesy of Bishop Museum.

From the flood insurance studies for Hawaii, the X zone is determined by the inland extent of the 500-year event. The A-AE zone is determined where water depth is between 0 and 1.3 meters (4 ft.) for the 100-year event. Hazard mitigation measures for this flood zone can be addressed with construction measures suitable to address flooding damage (e.g., elevate structures and allow passage of entry and exit waters) (Figure 2-4). An example of a design standard for low velocity flooding is to tie the size of openings for the exit water to the surface area of the incoming water (e.g., 2 or more wall openings of 2.54 cm^2 (1 in^2) for every .33 m^2 (1 ft^2) subject to flood). The openings will vent the water and release hydrostatic pressure.

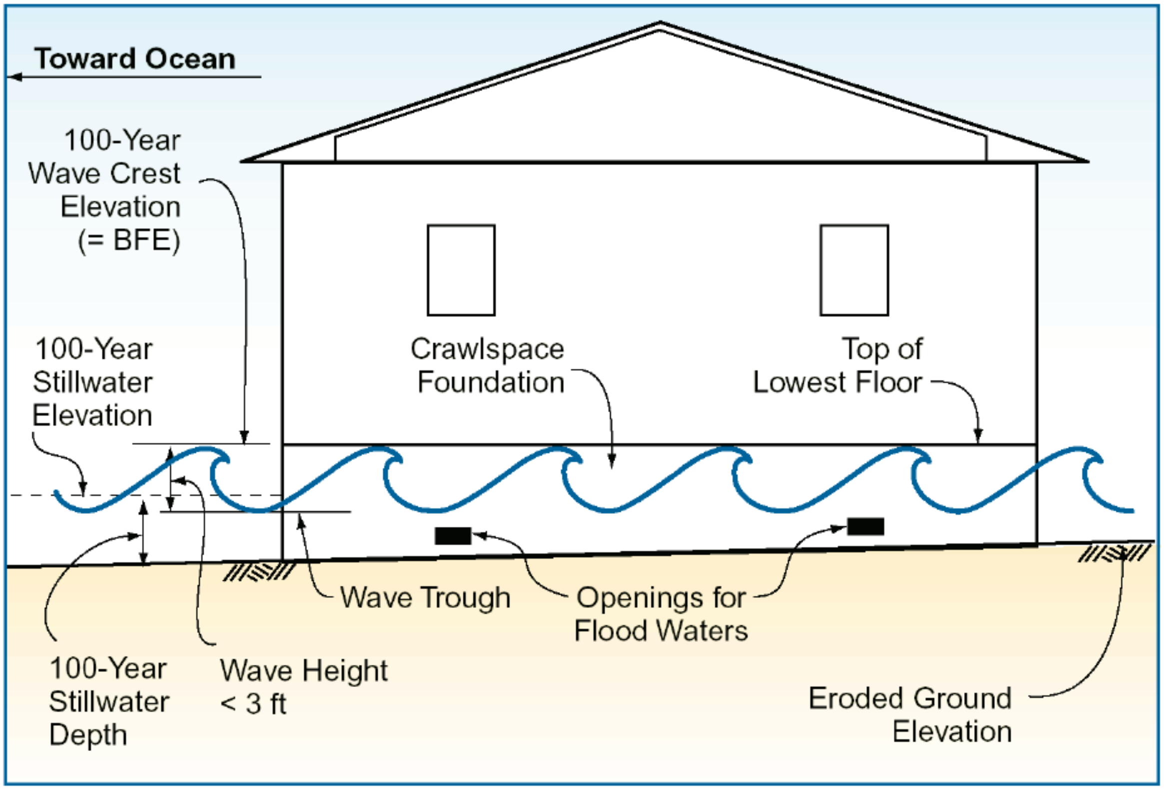


Figure 2-4 - National Flood Insurance Requirements for the A-AE (Flood) Zone (From FEMA CCM). Under the National Flood Insurance Program, structures must be elevated above the Base Flood Elevation, and supporting walls must have openings to allow entry and exit of flood waters.

Also from the Hawaii flood insurance studies, the high velocity V-VE zone is determined where water depth greater than 1.3 meters (4 ft.) is expected for the 100-year event. Hazard mitigation measures for this zone can be addressed by elevating structures on piers or columns with proper foundation that resist scour, hydrostatic and hydrodynamic forces (Figure 2-5).

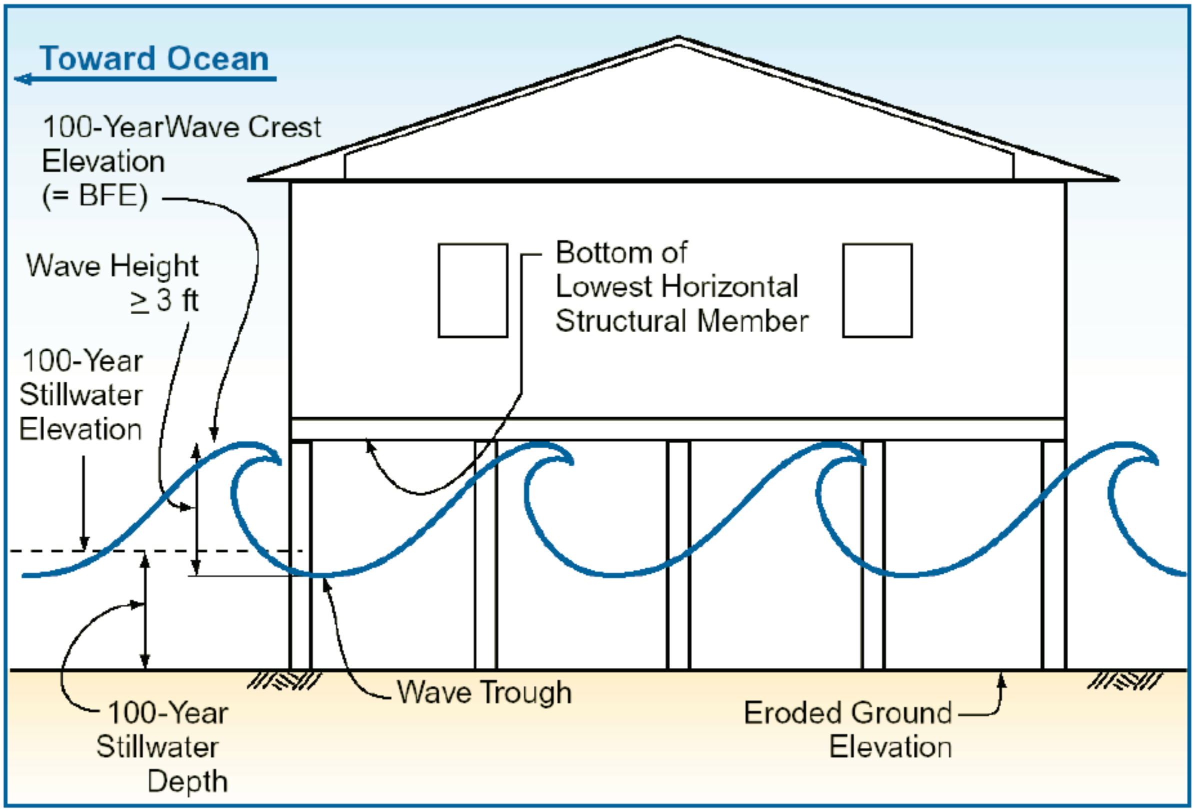


Figure 2-5 - National Flood Insurance Requirements for the V-VE (Wave) Zone (From FEMA CCM). Under the National Flood Insurance Program, structures must be elevated above the Base Flood Elevation on piers and columns, posts or pilings.

For wave heights of 1.3 meters (4 ft.) to those roughly estimated between 5 to 10 meters (16.5 to 33 ft.) water depth, the hazard mitigation measures should address high velocity wave action. It is important to note that the 5 to 10 meters (16.5 to 33 ft.) water depth is a rough preliminary estimate of tolerable water level before it becomes impossible, or at least unfeasible to engineer a structure to withstand associated wave forces (Figure 2-6). Residential structures in Hawaii have been elevated up to 6 to 7 meters (19.8 to 23.1 ft.) to meet flood insurance requirements for high velocity wave action.

Scientists, engineers, and architects need to refine the wave height limit values for each particular country and section of the coastline based on the type of structure built, the local materials available, the anchoring of the supports, and the debris field anticipated. In addition, economic factors are important, such as the local cost of construction, the ability of the landowner to afford the structure, and the economic assistance provided.

Determining the maximum water or wave height to which buildings can be engineered to withstand depends partly on the type of structure built. Large concrete and steel structures could be built to withstand greater wave forces than smaller residential structures made of less durable material. For example, it is conceivable that a ten story building designed for wind and earthquake forces may be able to withstand a 15 meter tsunami if there is minimum surface area facing the incoming water and the outgoing water is vented (e.g., on piers and columns).[3] Such a design standard would not be possible for a smaller residential structure.

In the aftermath of the December 26, 2004 tsunami, many have proposed the construction of tsunami resistant structures. While this is very important, an upper bracket needs to be provided that identifies the maximum wave height or water depth the design is suitable for, otherwise, inhabitants may encounter wave heights that the structure cannot withstand.

Eventually, there becomes a water level for which it becomes impossible or unfeasible to design. Preliminary observations from discussion with tsunami survey teams indicate that for water elevations greater than 10 meters, many structures were severely or completely destroyed, regardless of structure type.[4] In areas where such wave heights are expected, hazard mitigation measures for construction should give way to hazard mitigation measures for siting.

Thus, for anticipated water depths greater than 5 to 10 meters, the strategy for recovery and redevelopment should include land use concepts (smart growth, green belts, flexible implementation, innovative design) along with vertical and horizontal evacuation. Even if it is not possible to control all development in the most intense seaward zone (greater than 5 to 10 meter water level), it is possible to reduce density, which will go a long way to reduce hazard risk.

It is interesting to note that based on the field assessments of scientific and engineering teams after the tsunami, as well as preliminary data from USAID, hazard mitigation issues for most coastlines can be addressed with hazard mitigation construction measures, coupled with an early warning system. Major exceptions would be for Indonesia (where water levels up to 35 meters were encountered and tsunami warning times would often be too short) and possibly Thailand (heights up to 15 meters) (Table 2-1). For these countries, and in particular Indonesia, a greater percentage of tsunami inundated areas would rely on siting precautions and/or evacuation to adequately protect the public.

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[3] Interview with Steven Baldridge of Baldridge & Associates Structural Engineering, Inc.

[4] Note however that many large concrete mosques in Indonesia (Lhok Nga, Banda Aceh, Jantang) were able to withstand unusually high wave heights. Important factors in their survival were the massive construction in concrete with reinforced columns, and the numerous openings in the front and back that reduced incoming loads and vented high velocity water.

Country	Maximum Run Up Height	Warning Time
Somalia	4 m. (12 ft.)	8 hours
Maldives	1.5 m. (5 ft).	3.5 hours
Nicobar, India	7 m. (23 ft.)	1.5 hours
Sri Lanka	10 m. (33 ft).	2 hours
India	12 m. (40 ft).	2 hours
Andaman, India	12 m. (40 ft.)	1.5 hours
Phuket, Thailand	15 m. (50 ft.)	1 hour
Sumatra, Indonesia	35 m. (116 ft.)	15 minutes

Table 2-1- Key Parameters Relevant to Hazard Mitigation for the December 26, 2004 Tsunami. Colored text differentiates countries where the majority of hazard mitigation measures can rely on construction techniques (green) as opposed to where siting measures would play a more important factor (red). Runup heights for India, Thailand, Andaman, Nicobar and Indonesia from Choi.[5] Heights for Sri Lanka from Wijetunge.[6] Heights for Somalia and Maldives, as well as warning times are from USAID – Tsunami Relief – April, 2005.

The maximum runup heights shown above represent the extreme inundation for that country.[7] For example, data from Wijetunge indicate that the peak heights at most locations in Sri Lanka are 5-6 meters, while at a very few locations, up to 10 meters was measured. Data for India indicate the vast majority of runup heights were under 8 meters, while only two areas experienced the maximum height listed in Table 2-1. Tsunami inundation mapping can identify how wave heights and runup vary along the coastline for each country.

The key point from Table 2-1 is to show that tsunami preparations for a majority of coastlines in a particular country can be addressed with an early warning system and hazard mitigation constructions measures. For some of the countries, the maximum run-up height borders on the 5-10 meter range. For these areas, inundation maps are critical to identify the majority of sites that can be mitigated with construction techniques, and the few sites in which siting will play a more important role.[8]

A country may choose to implement siting measures in the recovery of an area for many reasons, such as environmental (to keep an area open space), social (to eliminate blighted areas) or cultural (as a memorial to past victims). However, from a purely hazard mitigation standpoint, the risk to property and life from flooding and wave action can be dealt with for most areas with a tsunami warning system **and** proper

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[5] Choi, Byung Ho, Siripong, A., Sundar, V., Wijetunge, J., and Diposaptono, S., (2005). *Post Runup Survey of the December 26, 2004 Earthquake Tsunami of the Indian Ocean.* In Sumatra Tsunami on 26th December 2004 – Proceedings of the Special Asia Tsunami Session at APAC 2005.

[6] Wijetunge, Janaka, (2005). Indian Ocean Tsunami on 26 December 2004: Spatial Distribution of Tsunami Height and Extent of Inundation along the Coastline of Sri Lanka. In Sumatra Tsunami on 26th December 2004 – Proceedings of the Special Asia Tsunami Session at APAC 2005.

[7] For example, the Maldives may have had water levels of up to 4 m. (12 ft.). Honolulu Star Bulletin, August 8, 2005. Japanese researchers have measured water levels of 40 m. (132 ft.) in North Sumatra (Interview with Professor Byung-Ho Choi, Sungkyunkwan University).

[8] The maps can also be used to: (i) differentiate between flood and high velocity construction and (ii) determine the height a structure should be elevated.

construction techniques. This should be viewed favorably, since as discussed previously, it is faster and easier to implement mitigative construction rather than siting measures. From the viewpoint of reducing hazard risk, many countries may be placing an overemphasis on fixed exclusion zones (siting measures), when construction measures would suffice.

Finally, the maximum wave height a structure can be designed to accommodate is a function of many factors such as the size of the structure, the materials used, and indirectly the use of the structure. Because of economies of scale, it may be more feasible to design larger structures such as hotels and commercial buildings to withstand a certain wave height versus smaller structures such as single family residences. In this regard the hazard mitigation measures, while construction related, take on a siting component related to zoning and allowable land uses (See Chapter 3).

2.1 Issues Related to Identification of Hazard Zones

In this section, several issues are discussed regarding the identification of overlapping hazard zones. Then, in Chapters 3-5, strategies and concepts are presented regarding the implementation of standards for the hazard zones. After discussion of these concepts, a case study for Banda Ache in Indonesia is provided to illustrate the application of some of the discussed concepts.

2.1.1 Limited or Preliminary Data Sets

The hazard zones proposed for Hawaii were based on the ten largest tsunamis at each coastal sector over a long historical period. The identification of these zones allowed a frequency analysis to be performed so that water elevations a certain distance from the shoreline could be determined for the 100-year and 500-year events. With that water elevation, the extent of inundation could be calculated. However, what can be done if there is very little, or no historical data for the level of inundation from past natural hazards?

While it is always best to have as much data as possible in the establishment of hazard zones, the data may be lacking for several reasons (e.g., not having the resources to collect data on past events, or encountering a coastline with little historical activity). When the data is lacking, several options are possible that require modeling, statistical analysis or extrapolation. While these methods introduce uncertainty, they are most likely to be an improvement over operating under the assumption that a coastline is free from hazard risks.

Based on interviews with several professionals dealing with floodplain management, several data scenarios are presented in Table 2.2. [9]

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[9] Interview with Steven Yamamoto, flood plain manager for the U.S. Army Corps of Engineers.

Data Availability	Method	Pros	Cons
No Flood - Inundation Data	• Extrapolate hazard data from a similar area. • Factor in depth of flooding based on local elevation. Use available topographic maps. • Use soil maps, aerial photographs or infrared images for inundation limits.	• Quick and easy to apply if maps are readily available. • Can fill in data gaps.	• Poor results if geographically different areas. • Does not take in to account variable site conditions, i.e. protective reefs, seawalls, etc.
One Flood - Inundation Event Data Set	Use historical flood event – Determination of frequency of event is not possible.	• Rapid data collection possible using GPS instruments. • Recent events can be well studied & understood.	• Flood elevations and inundation limits need to be quickly documented before data is lost from flood recovery efforts. • May over or under estimate true risk.
Two – Ten Flood - Inundation Event Data Set	Use highest historical flood event	.	• Statistical determination of frequency of event is possible, but confidence limit of true value is large making estimates unreliable. • May over or under estimate true frequency.
More than Ten Flood - Inundation Event Data Set	Apply statistical analysis on data set using an acceptable statistical distribution type, e.g., Gumbel, Log Normal, Log Pearson Type III, etc. Can also apply Monte Carlo simulation to generate thousands of hypothetical data sets for frequency determination.	• Statistical analysis can be applied. • More data can more accurately represent risk.	• Uncertainty in adopted distribution. • Time to develop and conduct analysis.

Table 2-2 – Limited Data Scenario – When there is limited data, estimations for hazard risk can be made by extrapolation of data, statistical analyses, or modeling. Each method introduces errors, but is likely to more accurately estimate risk than the alternative of using no or limited data.

Of particular interest in Table 2-2 is the scenario for one data set (row 3). Based on a lack of historical natural hazards in an area, or a failure to adequately document past inundation, this may apply to most countries struck by the December 26, 2004 tsunami. Nevertheless, even if there is only one data set, much about the risk to an area can be determined.

Flood plain managers occasionally place special significance on the most recent event. Since the field evidence is relatively fresh, it can be studied in detail. Critically important survey data can be extrapolated to other similar geographic areas using aerial photography or satellite imagery. The downside is that the most recent event, by itself, will not give information on recurrence interval. For an extreme event such as the December 2004 tsunami, the significance of the risk in terms of frequency of occurrence may be over estimated.

Nevertheless, if data are lacking, the most recent event can be used as an example of something that is possible in the area, without regard to recurrence interval. This conservative, but protective estimate can later be refined as new data or studies are completed (Section 2.1.3). The new data can come from modeling studies in the area of impact or in the area of tsunami generation, as well as by revisiting old historical or geological records or archives for past natural hazards.

2.1.2 Multi-Hazards

Since erosion, high velocity wave action, and flooding can be caused from several different natural hazards, it is important to collect and utilize inundation data from all potential disasters. This has been the trend in the United States and internationally, to implement a program for hazard mitigation that protects inhabitants from all natural hazards, whether it is flooding from a tsunami, hurricane storm surge or other natural event.

As an example, some of the inundation maps in Hawaii incorporate tsunami and hurricane inundation data. Although Hawaii has been subject to 22 damaging tsunamis (both local and distant) since 1819, there are certain sections of the coast where hurricane inundation levels exceeded recorded tsunami inundation levels. In particular, the flood maps for the south shore of Kauai needed to be redrawn to account for the significant storm surge associated with Hurricanes Iwa (1982) and Iniki (1992). In general, the south shores of the Hawaiian Islands are particularly susceptible to hurricane storm surge, while the north and east shores have historically been especially vulnerable to tsunami inundation.

The mapping of inundation from other past natural disasters can provide additional data sets which help to refine the recurrence interval for a certain level of flooding (Section 2.1.1). For example, it is conceivable that a country may be exposed to inundation by a tsunami every 250 years that inundates an area 500 meters inland. However, if the country is especially vulnerable to hurricane storm surge, when combined with tsunami events, the inundation recurrence interval may be 100 years for an area inundated 500 meters inland.

This example demonstrates the importance of knowing the history of natural disasters for an area. Countries can refine their hazard maps by evaluating and integrating historical data with the detailed mapping information that comes from the recent 2004 tsunami. In doing so, risk along the coast can be more accurately bracketed and appropriate measures implemented.

Although the dynamics of the hurricane and tsunami waves are significantly different (Figure 2-6), the measures to mitigate flood and wave damage can help to reduce risk from both natural hazards. For example, hazard mitigation for a 2 meter (6 foot) velocity wave, whether caused by a tsunami or hurricane storm surge, would be to elevate the structure on piers or columns that resist hydrodynamic forces and with sufficient anchoring to prevent uplift and scour (Figure 2-5).

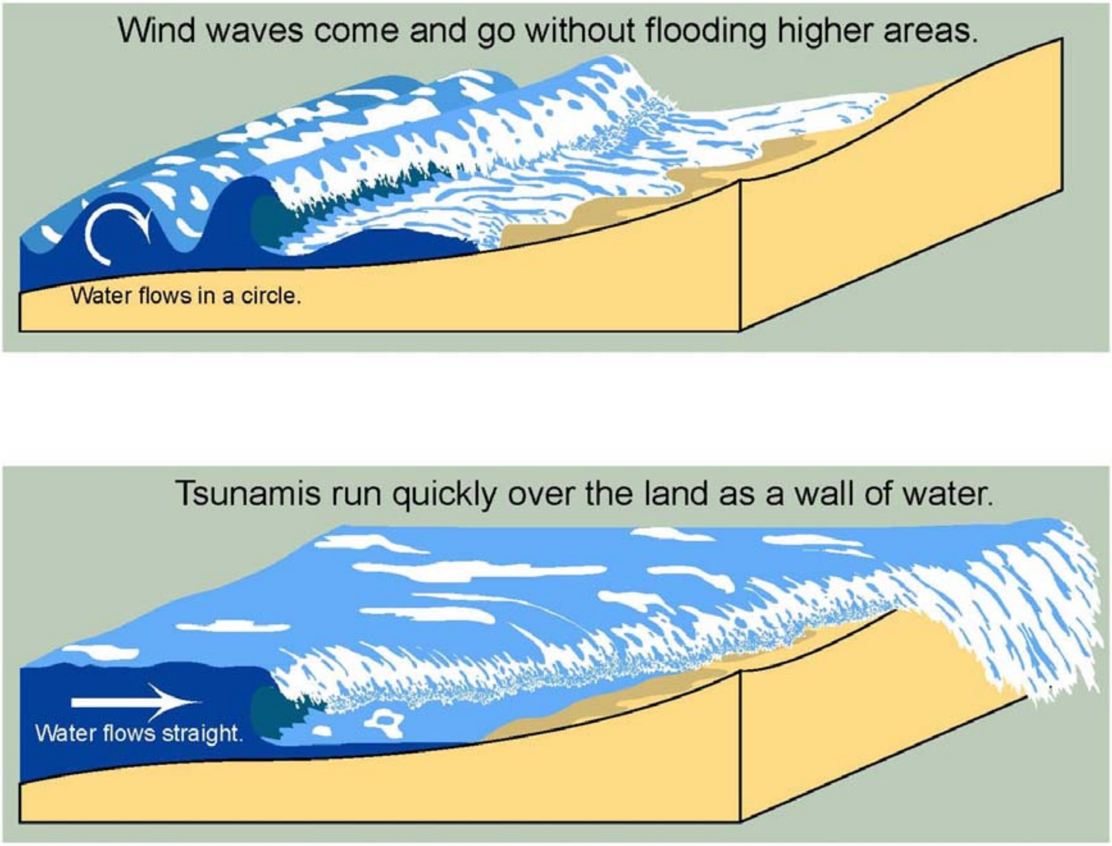

Figure 2-6 – Comparison of Wind Generated Wave with Tsunami Wave. The wind generated wave on the top has a shorter period and wavelength and the water flows in circles. The tsunami wave (bottom) has a much longer period (many minutes) and wavelength (many kilometers). Thus the force and momentum behind a tsunami wave is greater, and will inundate an area farther in. However, if a wind generated wave is associated with a hurricane or tropical cyclone, storm surge (water level elevation) may result in significantly greater inundation that approaches what may be seen for a tsunami. Image from University of Washington.

Generally, mitigation measures for different hazards reinforce each other (e.g., mitigation measures reduce the effects of flooding from a tsunami or hurricane storm surge). The one example of conflicting measures is when elevated structures designed to withstand wave and flood forces are also subject to earthquakes. In this case, columns and piers need to be reinforced for expected accelerations from an earthquake. (e.g., cross bracing, over design of column strength or anchoring – see Chapter 4).

2.1.3 Recurrence Interval

It is vital to determine if the 2004 tsunami was a 100-year event, a 500-year event, somewhere in between, or something greater. Various avenues of investigation to determine the recurrence interval include historical analysis, plate tectonic theory, modeling, and paleo-seismology.

Preliminary work by Professors Seth Stein and Emil Okal of Northwestern University indicate that the expected recurrence interval for the particular segment of the fault causing the 2004 tsunami is at least 400 years. This estimate is based on the rate of convergence of the Indian-Burma Plates, and the assumption that future events will have similar slip during the tsunami-generating earthquake.[10] Given the variability of earthquakes in general, an expected recurrence may be between 200 and 600 or more years. However, they note that for segments of the fault southeast of the segments that broke in 2004, strain was not relieved by the 2004 event and the probability of an earthquake in the next 100 years may have actually increased, as illustrated by the March 2005 magnitude 8.7 earthquake.

Preliminary probabilistic tsunami hazard calculations for the Sumatra-Andaman subduction zone (Thio et al., 2005)[11] are based on the earthquake recurrence model of Peterson et al. (2004),[12] who performed a probability seismic hazard analysis for the island of Sumatra and surrounding regions. The calculations use a set of 2,000 scenario earthquakes to provide a probabilistic description of earthquake occurrence in the region. Then, the complete tsunami wave field for each scenario earthquake is computed. Figure 2-7 shows the probabilistic tsunami shoreline wave heights for return periods of 50, 475 and 975 years, corresponding to probabilities of exceedance of 50%, 10% and 5% in 50 years.

Probabilistic shoreline wave height hazard analyses indicates that for a return period of 475 years, tsunami shoreline wave height could exceed 20 meters throughout the coastline that is immediately adjacent to the India-Burma subduction zone. The significance of this finding is that a major tsunami event should be expected at least every 500 years in this region.

Away from the subduction zone, the amplitudes are significantly lower, but there is strong variability along the coastline of Thailand. This illustrates the usefulness of this method as a screening tool for identifying locations on the coastline that are particularly vulnerable to tsunami damage.

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[10] See www.earth.northwestern.edu/people/seth/research/sumatra2.html.

[11] Thio, H.K., G. Ichinose and P.G. Somerville. Probabilistic tsunami hazard analysis. Manuscript in preparation.

[12] Petersen, M. D, J. Dewey, S. Hartzell, C. Mueller, S. Harmsen, A.D. Frankel, and K. Rukstales (2004). Probabilistic seismic hazard analysis for Sumatra, Indonesia and across the Southern Malaysian Peninsula. Tectonophysics 390, 141-158.

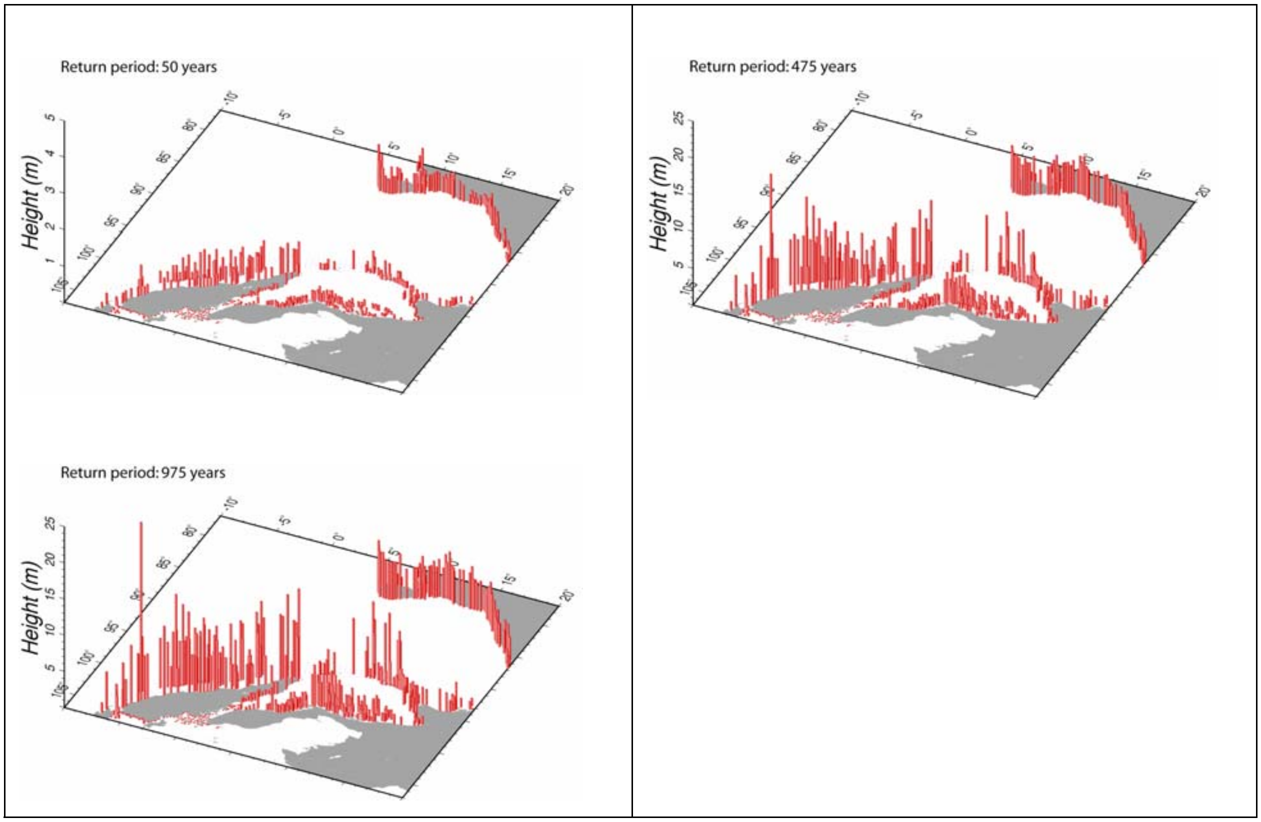

Figure 2-7 - Probabilistic tsunami hazard for the northeastern Indian Ocean for three return periods. The vertical scale for the 50 year case is different from those of the 475 and 975 year cases. Note that the height is at a location represented by the 15 meter bathymetry line. As the tsunami wave moves closer to the shore, the wave height will increase due to shoaling and runup. From Thio et al (2005).

Figure 2-8, shows tsunami wave height hazard curves at four locations in the northeast Indian Ocean region. These curves indicate that the December 26, 2004 tsunami was an approximately 500 to 1,000 year event.

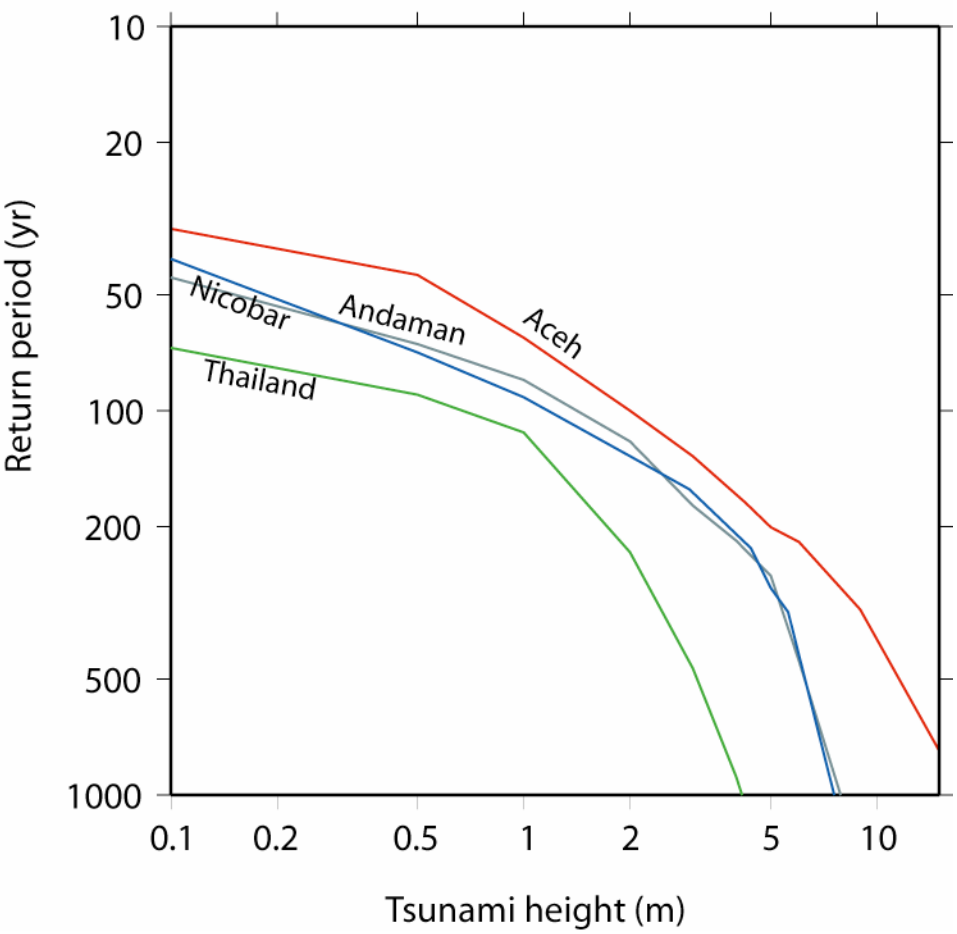

Figure 2-8 - Tsunami height hazard curves at four locations in the northeast Indian Ocean region. The heights are at the 15 meter bathymetry line. Subsequent shoaling and run up will cause the height to increase. From Thio et al (2005).

Researchers Kerry Sieh and Danny Natawidjaja of the California Institute of Technology have been studying corals fringing the islands of the outer-arc ridge beneath the subduction zone for the Indian-Burma Plates. These corals record a history of strain accumulation and relief above the subduction zone. For example, coral heads killed in 1935 were caused by 85 cm of emergence associated with the 1935 earthquake event. Another coral head experienced two centuries of strain accumulation before the 1935 event (Mw 7.7). Besides the 1935 event, there is discussion of an 1833 earthquake (Mw ~ 9) south of the equator and an 1861 earthquake (Mw ~8.5) north of the equator.[13] According to Dr. Sieh, each segment of the fault line ruptures about every 200 years.[14]

Based on plate tectonic theory and the history of past events in the area, Professors Seth Stein and Emile Okal roughly estimate that the recurrence interval for

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[13] For more information on this preliminary work, the reader is referred to the website www.gps.caltech.edu/~sieh/home.html.

[14] February 13, 2005 – Sixty Minutes Article

an ocean-wide tsunami generated by a magnitude 9.3 earthquake, similar to the December, 2004 event that threatens Thailand, India or Sri Lanka and that *occurred at the same spot* is about 500-1,000 years. The recurrence interval *at any one spot* for a local earthquake of magnitude 8 is roughly estimated at 120-400 years. The recurrence interval for a local tsunami of magnitude 8, that occurs *anywhere along* the 5,000 km long Indian-Burma trench is estimated to be about 30-100 years.

Given the range of numbers provided above, a conservative recurrence range for hazard mitigation planning purposes can be provided. The estimated recurrence interval for a large ocean-wide tsunami generated by a magnitude 9 earthquake at the same location as the December, 2004 event is 500-1,000 years. Due to additional uncertainties inherent in attempting to predict future natural hazard events, the lower number of 500 years is used as a conservative estimate for the magnitude 9 event. In addition, coastlines may be subject to tsunamis generated by a local tsunami of magnitude 8, and here the estimated range is provided as 120-400 years. To be conservative, the lower estimate of 120 years, or 100 years is utilized in this report.

For further discussion in this report, a tsunami generated by a magnitude 8 earthquake should be expected at least every 100 years and that for a magnitude 9 earthquake, at least every 500 years. Thus for Indonesia, the recurrence interval for a damaging tsunami is anywhere between 100 to 500 years.[15] Other countries damaged by the 2004 tsunami are likely to have a similar bracket with recurrence more closely matching the frequency for the large ocean wide tsunami, due to lack of known local tsunami generating sources. These brackets are consistent with the estimates of Sieh (200 years); Thio (at least every 475 years for 20 meter tsunami, 500-1,000 years for greater) and Stein (magnitude 8 – 125-400 years; magnitude 9 – 500-1,000 years).

Over time, it is likely that these numbers will be refined as further studies in this area are conducted. However, based on the limited information available to date, these are the numbers utilized in this report and are presented for discussion and interim hazard mitigation planning until further studies are completed. Consideration should be given to conducting studies that model the tsunami impact for each country as different portions of the active subduction zones around the Indian Ocean rupture to relieve built up stress (Figure 2-9). The scientists mentioned in this section should be considered for follow up work in this critically important area.

As a further qualification, both Sieh and Stein & Okal recognize that the December 2004 event did not relieve stress along the southern portions of the Indian-Burma plates. While this report covers recovery of areas stricken by the December 2004 tsunami, special precautions should be taken for areas not damaged by the recent event, most notably for the central and southern portions of Sumatra. In these areas conditions may be building up for a damaging earthquake and tsunami. So although this report covers recovery from the December, 2004 event, consideration should be given to incorporating mitigation measures for areas that have so far been unaffected.

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[15] Note that this estimate is just for local tsunamis, and does not factor in distant tsunamis from numerous potential sources, including from subduction zones, underwater landslides or volcanic eruptions.

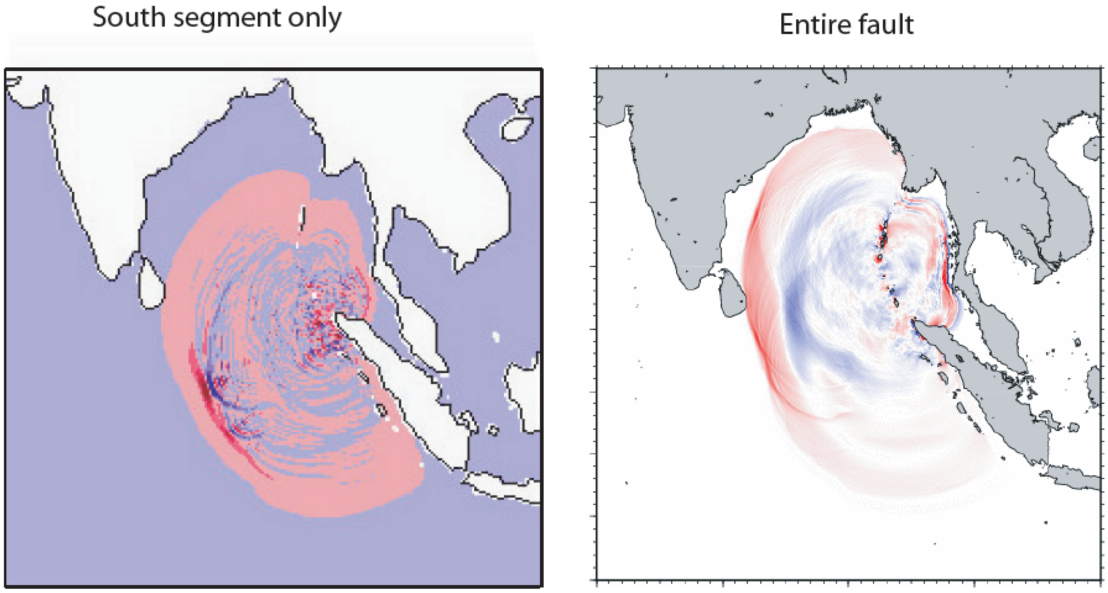

Figure 2-9 - Tsunami Activity versus Location of Active Earthquake. If only the south segment of the Indian-Burma subduction zone ruptured, India and Sri Lanka would have suffered much less damage. Because the rupture was along the south and northern section (right), these countries experienced much greater damage (Stein & Okal, 2005). This diagram demonstrates the importance of the location of fault rupture on the magnitude and location of the tsunami generated. Locational studies like this are important to predict coastlines especially vulnerable to tsunami damage.

Studies that model the effect of earthquakes along different portions of the plate boundary can be used to: (i) refine recurrence interval, (ii) help predict the range of tsunami warning times, and (iii) define areas that need to be designed for both tsunami and earthquake activity. In general, buildings in Indonesia need to be designed for earthquake shaking, which is less of a problem for Thailand and not an apparent problem for Sri Lanka and coastal India.

2.1.4 Adjusting the Hazard Mitigation Measures for Recurrence Interval

As discussed above, the recurrence interval should be accounted for, if structures are designed to withstand wave and flood forces along the coast. The more frequent the event, the greater the need there is to implement appropriate construction or siting measures into the development.

Depending on the recurrence interval, the standards and strategies for each hazard zone would need to be modified. If the December 2004 tsunami were a 100-year event, the case can be made that all structures in the inundation zone should likely be built with appropriate flood and wave standards.[16] However, if the tsunami was a 500-year event, or greater, questions may be raised about the applicability of hazard construction standards, when the life expectancy of a structure may only be 70 to 100 years. In the United States, coastal communities generally build for the 100-year event, but accept the risk from the extreme 500-year event.

Even for the 500-year event, however, special precautions can and are commonly taken for critical structures. Structures can be considered critical because: (i) the inhabitants are not sufficiently mobile to avoid injury or death during a flood; (ii) the facility is needed for flood response activities before, during and after a flood; or (iii) the facility is vital to maintaining or restoring normal services to flooded areas before, during and after a flood.

Critical facilities that provide emergency support to the community include emergency operation centers, hospitals, police and fire stations, power generation plants, waste disposal facilities, shelters, and evacuation centers. Critical facilities also include especially sensitive structures in which no risk of flooding can be tolerated such as schools, government buildings, sewage pumping stations, day care facilities, nursing homes, elderly homes, hazardous material facilities, and applicable access routes to the above facilities. Countries could add or delete to the list of facilities defined as critical. It may also be possible to prioritize the identified facilities.

In the United States, an attempt is made to avoid development of critical facilities in the 500-year flood zone (Executive Order 11988).[17] If avoidance is not possible through the evaluation of alternative sites, then flood construction standards are typically employed (e.g., flood and wave construction standards).

Regardless of whether the December 2004 tsunami was a 100-year or 500-year event, it may be prudent to design land use standards so that critical facilities are kept away from the tsunami inundation zone. If avoidance is not possible, flood and wave building standards as shown for Figures 2-4 and 2-5 could be considered. However, care should be taken because of the considerations previously discussed about the ability to design structures for unusually large wave heights.

Table 2.3 provides a summary of how construction and siting standards in the United States could be adjusted based on recurrence interval. Certainly countries need not follow what may be implemented in the United States, but the logic for purposes of hazard mitigation applies and is discussed below.

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[16] Note that for the 100-year hurricane which strikes an area, the probability remains the same for recurrence the next year (1% chance of occurring in any given year). This may not be the case for earthquake generated tsunamis in that after the release of stress along a fault that causes the tsunami, time may be required for strain to reaccumulate on the fault.

[17] Interview with Jerry Bare, P.E., Floodplain Manager for the California Department of Water Resources.

1. 50-year - If an area is severely damaged with high frequency (e.g., every 50 years), and the damage cannot be mitigated by construction standards, it may make sense to avoid the area by siting.

2. 100-year - If an area is damaged once every 100-years, flood and wave mitigation construction standards would be applicable. If it is not possible to design to the 100-year event (wave too high), consideration should be made to avoiding this area with siting measures.

3. 250-500 years - For events greater than a 100-year frequency (250 or 500 year event) the only requirement would be for the avoidance of the area for critical facilities that are so sensitive that even a slight risk of flooding cannot be accepted. This is consistent with practice in the U.S., where structures are designed to withstand the 100-year event, but accept the risk of the 500-year event. Given the capital investment of a building, and its anticipated life expectancy of 70-100 years, it may be considered inappropriate to design for property damage that may occur with a recurrence risk of 500 years (.2 percent chance of occurring in any given year).

Hypothetical Recurrence Interval	**Construction Standards**	**Siting Standards**	**Example**
50 years	No construction-Avoid area	No critical facilities No structures Consider avoiding if major property damage every 50 years.	Hilo, Hawaii – after severe property damage from the 1946 and 1960 tsunamis, the waterfront was kept an open space (Green Belt).
100 years	Build to wave and flood standards, if appropriate.	No critical facilities. Consider avoiding if cannot build to avoid damage from 100-year event (e.g., wave too high).	U.S. National Flood Insurance Program – flood and wave design standards for 100-year event – No critical facilities in 500 year floodplain
250 years	Construction allowed – no design standards	No critical facilities	No critical facilities in 500 year floodplain
500 years	Construction allowed – no design standards	No critical facilities	No critical facilities in 500 year floodplain

Table 2.3 - Recurrence Interval vs. Appropriate Standard. Example of how emphasis on construction vs. siting mitigation standards may change based on recurrence interval.

It is suggested that each country modify these thresholds based on their own cultural, social and community conditions. Some of the more important factors that play a role on setting the limits include the life expectancy of structures, their value, and the local cost of construction.

An especially important factor is the risk to human life, which is a special factor that is considered in chapter 5. Areas where there are inadequate evacuation routes, or little warning time even with a fully functional tsunami warning system (local tsunami), warrant special consideration. These areas may shift the hazard mitigation strategy from one based on construction design standards to those based on siting. This factor has been taken into account for the case study discussion for Banda Aceh, Sumatra (chapter 6).

2.2 Scientific Information Vital for Redevelopment and Recovery

It is vital that the scientific and engineering community provide information in a form that is useable to government officials planning recovery of the area. Critical information would include maps that break the inundation zone into multi-hazard sub zones. Absent the scientific research, preliminary analysis on inundation should be provided to facilitate recovery. Subsequent inundation maps can then later be refined. This information should help planners and government officials to answer the question of where to build (siting) and how to build (construction).

It is also up to the scientific and engineering community to determine at what water depth, it is no longer possible or feasible to design various types of structures to withstand high velocity wave action. This can come from engineering studies coupled with observations from the tsunami inundation survey teams, as well as the building assessment teams. The maximum height will likely be dependant on many factors, one key being the type of structure built (e.g., single residential versus hotel or commercial).

Chapter 3 – Implementation Strategy - Use a Flexible Light-Handed Approach

Just as important in the development of technically based hazard mitigation standards, as described in chapter 2, is how a local government or country implements the measures. If the implementation is too burdensome, or inappropriate, the standards are likely to be diluted and the end result may expose inhabitants and coastal structures to unnecessary risk. Another important factor in implementation is the sovereignty and culture of affected countries.

This report addresses these concerns by proposing a light handed approach to implementation based on the use of planning information, guidance, industry standards and policy. This should provide the greatest flexibility to countries attempting to recover. In addition, such an approach allows countries, or sectors of countries, to overlay their own individual needs and requirements for the reconstruction effort.

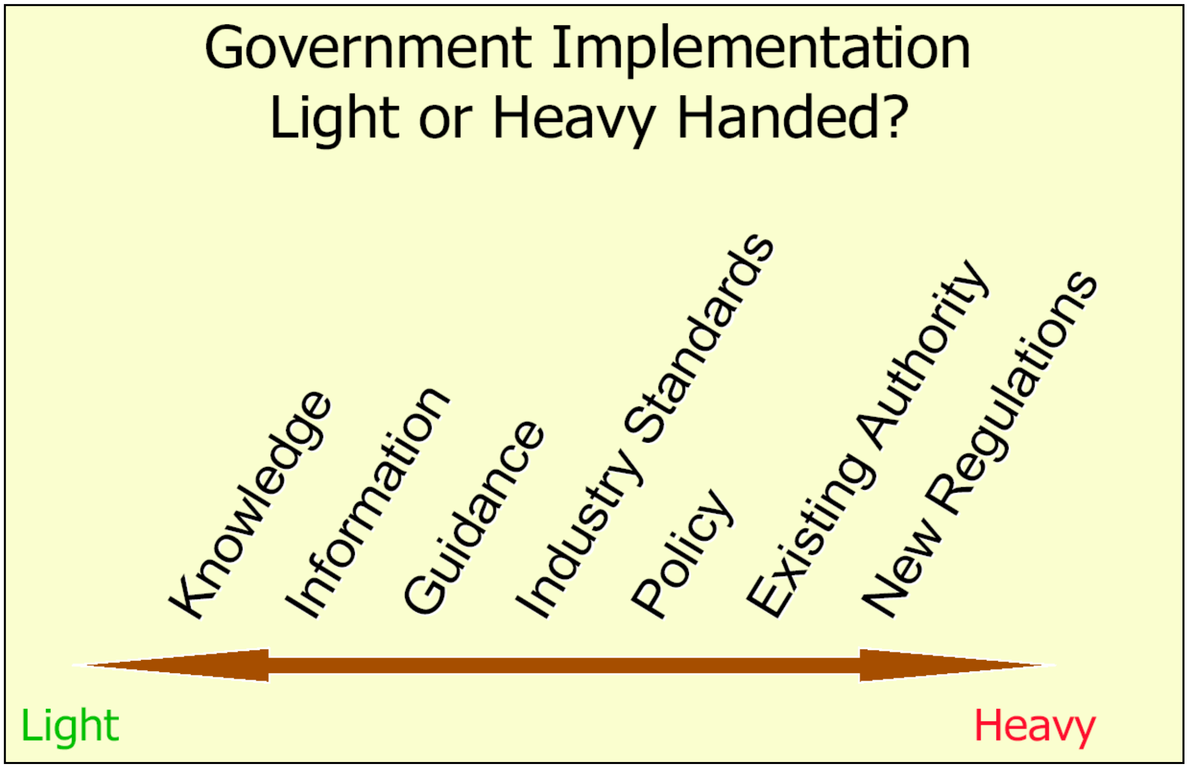


Figure 3-1 - Light Handed Approach to Implementation. It is recommended that countries recovering from a tsunami consider a light handed approach for implementation, based on planning information, guidance, industry standards and well- written policy.

The Hawaii Guidebook was designed so that it could be implemented with a light-handed approach based on an agency's existing authority through the use of planning information (e.g., inundation zones, water levels), guidance, industry standards and policy (Figure 3-1). This strategy was designed to maximize flexibility since a multitude of agencies, with different policies, rules, and hazard mitigation issues would be involved.

Essentially, an attempt was made to identify protective mitigation measures and the lowest common denominator that could be implemented for various government entities. Each agency could then decide on their own initiative how far to implement the measures. One agency could decide to only encourage its use as guidance (e.g., hand the book out to applicants for a project), while at the opposite extreme, another agency may generate new rules that require the implementation of the measures (heavy-handed approach). A similar approach is recommended for countries recovering from the tsunami, because utmost flexibility is required in the recovery from any natural disaster.

The elements of government implementation (Figure 3-1) form a continuum that can provide hundreds of new options if it is realized that they can be used in varying degrees and in different combinations to match the characteristics and social needs of the local community. Thus it is important to describe some of the key elements in the continuum.

3.1 Knowledge

Knowledge is an awareness that a coastal area is subject to certain coastal hazards. For tsunami hazard mitigation, this element is crucial. Because many coastal communities had no knowledge or awareness of the risk of tsunamis, many people lost their lives when the sea withdrew and they rushed to the ocean to observe the phenomena. Education in this regard is critical so that if there is severe ground shaking, or the sea withdraws, people know to quickly run to higher ground.

It is a natural progression that knowledge of the risk of a danger will lead to obtaining more information so that future risk can be planned in the development process and the damage mitigated.

3.2 Information

Information in this context is planning information. In the aftermath of the December tsunami, many scientific and engineering teams visited the inundation sites to gather information such as inundation limits, wave heights, water levels, run up heights and building performance. This data is vital for planning and the recovery of tsunami damaged areas.

Unfortunately, the gathering and analysis of data takes time, and there is often a lag between finalizing the necessary planning information and the creation of recovery plans based on needed data. This is understandable since leaders of a country place top priority on relieving human suffering. If the time lag between the creation of recovery plans and the delivery of necessary planning information becomes too great, the plans are more likely to be developed without a solid scientific basis.

It is hoped that this report will help to alleviate some of these problems by: (i) providing interim measures for inundation mapping (Section 2.1.1), (ii) emphasizing a flexible implementation strategy that could be adjusted as new data becomes available (this chapter), (iii) suggesting certain strategies in the development process (chapter 4), and (iv) making recommendations on data that are especially useful for recovery and redevelopment (see below).

With regard to item iv, information especially useful for recovery includes the development of inundation maps that break the inundation zone into subzones, estimation of recurrence interval, and the design of coastal structures that can withstand high velocity wave action, with an upper limit on wave height/depth of water when the design becomes unfeasible. With this information, countries will know how and where to develop in order to reduce future hazard risk.

3.3 Guidance

Guidance takes the planning information and provides direction on how to use it in construction and siting design so that hazard risk is reduced. The advantage of guidance in that it is more flexible than strict mandatory rules. In general, a wider variety of scenarios can be dealt with by guidance.

Through this report it is hoped that countries develop their own guidance on how to recover from the tsunami. For instance, if a country decides that a certain building design is suitable to protect against high velocity wave action, guidance could be provided to the community on: (i) low cost hazard construction measures; (ii) suitable designs; (iii) key design characteristics, such as pile and anchoring specifications, (iv) local materials to build the structure, (v) where to obtain the materials, (vi) where to find a qualified contractor, or even (vii) how to get financial assistance to build.

Through guidance, countries can provide communities the tools to rebuild more safely. The more direction and assistance provided, the greater the chance that individuals and communities can take the lead and implement on their own initiative. Ideally, countries could provide communities the know-how, materials, and financial assistance to begin reconstruction of damaged areas. This will allow the maximum participation by individuals and communities to participate in recovery. This recipe for reconstruction and recovery is strongly encouraged in this report.

3.4 Industry Standards

Industry standards are practices followed by an industry, even though there may be no requirement to do so. The standards are well developed in the United States, but an investigation of their role in foreign countries was beyond the scope of this report. Nevertheless, industry standards could develop through encouragement by the local public, policy developed by the country or local community, or the initiative of a few companies in the industry. A combination of guidance with well-written policy (Figure 3-1) can strongly encourage the development of industry standards.

3.5 Policy

Policy refers to the general principles which guide a government in managing its public affairs. Policy can help to interpret and guide existing regulations and rules. It should enhance and further the goals of existing rules and laws, and generally not conflict. Sometimes new rules are created after polices are set, while other times new policies maybe created to further expand or explain an existing rule.

For a country recovering from a natural disaster, policies are very important. For example a policy to: "Reduce the risk to life and property from tsunami inundation," can have a ripple effect that simultaneously justifies the government to: (i) collect planning information such as tsunami inundation, (ii) create guidance for low cost residential designs resistant against inundation, (iii) further the use of standards in the building industry that protect against wave action, (iv) interpret existing rules in a way that is consistent with reducing the risk from inundation, or (v) creating new rules on inundation.

Policy should be well written to avoid concerns with favoritism or corruption. For example, a policy that only allows large commercial buildings in a coastal area may be viewed as favoring the business industry. An alternative is a policy to limit an area to buildings able to withstand the hydrodynamic forces from a wave equivalent to the most recent tsunami event by the use of suitable elevation. The end result may be that due to the difficulty in elevating small residential structures to such a height, only larger commercial buildings would be able to build to such a standard. However, the purpose for restriction, in terms of hazard mitigation is clearly given. As a result, there is less likely a chance that the policy would be questioned as being corrupt.

3.6 Summary

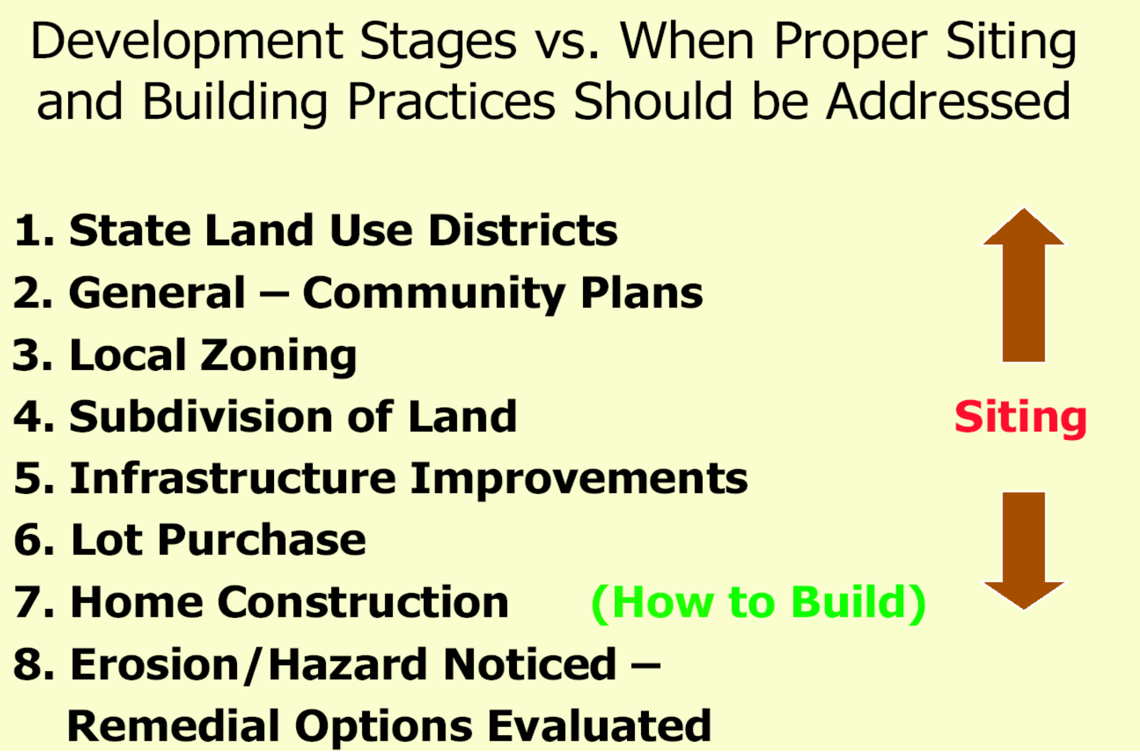
This report recommends that countries emphasize the use of guidance, industry standards, and well-written policy to maximize needed flexibility. New regulations may be important, but in general, should be used as a last resort. This approach allows maximum flexibility to deal with the different scenarios inherent in any redevelopment effort after a natural disaster. In addition, it will be easier for countries and local communities to overlay their own particular needs onto the measures identified to reduce hazard risk.

Figure 3-1 offers developing countries a multitude of options because the elements form a continuum. A good example is this report, which is a strategy, concept, option paper, which falls in between planning information and guidance. The real guidance countries need can be developed by each nation and can address issues such as those listed above on the section on guidance. It is hoped that this report encourages countries to develop the guidance that is needed to decide how and where to build better in order to reduce the risk of natural hazards.

Since Figure 3-1 represents a continuum of elements for implementation, each governmental organization can take guidance and decide how far along the sliding scale they wish to implement the measures (e.g., from policy to new regulations). For example, once the Guidebook was created for the State of Hawaii, it was anticipated that the four counties could decide individually at the local level how far the measures would be implemented. Similarly, initial interest has been expressed in Louisiana to employ such a concept for recovery from Hurricanes Katrina and Rita because of the numerous parishes involved (19 coastal parishes and 64 in total). Using a flexible approach based on guidance, each parish could conceivably decide, on their own, how much of the guidance should be followed.

Chapter 4 - Divide the Development Process into Stages

In the Hawaii Guidebook, the development process was been broken up into stages, in order to facilitate implementation of the hazard mitigation strategies (Figure 4-1). It is important to break up the development process into stages because with each stage, there will be different affected parties, agencies and rules, as well as distinct hazard mitigation issues, and opportunities to implement those measures. For instance Best Management Practices to preserve coastal dunes that protect against erosion and flooding are best addressed during the infrastructure improvements stage, when grading permits are issued. However, siting using scientifically based setbacks is best addressed as early as possible in the development process (community planning and zoning stages).



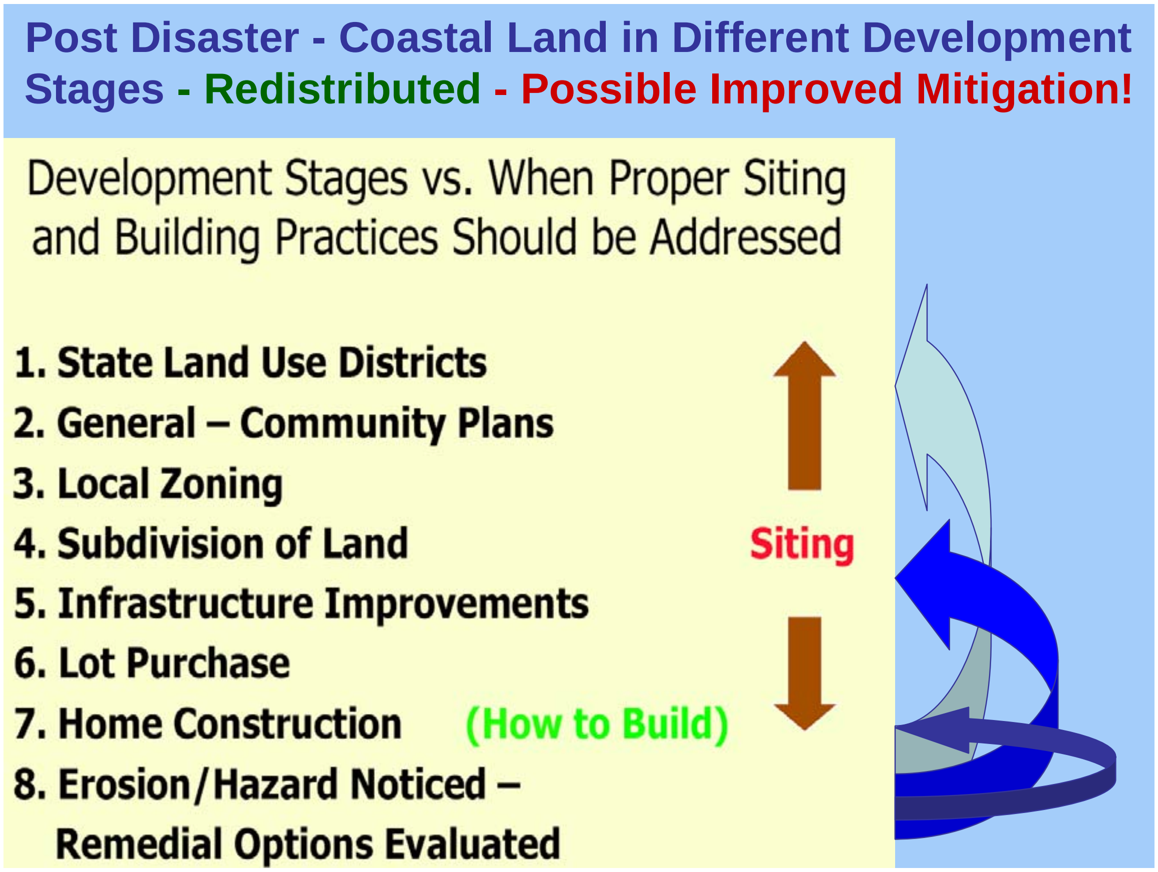
Development Stages vs. When Proper Siting and Building Practices Should be Addressed

1. **State Land Use Districts**
2. **General – Community Plans**
3. **Local Zoning**
4. **Subdivision of Land**
5. **Infrastructure Improvements**
6. **Lot Purchase**
7. **Home Construction** **(How to Build)**
8. **Erosion/Hazard Noticed – Remedial Options Evaluated**

Figure 4-1 - Stages of Development in Hawaii Showing When Siting and Construction Issues are Addressed. Generally, for legal, political and practical purposes, siting issues (where to build) should be addressed as early as possible in the development process. Building correctly (how to build) can be done at Stage 7.

For tsunami stricken areas, the development process for each country will vary significantly, but similar concepts apply in that there is usually a hierarchal process by which land is developed. Most countries have a form of zoning, community involvement or planning and a subdivision or master plan process. Each section of coastline may be in various stages of development.

After a natural disaster such as the December 2004 tsunami, the percentage of coastal land within the different stages of development will become redistributed (Figure 4-2). This will provide an opportunity for government agencies, communities and individuals to implement new hazard mitigation measures for siting and construction, where it may not have been feasible or appropriate before.



Post Disaster - Coastal Land in Different Development Stages - Redistributed - Possible Improved Mitigation!

Development Stages vs. When Proper Siting and Building Practices Should be Addressed

1. **State Land Use Districts**
2. **General – Community Plans**
3. **Local Zoning**
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5. **Infrastructure Improvements**
6. **Lot Purchase**
7. **Home Construction** (How to Build)
8. **Erosion/Hazard Noticed – Remedial Options Evaluated**

Siting

Figure 4-2 - For areas damaged by a natural disaster, it will be possible to move up the development ladder and rebuild with more protective siting or construction measures.

It is up to the government officials to recognize when and where opportunities arise to implement hazard mitigation measures based on the particular section of coastal land. For example, if many lots can be legally consolidated, it may be possible to rezone and resubdivide an area in a manner that allows residential structures along the coast, but with considerably greater protection against wave and flood action (moving from Stage 7 or 8 to Stage 2, 3 or 4 on Figure 4-1 and 4-2). Another alternative is to just keep the consolidated area open space. The areas most likely to be candidates for consolidation are the areas that suffered the most extensive property damage.

Even if land cannot be consolidated, it may be possible for homeowners to rebuild damaged structures with new construction measures that protect against waves, flooding or seismic forces (moving from Stage 8 to 7 on Figure 4-1 and 4-2). For example, a house destroyed by wave action can be rebuilt stronger to withstand flooding and wave action (Figures 2-4 and 2-5), given that the wave heights are not too high (Table 2-1, Figure 7-1).

Some of the more important stages in the development process and their role in hazard mitigation are described below. Additional information on this topic is provided in the Hawaii Guidebook.

4.1 Zoning

There will usually be some form of zoning in which certain uses of the land are designated or restrictions placed. It is important to distinguish scientifically developed hazard zones (e.g., Figures 2-1 and 2-2) versus land use zones (e.g., agricultural versus urban use). The question often arises, is it suitable to substitute the land use zone for the scientifically developed hazard zones? *This report strongly recommends that scientifically developed zones be developed for all inundation areas*. The identification of the zones provides incentive to craft force-specific hazard mitigation strategies, while encouraging individuals to implement them, even if they are not legally required to do so.

After inundation subzones are determined, each country or coastal community can develop their own land use zones that overlay the scientific zones. *The overlay process, coupled with a flexible approach described in chapter 3, provides a mechanism by which a country can integrate its own social, cultural, economic, or religious needs on top of the scientifically developed hazard mitigation measures*.

Another important reason to develop the scientific zones is because they play a key role in how a structure is built (e.g., how high a structure is elevated would come from the inundation maps). Countries that have failed to develop adequate inundation maps that allow the area to be scientifically zoned have later scrambled to gather this information due to the need for long range strategic planning and hazard mitigation recovery. In some cases, the scientific zones may drive how the area is zoned for land use.

Even if no hard regulatory zones for land use are established, it will be possible to create zones in which certain flexible recovery strategies apply. For example, in an inland zone, the major hazard mitigation measures may all be construction related. For this zone, options can range from strict building codes to flexible guidance on preferable construction practices. For certain zones and districts subject to high velocity wave action, strategies may range from purely siting, to a mix of siting, construction and evacuation measures. Therefore the creation of scientific zones will help a jurisdiction better understand the spatial variability of a future possible disaster and facilitate the creation of appropriate and protective mitigation measures.

4.2 General and Community Plans

In the recovery of an area, community input and planning is also vital. Governments that have attempted to redevelop without community input have been criticized and have often had to remodify initial plans for how an area should be developed.

However, it is important to distinguish in the recovery when community input is most appropriate. Community planning is critical in deciding the future of public infrastructure such as roads, parks, schools, and other public facilities. It is not as critical in deciding the fate of individual lots in which homes have been destroyed. This is because the lot owner may have established rights in the property that are generally not proper for the community to decide. This is an especially important consideration for countries that allow individual lot owners decide if they wish to move off the property after a structure is destroyed.

There may be times when the community cannot decide on the fate of a certain area. In this case, some of the factors discussed in chapter 5 should be considered. It is up to the government to make the final decision, after community input on the fate of public areas in the inundation zone. However, governments should generally justify their decisions and the important factor of hazard mitigation for life and property can be compelling.

4.3 Subdivision of Land

The subdivision process is where large parcels of land are taken and divided into many smaller ones. This process can have a significant impact on the implementation of effective hazard mitigation siting measures. The subdivision process can play a role in the recovery from a natural disaster under many different scenarios such as if: (i) individual lots can be consolidated and then re-subdivided, (ii) a new undeveloped area is targeted for development (e.g., perhaps to resettle evacuees displaced from a natural disaster; or (iii) structures in an area are severely damaged or destroyed and the government buys out the area, or exchanges some of the lots for alternative land that is more safely located.

In the subdivision process, it is important to consider hazard mitigation early in the design phase so lots can be created that are big enough to accommodate appropriate erosion and hazard buffers. Thus early planning in the preliminary stages of subdivision, or even better during the zoning and community planning stage are important.

It is also necessary to use innovation and flexibility in subdivision design. For example, instead of creating lots that are all of one size and shape, different lot sizes and geometries can be used to increase the hazard buffer zones, while allowing almost the same density of construction.

Finally the importance of road layout for hazard mitigation design should not be overlooked. If parallel roads close to the coastline cause the creation of small lots, they may expose inhabitants to unnecessary risk from erosion, flood or wave forces. Consideration should be given to creating parallel roads further from the coast to create deeper hazard buffers, or building lot access through roads perpendicular to the coast. Because most coastal areas generally gain elevation away from the ocean, roads perpendicular to the coast can also serve as important evacuation routes.

For the sake of brevity, only two examples of how subdivision design can change exposure to coastal hazards are given in this report (Figures 4-3, and 4-4). Many more examples could be provided and the reader is referred to the FEMA Coastal Construction Manual (2000) for more examples. It is also encouraged that the reader or applicant develop new village designs based on the specifics for that coastal area. It is up to parties such as the landowner, project applicant, community, architects or planners to come up with designs that are suitable to the specific conditions of the area. Each area is different and will have different requirements. However, there are many ways to design subdivisions to reduce the risk of coastal hazards.

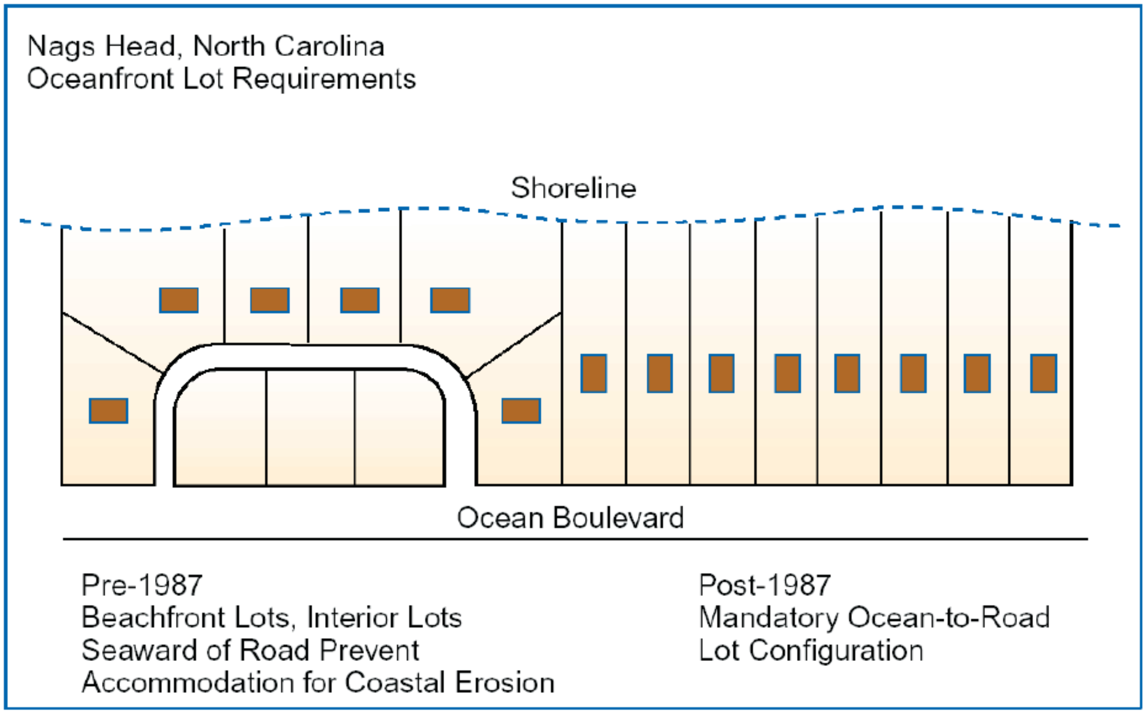

Figure 4-3 - Early subdivision design along the east coast of the United States in North Carolina placed lots seaward of an arterial road that is parallel to the coast. The small lots cannot accommodate erosion. New design creates deep, narrow lots by eliminating the feeder road. The deep lots can better accommodate coastal hazards such as erosion, flooding and wave action. From Morris, 1997 and FEMA CCM, 2000.

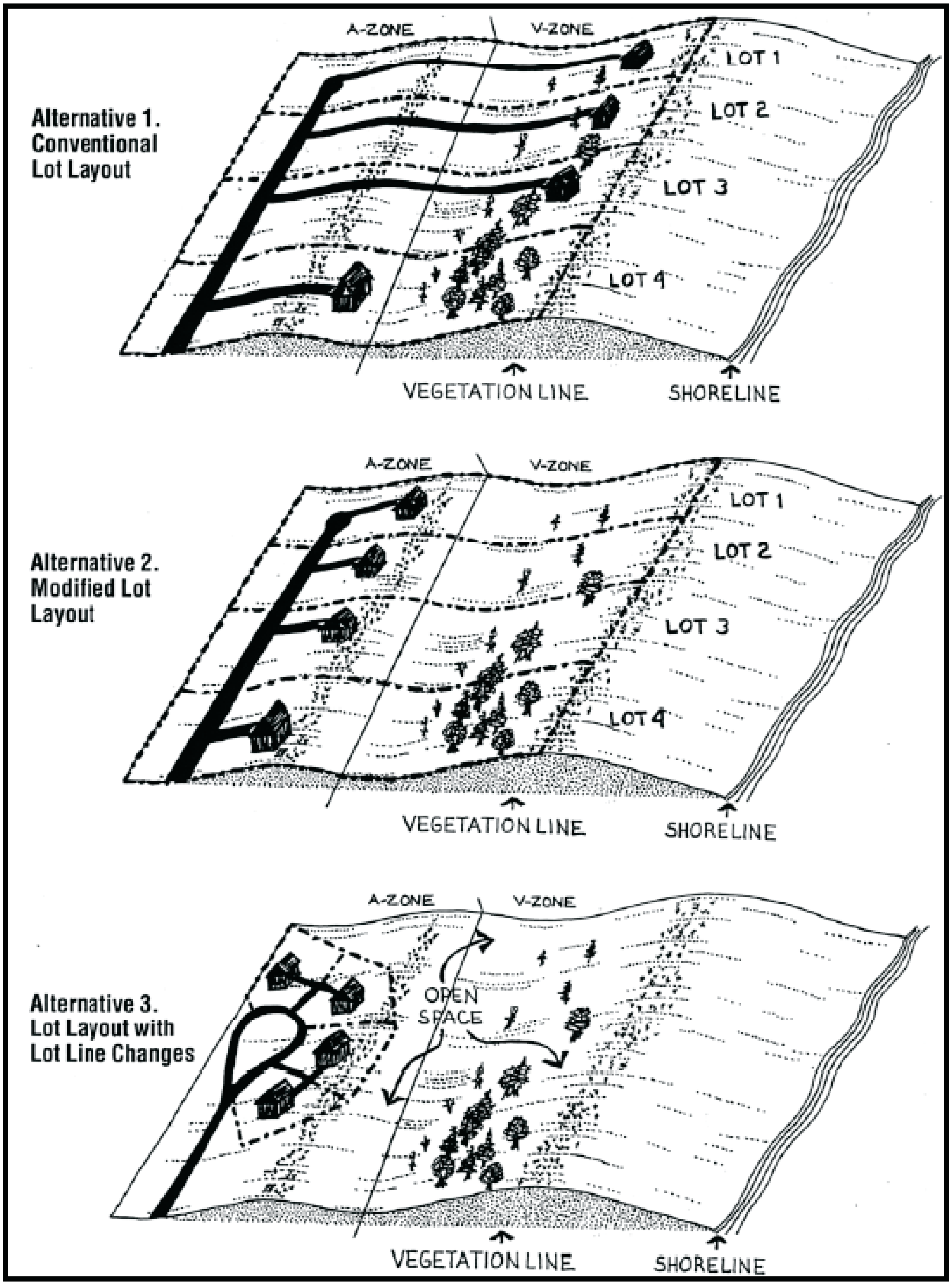

Figure 4-4 - Cluster Development - Comparison of conventional lot layout compared with a modified lot layout and cluster layout to create a safety buffer zone from the ocean. Cluster design may be especially useful for countries that want to allow limited development near a hazard zone. From FEMA CCM, 2000 and Morris, 1997; adapted from California Coastal Commission, 1994.

Some key factors that determine how land can be used while reducing hazard risk include lot layout, lot size, lot geometry, mixing of different lot sizes, mixing of different lot geometries, road layout, and road orientation (i.e., parallel or perpendicular to the coast). Given the number of variables listed above and the numerous combinations of the variables, many options to create safety buffer zones along the coast are possible.

4.4 Infrastructure Improvement

Infrastructure improvement for hazard mitigation includes the preparation of land for development, the layout of roads, and the installation of utilities to survive flood and wave forces. Regarding the layout of roads, this important subject was covered briefly on the section for subdivision. This report encourages countries to consider building roads away from the coast, when appropriate, to create more effective and larger hazard/flood buffers, as well as evacuation routes.

With regard to the provision of utilities, such as electricity, phone and water, these should either be elevated or made waterproof to avoid or reduce risk from flood damage. This is required for many flood control standards in the United States.

This section of the paper covers three subjects, (i) the importance of protecting coastal dunes to reduce the risk from flood, wave and erosive forces, (ii) the use of mangroves to limit the inundation from a tsunami, and (iii) the use of other hardened structures such as breakwaters, revetments and seawalls. All three can help to reduce the risk from flood and wave forces. However, if these actions are the only tools implemented to reduce wave risk, then modeling studies should be conducted to determine how effective the measures are in reducing anticipated run up and wave height. If the impact is expected to be small, then these measures should not be used as the sole basis for hazard mitigation.

It is generally recognized that maintaining the coastal dunes can help to reduce risk from future erosion, flooding, and wave action. Coastal dunes generally contain salt tolerant plants, whose thick root systems help to bind the sand and prevent erosion (Figure 4-3). In some cases, barrier dunes can block wave and flood forces. Therefore in coastal areas, all effort should be made to preserve the natural dunes.

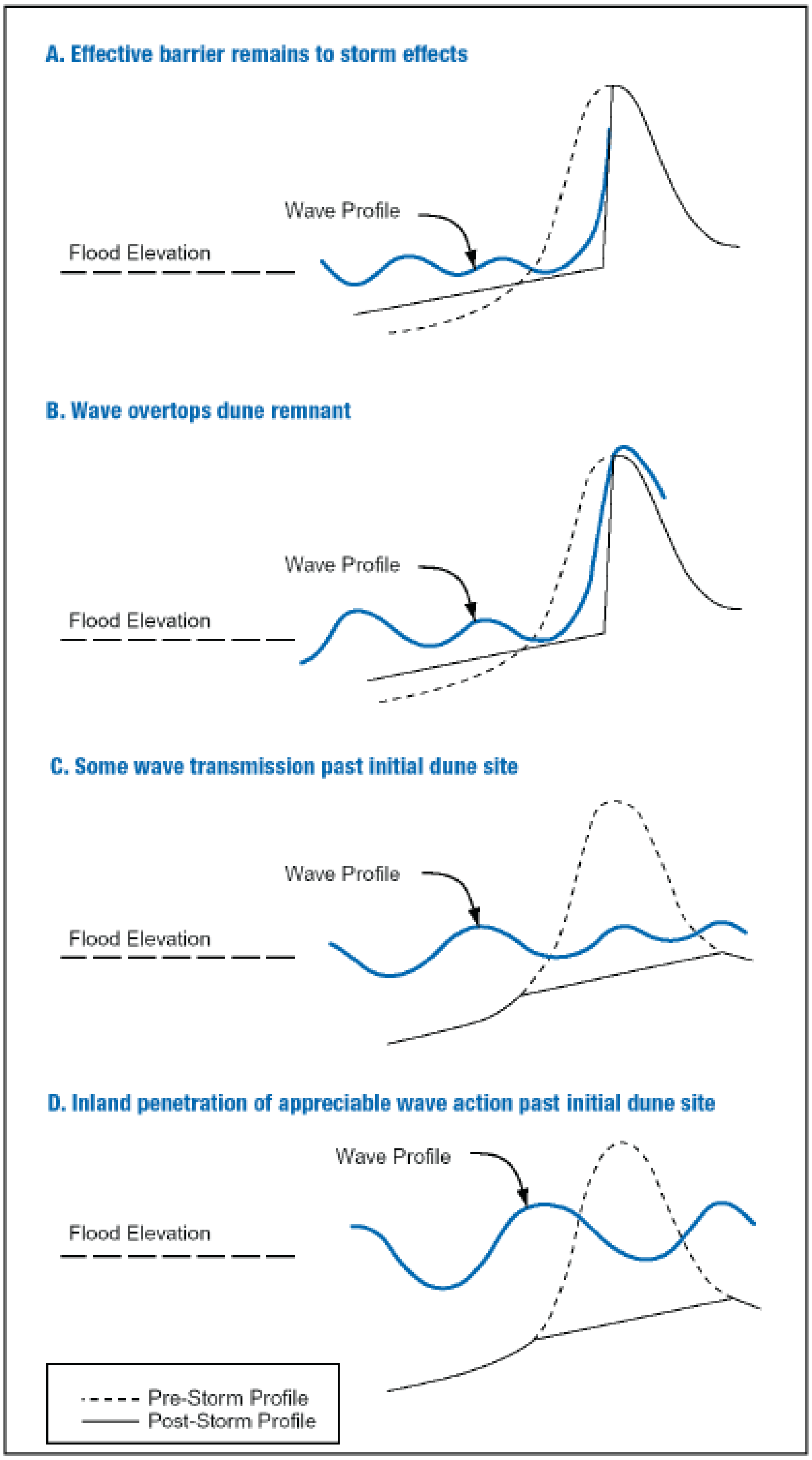

Figure 4-5 - Role of Dunes in Protection of Inland Areas. In A, small waves above a flood elevation are contained by the dune, but the dune retreats from its original profile. Backshore areas are protected.
In B, larger waves over the flood elevation overtop the dune. Backshore areas are subject to slight flooding. In C, the dune has been removed, exposing backshore areas to flooding and smaller waves. In D, larger waves remove the dune and expose backshore areas to significant flooding and wave action. This diagram demonstrates the importance of maintaining the dunes and coastal vegetation to protect inland areas from flooding, wave inundation and erosion. From Dewberry & Davis 1989 and FEMA CCM, 2000.

Numerous authors that have conducted field surveys of tsunami inundation areas have also noted the important function of mangroves in helping to reduce tsunami inundation and run up (Figure 4-6).[18] Other reports also recommend the use of trees as a buffer to reduce tsunami inundation.[19]

Figure 4-6 - Mangrove Forest Along Shoreline. Mangrove thickets along the coast can be used to create a green belt and reduce incoming tsunami wave energy. Photo from P. Warnitchai (2005).[20]

In some countries with high density urban development such as in Japan, seawalls, revetments, tetrapods, breakwaters and other stone reinforced measures are also used to reduce the impact of incoming tsunami and storm waves. However, these structures are very expensive and it is unlikely that the low density of coastal development in countries struck by the December tsunami would support such measures for the hundreds of miles of coastal areas needed to be protected. Nevertheless, these measures could be considered to protect especially important areas.

Whether dunes, mangroves, or hardened barriers are used to reduce the impact of tsunami and storm waves, the expected reduction in wave forces should be modeled so

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[18] Interview with Absornsuda Siripong, Chulalongkorn University, Thailand, and Dennes Borgado, Asian Institute of Technology, Thailand.

[19] National Tsunami Hazard Mitigation Program. 2001. Designing for Tsunamis – Seven Principles for Planning and Designing for Tsunami Hazards, p. 60.

[20] Warnitchai, P. (2005), Lessons learned from the 26 December 2004 tsunami disaster in Thailand, Proc. of Scientific Forum on Tsunami, its Impact and Recovery, 6 to 7 June 2005, AIT Conference Center, Bangkok, Thailand.

that the anticipated protective affects are not overestimated in a manner that places coastal residents in danger.

4.5 Home Construction

If residential structures have been determined to be safe for a particular area, but there may be periodic flooding or high velocity wave action, then appropriate measures to reduce risk of inundation can be built during home construction, provided the wave height is not too high. The key in building design is to account for hydrostatic and hydrodynamic forces (Figures 4-7 and 4-8).

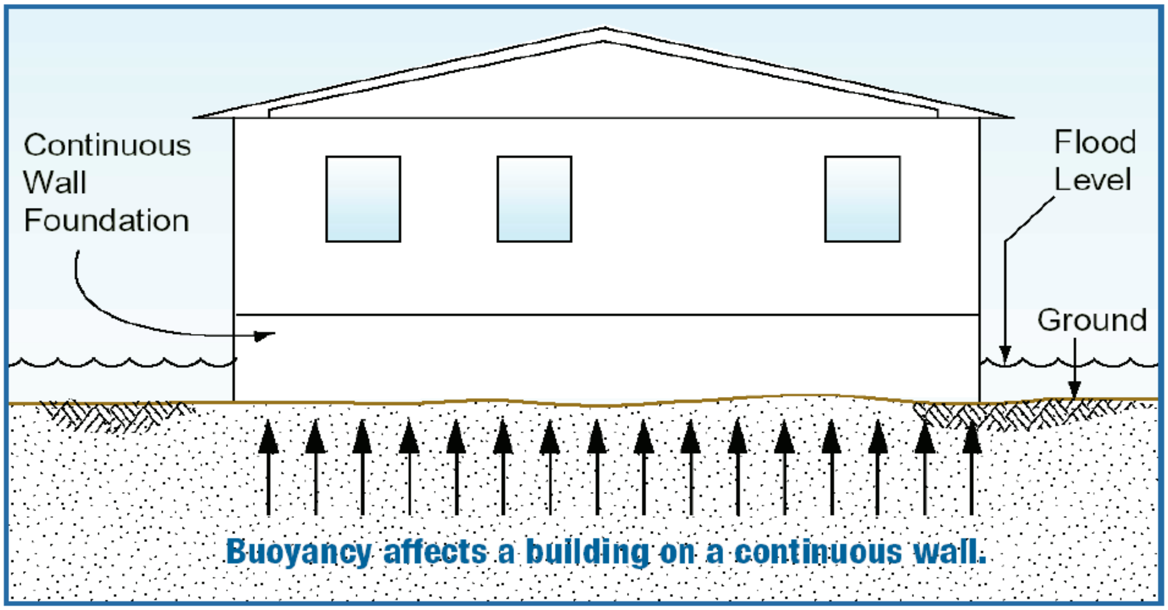

Figure 4-7 - Hydrostatic Forces. A continuous wall foundation for a house does not allow venting of flood waters. Hydrostatic forces associated with the buoyancy of the house may lift the structure off its foundation and cause it to topple. From FEMA CCM.

Flood-resistant construction such as shown on Figure 2-4 would prevent the buildup of hydrostatic forces. For simple flooding, the common practice is to have the structure elevated above the anticipated design flood level, and for supporting walls to have openings to vent the water.

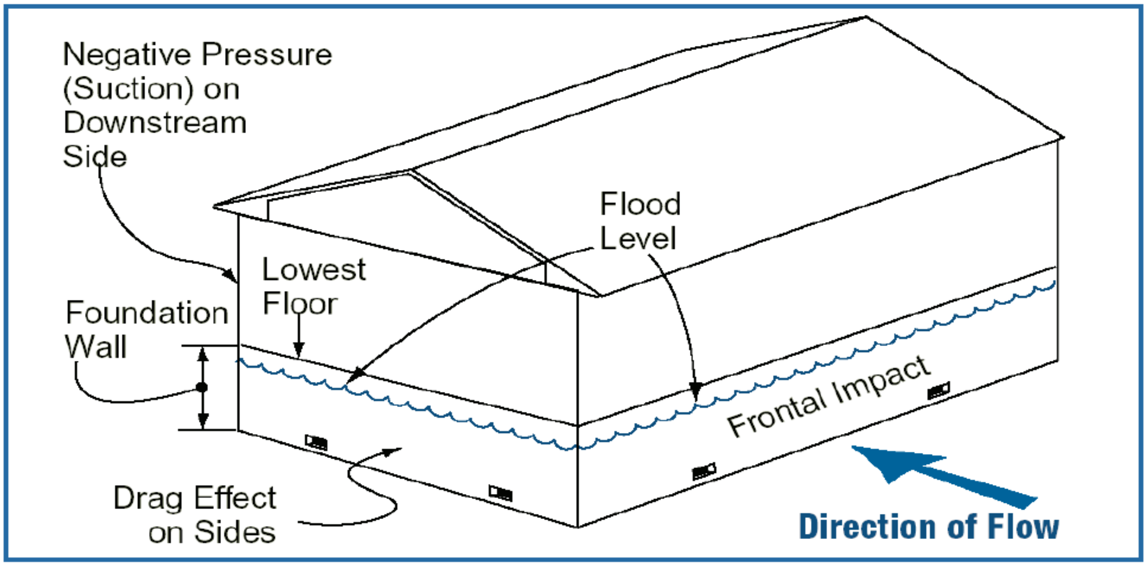

Figure 4-8 - Hydrodynamic Forces. High velocity moving water causes high pressure upstream, drag on the side of the structure and negative pressure at the downstream end. These hydrodynamic forces and the debris associated with moving water can cause significant damage and total failure to residential structures.

High velocity wave construction would prevent the damage associated with hydrodynamic forces and water-borne debris. If a structure is subject to high velocity wave action, it should not have supporting walls, but should be on well anchored piers or columns that allow the passage of water and waves (Figure 2-5). The piers or columns should be anchored to resist scour and erosion. Sometimes solid walls may be allowed in a wave zone, but the walls need to be designed to break away during passage of water and are not designed to support the weight of the building.

Figures 2-4 and 2-5 illustrate the concept of protecting a house against flood and wave forces. As each country develops guidelines for hazard mitigation, it would be useful to combine specific parameters that mitigate damage from flood and wave inundation with local customs, design and architecture for that area. In Chapter 6, an example is provided of local building design that follows, in a rough sense, the principle of venting of water to relieve hydrostatic and hydrodynamic forces.

The building code for Honolulu, Hawaii is a useful example that can assist countries in developing guidelines for construction that protect against wave and flood forces (http://www.co.honolulu.hi.us/refs/roh/16a11.htm). Principles in this code could be applied as new regulation, or in the form of more flexible guidance. In the Code, flood and tsunami criteria are combined under general flood hazards, using structural load requirements developed by the Hawaii Tsunami Technical Advisory Committee, which consisted of a group of government, university and consulting engineers.[21] Each of the Honolulu code provisions are based on varying degrees of scientific research. For example, some criteria are based on extensive hydrodynamic analysis and observations, while others are based on more limited data. Nevertheless, guidelines or standards were created based on the best scientific information at that time. Table 4-1 provides an example of key tsunami design criteria in the code that may be of use for other countries.

Standard	Explanation
Flood Elevation	Flood elevations are found on the Flood Insurance Rate Map – (see Figures 2-1 and 2-2). This determines how deep the anticipated water is for the design event (100 or 500 year event). See also Section 2.1.3.
Flow Conditions	Code assumes non-bore conditions except at historic bore sites. Bore conditions will have greater force based on higher velocity which is accounted for in the force equations. See Dames and Moore report.[20]
Foundation Type	Piles are required within ~100 m (300ft.) of the shoreline and for any location where scour depth is greater than ~1 m. (3 ft.). An alternative is to provide shore protection (bulkhead) on all sides with final elevations above flood level.
Design Scour Depth	Table provides depth as a percentage of water height and six material types ranging from loose sand to stiff clay.
Critical Tsunami Wave Load Combinations (components below)	According to the Dames & Moore report (footnote 20) referenced in the Code, the analysis of loads is required to be performed using “conservative judgment of a qualified engineer with experience and background in hydrostatic and hydrodynamic loading.” The code provides equations to calculate forces. Then the engineer designs to resist these forces.
Buoyant Force	Based on submergence of structure and volume of water.
Surge Force	Caused by leading edge of water hitting side of structure – force dependant on water height.
Impact Force	Debris carried by flood waters. The Code equation assumes a force of a 1,000 lb (454 kg) object moving at the velocity of the water on one square foot (929 cm^2). Nearby local conditions creating debris should be considered. Water height determines location of impact force.
Hydrostatic Force	Imbalance of pressure due to different water levels on different sides of structure. Function of water height and velocity.
Drag Force	Force from resistance to flow around an object. Function of velocity, water height, surface friction, and the structure geometry.
Floodwater Velocity	Simple function of water height; one equation for bore conditions and one for non-bore conditions.

Table 4-1 Key Tsunami Design Standard, Honolulu Building Code, Section 11

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[21] January 31, 1980 report by Dames & Moore entitled "Design and Construction Standards for Residential Construction in Tsunami-Prone Areas in Hawaii" prepared for the Federal Emergency Management Agency.

4.5.1 Design of Coastal Buildings for Tsunami Waves and Seismic Shaking

If an elevated structure on piers or columns is in an earthquake area, special precautions are required to reinforce the supporting columns and piers against ground motion. The reader is referred to the United State FEMA CCM (Chapters 11 and 12) for information on how to reinforce columns and piers to resist earthquake motion.

A common practice of elevating buildings 8-10 feet above grade on a pile or column foundation in low-lying and coastal zones can result in a condition that is called a “soft story” or “inverted pendulum” by the engineering community. This condition essentially introduces a weak story between the ground and the livable space. This condition requires that the building be properly designed to prevent collapse of the “soft” or “weak” story from seismic shaking as well as tsunami wave loads.

Therefore, the design for pile or column-supported residential buildings should be verified for necessary strength and rigidity below the first floor level to account for increased stresses in the foundation or soft story part of the structure from the seismic and/or tsunami wave loads on the structure up above. This can be done by comparing the anticipated calculated forces on the structure with the strength and rigidity of the structure. If the load demand on the structures exceeds its capacity, then a redesign (stronger more rigid columns) or bracing may be needed.

Acceptable building performance for life safety during a major seismic event is defined as non-collapse. Some structural and non-structural building damage is acceptable if it does not prevent egress from the building.

Elevated buildings placed in a coastal area can be subjected to various failure modes from flood, tsunami, wind and seismic forces. These failure modes are:

> ***Uplift:*** Vertical forces caused by seismic, wind or buoyancy exceed the weight of the structure and the strength of the soil anchorage. The building fails by being lifted off its foundations or because the foundation pulls out of the soil. (See Figure 12-2 of FEMA CCM)
>
> ***Overturning***: The applied moments caused by the wind, wave, earthquake, and buoyancy forces exceed the resisting moments of the building’s weight and anchorage. The building fails by rotating off its foundation or because the foundation rotates out of the soil. (See Figure 12-7 of the FEMA CCM)
>
> ***Sliding or Shearing***: Horizontal forces exceed the friction force or strength of the foundation. The building fails by sliding off its foundation, by shear failure of components transferring loads, or by the foundation sliding. (See Figure 12-10 of FEMA CCM)

Collapse: Structural components fail or become out of plumb or level under uplift, overturning or sliding. The building then becomes unstable and collapses. See Figure 12-4 of FEMA CCM.

The design for tsunami waves must properly consider the following:

Duration of Impact: The impact from wave and the debris riding it has a significant effect on the ground supported and elevated structures. The elevated structures are more vulnerable to the impact type loads and particularly vulnerable to significant damage or even collapse in the soft story portion of the structure. (Design Guidance is available in Chapter 11 of the FEMA CCM).

Localized Scour: Waves and currents during coastal flood conditions are capable of creating turbulence around foundation elements causing localized scour around those elements. Determining scour is critical in designing coastal foundations to ensure that failure during and after flood does not occur as a result of the loss of either bearing capacity or anchoring resistance around the posts, piles, piers, columns, footings, or walls. Localized scour determinations will require knowledge of flood depth, flow conditions, soil characteristics and foundation type. See Table 4-1 to determine scour depth. Any anticipated erosion or scour in the foundation soils should be properly considered in the analysis and the foundation soils can be protected from scour or erosion by either burying it deeper, reinforcing the earth or building rip-rap (i.e., a revetment).

Tsunami Loads: Tsunami loads on residential buildings may be calculated in the same fashion as other flood loads; the physical process are the same, but the scale of the flood loads are substantially different in that the wavelength and runup elevations of tsunamis are much greater than those of waves caused by tropical or extratropical cyclones. If the tsunami acts as rapidly rising tide, most damage will be caused by buoyant and hydrostatic forces. When the tsunami forms a borelike wave, the effect is a surge of water to the shore. When this occurs, the expected flood velocities are substantially higher. Figure 4-9 shows the relationship between design stillwater depth and expected velocity for tsunami and non-tsunami conditions.

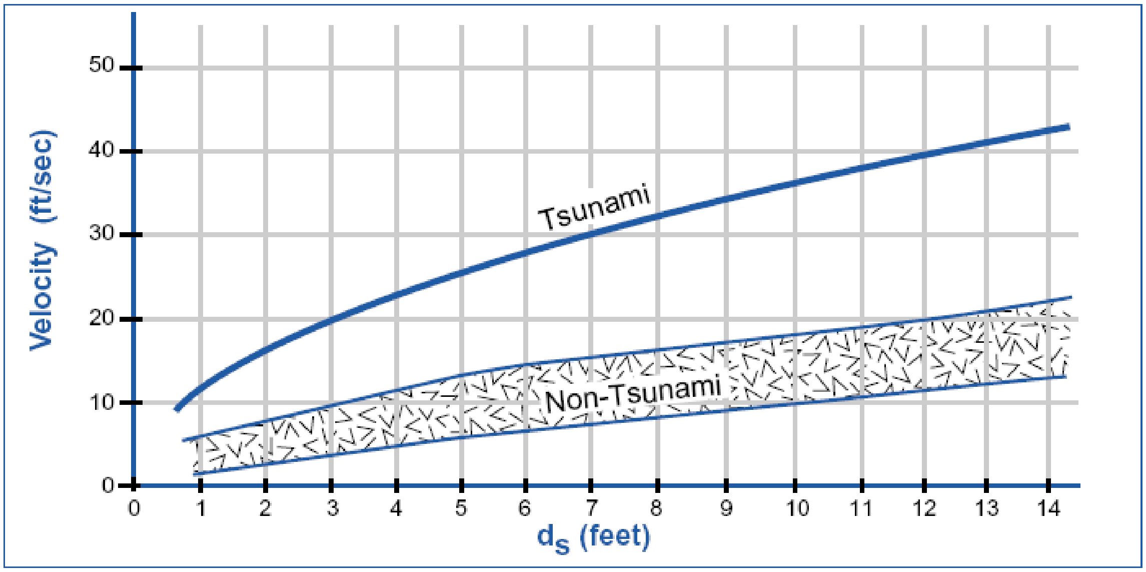

Figure 4-9 - Tsunami velocity vs. Design Stillwater Depth. Non-tsunami velocities are shown for comparison. From FEMA CCM, 2000. For a given depth of water, e.g., 7 feet, the tsunami velocity may be 2-3 times greater than the non-tsunami velocity.

The structural seismic-force-resisting system in coastal buildings can be of different types in the elevated foundation system and living spaces. Guidance is available in FEMA Manual for design of many such systems to include cantilevered piles, diagonal braced piles and knee-braced piles with and without grade beams. Whatever the system, it is important that the load paths must be continuous because any break or weakness in the load path "chain" can result in damage or even structural failure. Thus, the structure should be properly connected to the piers or columns so that the structure does not come off.

Here are some structural components that are used to enhance the performance of piers and columns to prevent collapse of structures.

Grade Beams, wooden or concrete, provide support in the horizontal plane parallel to the floors. Grade beams can be especially important to keep the structure from collapsing when significant soil support may have been lost from erosion and scour. See Figure 4-10. One disadvantage is that the scour potential around the grade beams can be significant.

Diagonal Braces are normally attached to the pile near the top and secured to the adjacent pile either near or ground surface or at the height that reduces unbraced length to the required height. See Figure 4-11. While diagonal braces can add considerable support to piers and columns, one disadvantage is that debris can be trapped, obstructing the flow of water. While it is possible to brace only in the direction of water flow, it is difficult to do with diagonal braces.

Figure 4-10 - Grade Beams. Grade beams can be used to tie the structure at the foundation and are especially useful if there is localized scour or erosion. In this case the grade beam may prevent localized collapse. From FEMA CCM, 2000.

Figure 4-11 - Cross Bracing. From FEMA CCM, 2000. Cross bracing can also add strength and rigidity to piers or columns, but mixed results in actual field conditions may warrant increasing strength by other means (e.g., stronger column material or greater widths).

Knee Braces are normally installed at 45 degree angles between the floor framing and the pile and are usually placed within 4 feet of the top of the pile. See Figure 4-12.

Figure 4-12 - Knee Braces.- Another way to increase strength and rigidity of piers and columns is to utilize knee bracing. Because there are no obstructions at grade, scour risk is reduced. Since bracing is near the top only, the potential for catching debris is reduced. However, knee braces are not as strong as diagonal braces and shear at the top is increased. Also, it may be difficult to brace only in the direction of flow. From FEMA CCM, 2000.

Chapter 5 - Recognize the Government Purpose for Regulating Land

The government regulates land for many purposes, including esthetics, protection of views, premature urbanization, population control, environmental concerns, hazard mitigation for property, and hazard mitigation for life. Some of these purposes, e.g., hazard mitigation of life, are clearly much more important than others. It is important to recognize this concept for two reasons. First, the government goal is related to mitigation of life safety hazards if an area is subject to high waves (greater than 5-10 meters) that cannot be properly designed for in construction, nor evacuated by vertical or horizontal means, even with a fully functional tsunami warning system. This situation should be accounted for in a recovery plan.

Prioritizing the government purpose for controlling land also can provide flexibility if it is recognized that less important standards, such as those for esthetics, can be relaxed if it will assist the implementation of more important measures related to hazard mitigation for property and life.

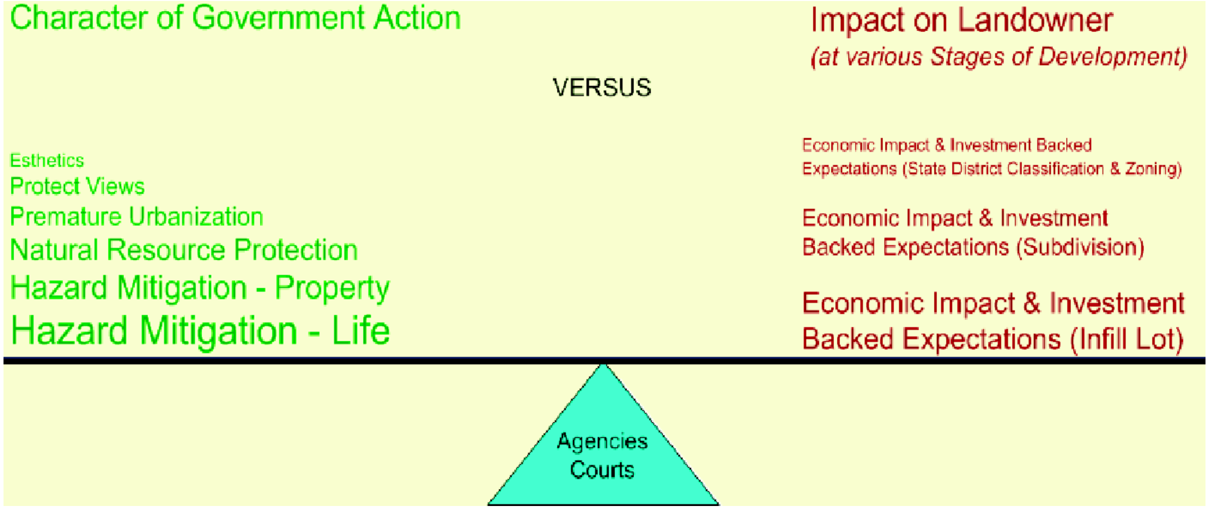

Figure 5-1 – Government must often weigh the purpose of the action or regulation (esthetics, environmental protection, hazard mitigation) versus the economic impact. In this figure, the size of the text reflects relative weighting. Of most importance are measures for the mitigation of risk to property and life.

The paramount need to protect human life may warrant a change in development strategies based on this concern itself. For instance, in the United States, structures are built for the 100-year event, and the risk is accepted for the 500-year event. However, when human life is involved, such as the threat to critical facilities (schools, hospitals, emergency facilities, shelters), then the risk of flooding or inundation is not accepted for the 500-year event. An attempt is made to site these structures outside of the flood or inundation area. Examples of critical facilities are provided in Figure 5-2.

Critical Facilities

- Hospitals, medical facilities, nursing homes, schools or other facilities where occupants are not sufficiently mobile;
- Police stations, fire stations, emergency operation centers, shelters or other facilities that are needed to respond, or are used during a natural disaster; and
- Utilities such as water, electricity, sewer, wastewater, or communications that are vital to maintain services before, during and after a natural disaster.

Figure 5-2 – Critical Facilities – Critical Facilities are those facilities that are of such importance to the community that no risk can be tolerated even if it is very small (e.g., 500-year event).

Also related to the need to protect human life is to assess how developments may affect evacuation plans for an area. All developments should be designed so that residents can safely evacuate an area in sufficient time, given the anticipated amount of warning. For some countries, the warning time may be several hours (see Table 2-1). Countries with sufficient warning time are generally subject to distant tsunamis and can have a functioning tsunami warning system.

However, when the tsunami is of local origin, the warning time may be only 15 minutes, or less, such that a warning system is impractical. For a local tsunami, the only warning may be shaking of the ground. Estimates should be made as to how much distance can be covered by women and children evacuating, from the time of ground shaking to onset of the first wave. No developments should be approved in which members of the public cannot be properly evacuated in sufficient time to escape inundation.

Chapter 6 – Case Study – Banda Aceh

Many of the concepts discussed in this paper can be applied for developing recovery plans, strategies, or guidelines on recovery after the tsunami. An example of how these concepts apply, but at the same time need to be modified for the specific locality, is given for the Banda Aceh province of Indonesia. This area represents the greatest planning and recovery challenge, because of all coastal sectors affected by the December tsunami, it had the largest wave heights and the shortest warning time (Table 2-1).

6.1 Multi-Hazard Zonation

It is likely that for areas of Indonesia struck by the December tsunami, there is limited data on historical inundation events such as runup heights, or water elevations. If this is the case, the December event can still be used as a benchmark for hazard mitigation purposes (See Table 2.2). This situation can be improved if geologic records of earlier tsunamis can be found.

As stated previously, flood plain managers are sometimes forced to use solely the most recent flooding event because of the lack of prior data. Nevertheless, much can be determined by observing in detail the recent events, because they are the most easily studied and most of the relevant data may still be on the ground or easily retrieved. While the most recent event can be used for planning, efforts should nevertheless be made to extrapolate data from past events. This may require modeling studies.

Initial relevant information on building performance during the tsunami was compiled from the JICA study team and put on a geographical information system (GIS).[22] As seen from the GIS overlay for building performance, there is a zonation of damage from the tsunami in the Banda Aceh area (Figure 6-1). Farthest inland (white zone), there are no effects from flooding. The only natural hazard of concern would be those not associated with water, such as an earthquake. This zone would be analogous to the inland zone in Figure 2-1.

The zone in cyan is characterized by flooding damage, but none of the buildings were destroyed. This would be characteristic of simple flooding with no high velocity water action and would be analogous to the flood zone in Figure 2-1.

In the yellow zone, 0-50% of the structures are destroyed, and there is mudflow. If this data were to be calibrated in the field, it would likely be found that portions of the yellow zone are analogous to the wave zone in Figure 2-1. Probably with proper

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[22] The GIS allows many layers of information vital for the planning of a community to be overlaid on one base map. GIS systems are needed for the proper planning of hazard, environmental, hazard, social and economic concerns.

construction for high velocity wave action (Figure 2-5), many if not all of these structures could have survived the moving water.

For the orange and red zones, the depth of water, or wave height were so great that almost all the structures are destroyed, no matter how they were built. This zone, while being different than the erosion zone in Figure 2-1 in terms of geological processes, should be treated similarly. In this zone, the emphasis should switch to one of increased importance for evacuation and siting measures. Construction measures would possibly be feasible for evacuation structures that can be especially engineered for unusually great wave heights or water depths. However, if evacuation is not possible, siting and resettlement should definitely be considered.

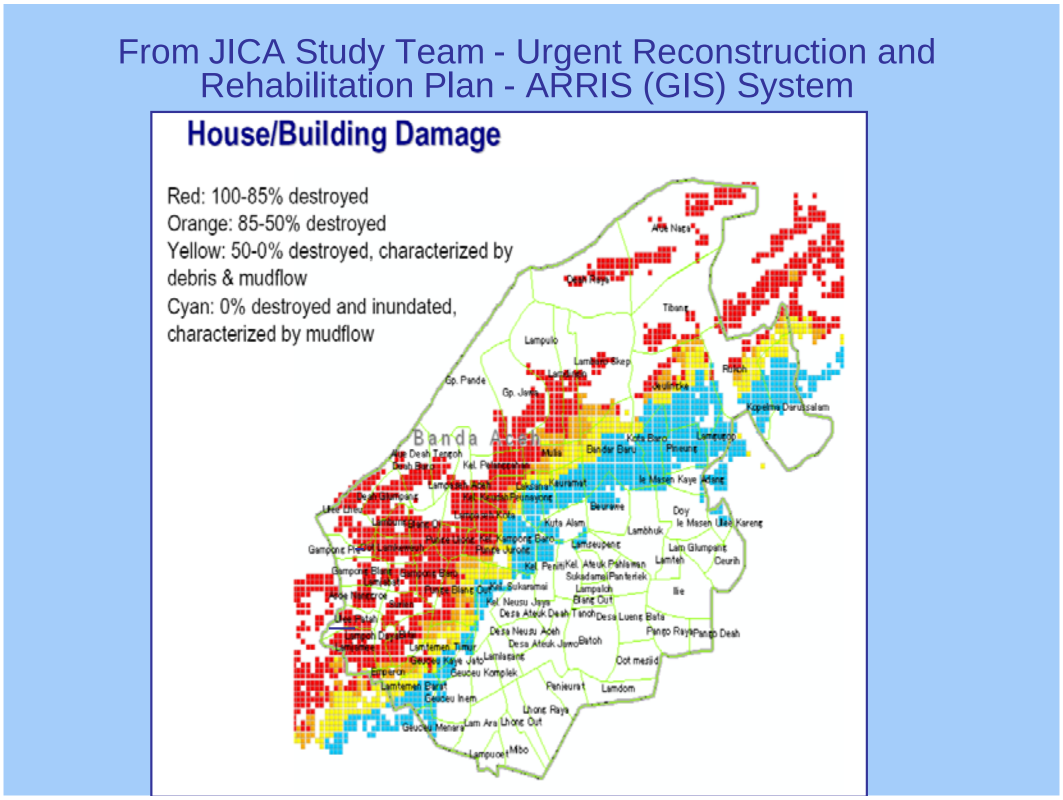

Figure 6-1 – Zonation of Building Damage in the Banda Aceh area. From JICA study team.

The zonation of damage as shown on Figure 6-2 needs to be further calibrated with the field data. Nevertheless the zonation is very important and does not mean hard regulatory zones need to be established, although that is one of many options. More importantly, the zones can be used to identify where different strategies, concepts and hazard mitigation measures are applicable and appropriate. It may also help to determine what structures are built to different standards.

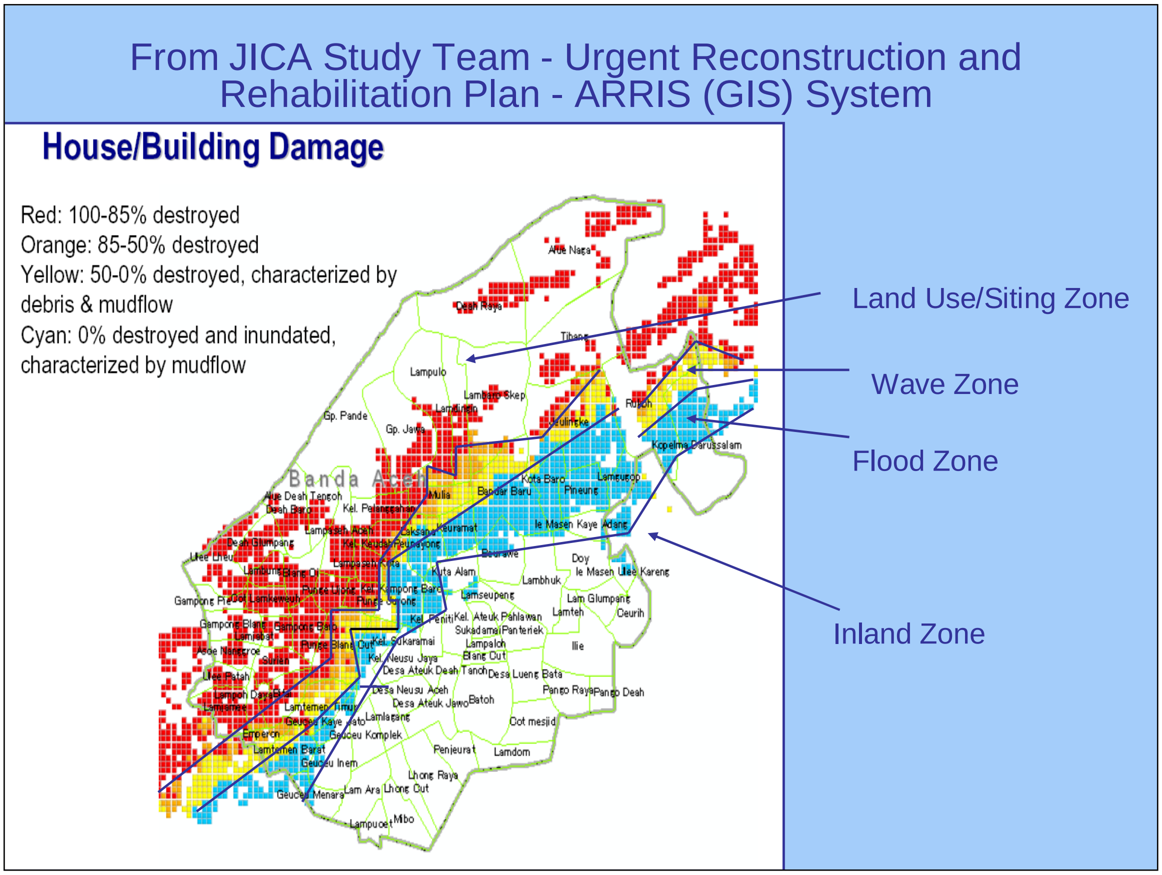

Figure 6-2 – Zonation of Building Damage – Using the zonation of Building Damage in Figure 6-1, zones roughly equivalent to those in Figure 2-1 can be identified. With further calibration and refinement in the field, these zones can help to formulate numerous options, strategies and measures for hazard mitigation, evacuation and overall recovery.

6.2 Use of Light Handed Flexible Approach

This report advocates the use of a light handed flexible approach based on guidance, policy, industry standards and the use of existing regulatory authority. Such an approach has been embraced in Indonesia for recovery from the tsunami, as indicated by the numerous guidance documents developed to address: (1) land mapping, (2) land boundaries and ownership, (3) housing repair and construction and (4) village restructuring and construction.

Furthermore, the local government has indicated a desire to produce a guidebook that will allow a light-handed flexible approach similar to many of the concepts in this report. They are interested in such a flexible approach for implementation of their recovery efforts. Note that prior to this direction, a strict regulatory ban on development was instituted, but such a strategy was criticized so the new approach is being implemented.

The light-handed flexible approach is especially needed in Indonesia, because the guidance documents listed above, and the Master Plan for the Reconstruction and

Rehabilitation of the NAD–Nias area, give individuals and communities the right to choose where and how they build. Given the individual freedom and flexibility provided to the local governments, the best that can be done is to provide individuals and communities guidance on how and where to build, along with the appropriate tools and the proper education and incentives. If individuals choose not to implement the suggested measures, they will have done so with knowledge of the anticipated risks.

6.3 Relevance of Development Stages

As discussed in Chapter 4 and Figure 4-2, after a natural disaster the percentage of coastal land in different development stages is redistributed, providing many opportunities to build safer with less risk to future inhabitants. For example, it is possible to consolidate lots, and then resubdivide the larger area, or create a new master plan or village plan that provides for different lot, road and infrastructure layout. New layouts provide many ways to mitigate potential hazards.

An example of such lot consolidation after a disaster is the approved village plan for the Aceh Besar area (Figure 6-3). For this area, over 100 lots were consolidated, and then the larger plot was designed as if it were a new subdivision. The approved plan incorporates wider roads for evacuation to address the problem of people trapped in narrow roads that were not designed for escape purposes. Furthermore, there are trees in the area to block incoming water.

The most noticeable feature of this plan is the presence of an escape hill that is within 15 minutes, or 200 meters of all residential structures. This equates to an evacuation rate of speed of .8 km per hour, and is meant to account for women carrying children.

The escape hill is 12 meters high, or 2 meters above the inundation level for the December tsunami. This hill has been designed to accommodate the anticipated population needed to be evacuated, using a formula of 1 square meter per person. There is also an agreement with the community that the density of the village will not be exceeded to the point that the escape hill would be overloaded.

Figure 6-3 - Approved Village Plan for Aceh Besar Area - from local architect Andy Siswanto. The plan has provisions for trees as a water buffer, extra wide roads for evacuation, and an escape hill that is 2 meters above the water elevation reached by the December tsunami. All houses are within 15 minutes of the escape hill.

Another design for an escape hill is provided by staff at the Asian Institute of Technology (Figure 6-4). The escape hill is built with geosynthetic reinforcements and erosion protection. The hill should be built from 5 to 10 meters high with about 30 to 15 meters rectangular area at the top. The escape hill can be built to heights more than 10 m. However, under a 10 m height maybe more economically feasible depending on the locality and need.

The design in Figure 6-4 allows access of people in all four sides of the hill. The earthquake resistance of the geosynthetic reinforced structure is well known. During earthquake occurrence, the geosynthetic reinforced embankment can survive due to its strength, durability and flexibility. The escape hill can accommodate about 2 people per square meter.[23]

How a village plan, master plan, or subdivision is created can have a big impact for hazard mitigation purposes. Architects and planners should evaluate the local conditions at the site and help to create plans that protect the inhabitants. Factors in the design can include the number of lots, the size and geometry of the lots, and how they are integrated together. With increased flexibility, it will be possible to create larger hazard safety buffer zones, while minimizing any economic impact.

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[23] Interview with Professor Dennes Bergado, Asia Institute of Technology

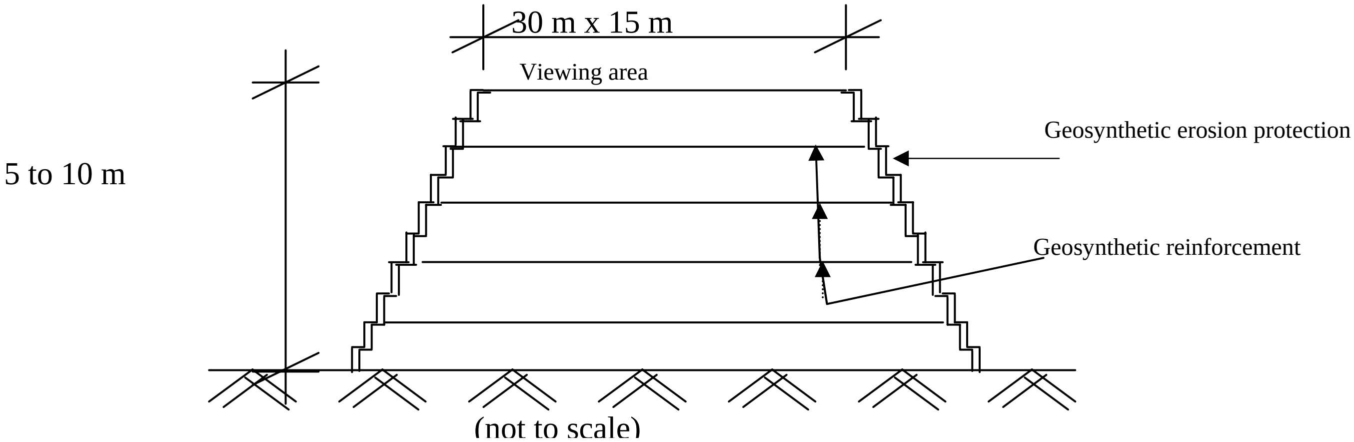

Figure 6-4 - Concept of an Escape Hill. From Bergado, D. T., Asian Institute of Technology, Thailand.

How evacuation is incorporated into a new village or master plan requires early planning and knowledge of the conditions at the site. Evacuation options include vertical evacuation (escape hills, mosques, buildings, or other structures) and horizontal evacuation (canals and roads).

The location and orientation of roads plays an important role in protection of inhabitants. Roads perpendicular to the coast can provide both access to living areas, while providing an evacuation route in areas where evacuation time is limited. In this case the roads must be wide enough to accommodate anticipated traffic.

Another variation of this concept incorporates canals that provide access to the ocean for fisherman, while living areas are situated behind berms, or mangrove forests and accessed from the canal (Figure 6-5). In many cases, it may be better to curve the canal away from the coastline, rather than building perpendicular to the coast, so that the tsunami does not inflict a direct hit on relocated houses.[24] Again, local conditions should dictate the best orientation of roads and canals to provide the needed protection.

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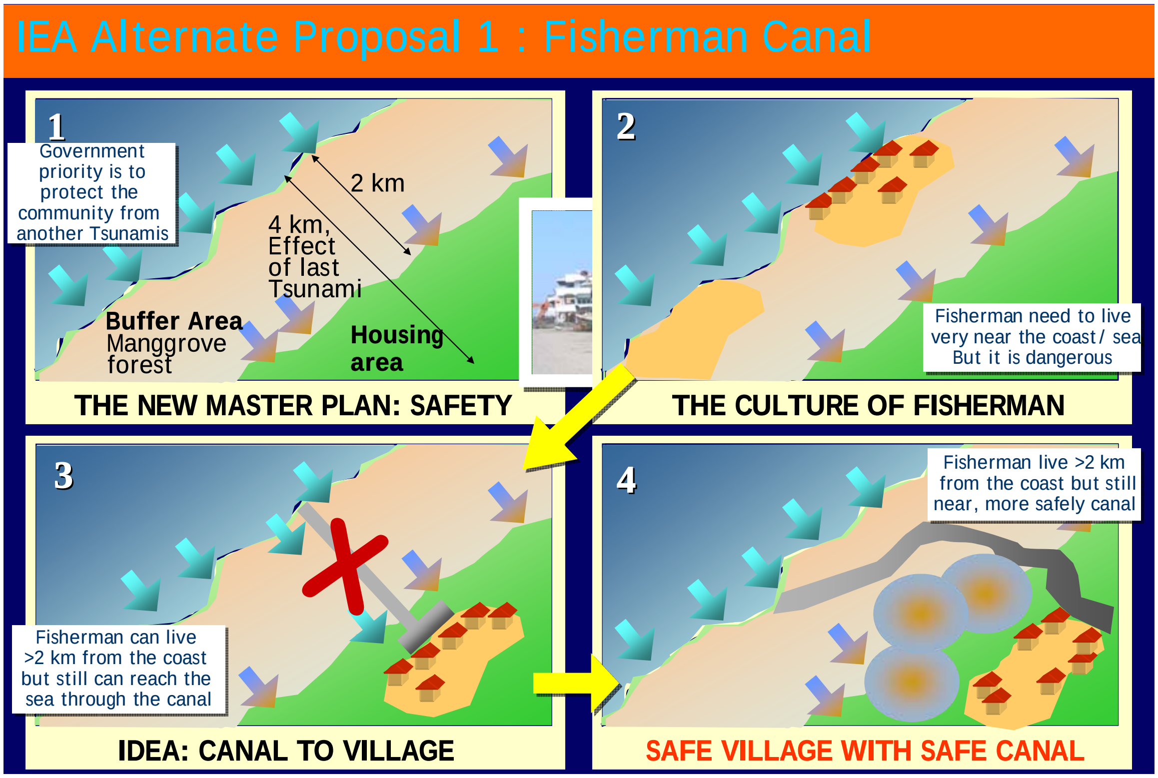
[24] Interview with Professor Dennes Bergado, Asian Institute of Technology.



IEA Alternate Proposal 1 : Fisherman Canal

1

Government priority is to protect the community from another Tsunamis

2 km

4 km, Effect of last Tsunami

Buffer Area
Manggrove forest

Housing area

THE NEW MASTER PLAN: SAFETY

2

Fisherman need to live very near the coast / sea
But it is dangerous

THE CULTURE OF FISHERMAN

3

Fisherman can live >2 km from the coast but still can reach the sea through the canal

IDEA: CANAL TO VILLAGE

4

Fisherman live >2 km from the coast but still near, more safely canal

SAFE VILLAGE WITH SAFE CANAL

Figure 6-5 - Access Canals or Roads. The concept of canals leading away from the coastline can link fishing areas with living areas, while still providing the necessary protection from future tsunami inundation. From Abednego (2005).[25]

Even if consolidation of lots is not possible to make a new village plan, master plan or subdivision, it is possible to rebuild damaged or destroyed structures to better address the issues with flood, wave or earthquake forces. While such construction standards may not be appropriate for all structures, because of the recurrence interval issue discussed in Section 2.1.3, it may be appropriate for certain stone structures or critical facilities that have to be located in an inundation zone (see Section 6.4). For critical facilities, it is especially important that they be sited in safe areas, and if this is not possible, they at least be constructed to avoid flood and wave forces by venting water in and out of the structure (Figures 2-4, 2-5).

Related to building certain structures to withstand wave and flood forces, is the concept of an escape mosque. One must take notice of the numerous mosques in Sumatra that survived the tsunami. In many locations the mosques were the closest structures to the coast that survived. For example, mosques in Banda Aceh, Jantang and Lhok Nga survived extreme water heights, while adjacent structures did not survive. The concrete structure combined with the open framework that vented flow

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[25] Abednego, L.G. (2005), The contribution of Indonesian Engineers Association to Aceh Province after earthquake and tsunami, Proc. of Scientific Forum on Tsunami, its Impact and Recovery, 6 to 7 June 2005, AIT Conference Center, Bangkok, Thailand.

through water is a major factor that allowed for the survival of these structures (Figures 6-6 and 6-7).

Figure 6-6 - Mosque at Lhok Nga. Many mosques in Indonesia were able to survive, despite the extreme wave height, even though all structures around them were destroyed. This is attributed to the concrete structure and open walls that allowed entry and exit water to vent through the structure. Note person at base of pole for scale. The water level was at a minimum 12 meters, or near the top of the first level. Mosque was about 800 meters from the shoreline.[26] Reports by interviewed survivors indicate water levels may have been higher.

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[26] Interview with Jose Borrero, University of Southern California.

Figure 6-7 - Mosque at Jantang. This mosque was one of the few structures in the surrounding area that survived the tsunami inundation. Villagers climbed onto the upper floors to escape wave inundation. Again the concrete open framework that vented water played a role in allowing the structure to survive.

If it is not possible to incorporate an escape hill into a new village plan because of space considerations, it may be possible to build an escape mosque (Figure 6-8). Given the numerous mosques that survived the tsunami, and their ability to withstand wave attack, these structures may play an important role in hazard mitigation and evacuation. However, if these structures are used, there must be sufficient space to accommodate the people that need to be evacuated.

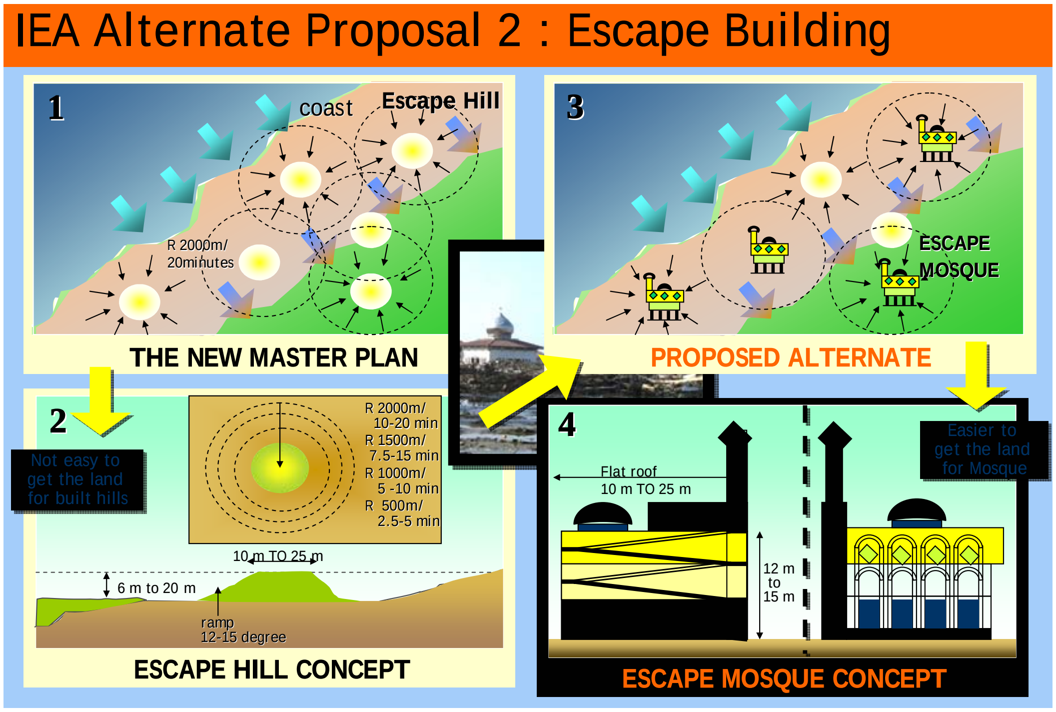

Figure 6-8 - Escape Building Concept. As an alternative to escape hills, a Village plan can incorporate an escape mosque, or both. From Abednego (2005).[27]

Because of the ability of many mosques to survive tsunami inundation, it is possible that some of the older mosques, or newly rebuilt ones, if sufficiently high and well constructed, can be used for evacuation purposes. The use of mosques to provide vertical evacuation for nearby residents is possible provided the following conditions are met. First, there is ample room for all those that may use it. Second, there is sufficient time so that people can reach the upper safe levels in time. Finally, that the structure is sufficiently high and well built to withstand tsunami inundation. The concept of using mosques for escape purposes is a feasible alternative to the use of an escape hill.

Besides evacuation structures that are designed and constructed to withstand wave and flood forces, it is also possible to use similar concepts regarding the venting of water to build residential structures. In deciding to implement these designs, two factors are important. One is the recurrence interval of the disaster event and the decision to elevate, which adds costs. Given a short life expectancy of a structure and a high recurrence interval, it may not be feasible to elevate. Still this is a decision each person can make on their own. Another factor is what the building will be used for. If

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[27] Abednego, L.G. (2005), The contribution of Indonesian Engineers Association to Aceh Province after earthquake and tsunami, Proc. of Scientific Forum on Tsunami, its Impact and Recovery, 6 to 7 June 2005, AIT Conference Center, Bangkok, Thailand.

critical facilities cannot be sited away from the inundation zone, they should be at least be built to withstand anticipated wave forces.

After a natural disaster, it will also be possible to rebuild destroyed structures differently to better survive future events. Figure 6-9 shows an example of how structures can be designed to reduce the risk from flood and wave action, yet incorporate local design, using local materials, and contractors. Note that these designs would be especially useful for structures in an identified flood zone.

Figure 6-9 - Elevation on Piers and Columns to Address Flooding. Residential structures have been designed for Sri Lanka, using local materials and a modular design – From Dr. Carlo Ratti - MIT – Senseable City Laboratory, Boston, Massachusetts. Such a design is more economical and suitable for structures subject to flooding.

It is recommended that central or local governments create certain building designs that are suitable for the area, resistant to wave and flood forces, and able to withstand earthquake motion. With this generic design, local contractors, using local materials can mass produce safe and appropriate housing for the area.

6.4 Government Purpose for Regulating Land

As shown in Figure 5-1, the government may regulate land for many purposes. Not surprisingly, the protection of life in Indonesia is of paramount importance. In the Master Plan for the Rehabilitation and Reconstruction of the Regions and Communities of the Province of Nanggroe Aceh Darussalam and the Islands of Nias, Province of North

Sumatra, the first policy and strategy listed related to spatial planning is to make areas safe from disaster and life better.

Because of the difficulty in evacuating areas from the local tsunami, and the concern for women and children, the Executing Agency for the Rehabilitation and Reconstruction of NAD-Nias ("BRR"), along with local communities established a standard for evacuation. All structures should be placed within .2 kilometers or 200 meters of an evacuation hill or mosque. This standard was derived from using a 15 minute time for evacuation (onset of earthquake to first incoming wave – see Table 2-1). It was also assumed that women carrying a child could still move at least at the rate of .8 kilometers per hour. Normal walking speed may range from 2-5 kilometers per hour. Running speed may range from 6-12 kilometers per hour.

The concern for public safety and evacuation may drive the design for a village plan. For example, in Figure 6-3, the structures are centered around the evacuation hills and the escape roads are wide enough to prevent bottle necks that may cause loss of life. This was a problem encountered in some areas of Banda Aceh during the December tsunami.

BRR is now also evaluating the need for safe siting of critical facilities (Figure 5-2) away from the hazard zone. Because it is anticipated that many community members will want critical facilities such as medical centers located close to or within their community, this could create a potential conflict. One solution under consideration is to distinguish between medical facilities that provide daily walk-in service, and full service hospitals in which surgeries are performed and where overnight patients are consequently less mobile. For the later, there is a greater need to locate the structure outside of any inundation zone.

A similar analysis can be made for all critical facilities of a country or region. It can be decided if the need to have the critical facility in the community outweighs the need to safely site critical facilities because of the risk to the inhabitants in the facility, the need to provide essential services or emergency operations. An initial assumption can be that all critical facilities are located away from inundation zones, unless the community can provide a good reason why this should not be the case.

Another option though is to allow certain critical facilities in some of the hazard zones, (e.g., the inland, or flood zones in Figure 6-2), but build them to certain flood, wave (Figures 2-4 and 2-5) and earthquake standards. For example, it may be determined that a water or wastewater facility can perform all of its intended operations even if it is subject to flood conditions if it has the proper structural design and flood proofing measures.

As one more indication of the importance of hazard mitigation for life and property, the BRR has established guidance to allow individuals and communities to decide where and how to live. However, they must also provide for the necessary evacuation. According to the guidance related to village restructuring and reconstruction, being able to evacuate is an absolute necessity. Thus the issue of hazard mitigation of life may drive the design of the village plan, and may even in some places determine if an area needs to be resettled (using siting measures as discussed in Section 6.1 and shown on Figures 6-1 and 6-2 for the orange and red zones).

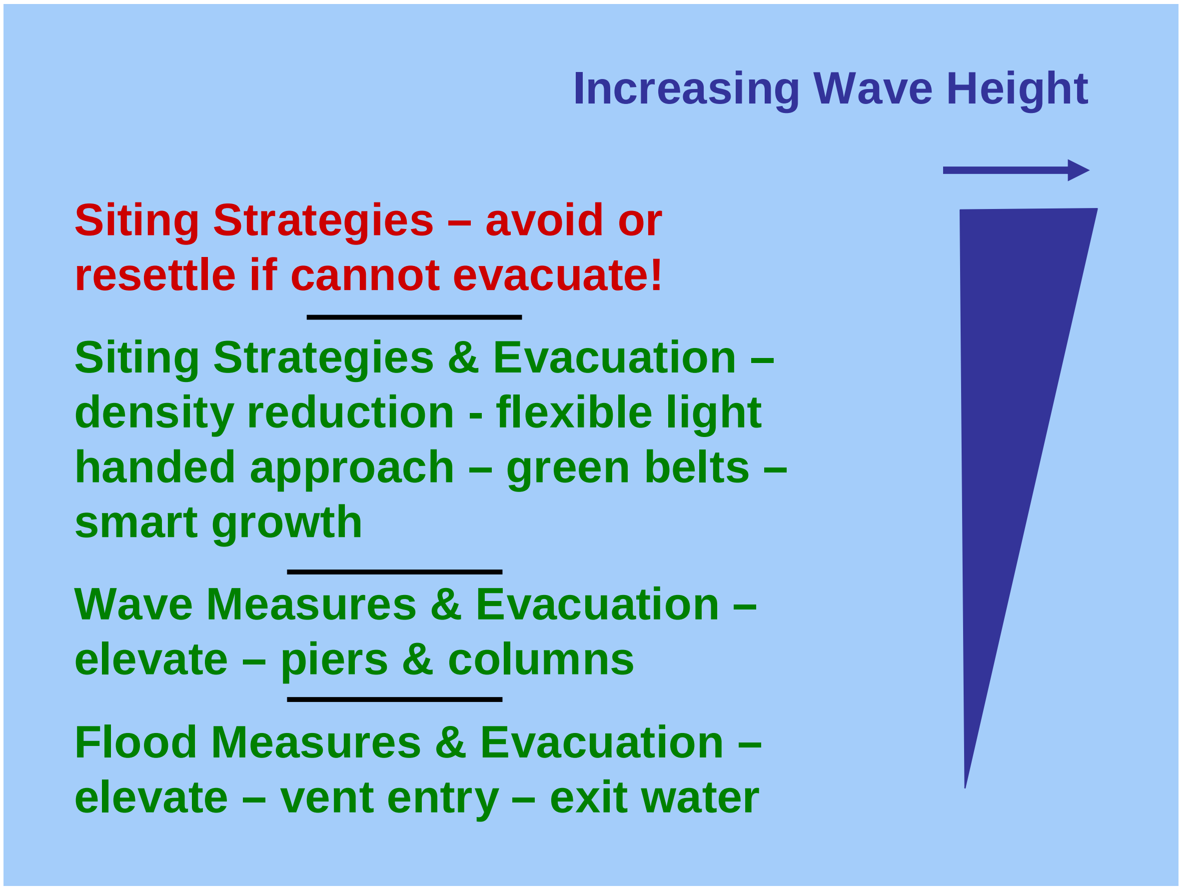
Chapter 7 – Summary

As can be seen from the zonation map of building damage (Figures 6-1 and 6-2), many of the hazard mitigation measures are driven by wave height or depth of water (Figure 7-1). Generally, the greater the water levels, the greater the building damage. Conversely, the smaller the anticipated water levels encountered, the easier it will be to implement mitigation measures to reduce risks.

Figure 7-1 summarizes the importance of water or wave heights in the overall hazard mitigation strategies. For water depth less than 0 meters, the inland zone is defined and mitigation measures are solely non-water related (e.g., building standards for earthquakes in the building code). For water depths less than 1-1.3 meters, water effects can be addressed by simple flood construction in which water is vented and hydrostatic pressure relieved. Somewhere between 1-1.3 meters and 5-10 meters, habitable structures can be built with construction designed to address wave action (elevation on piers and columns). Again the local scientific and engineering community needs to be involved in setting this threshold. To what degree such construction is followed may depend on the expected recurrence interval (previously discussed), the expected life of the structure, and its use (e.g., critical facilities). Also it is important to design for potential impacts from the anticipated debris field.

Eventually water depths become so great that it may not be feasible to build to withstand such forces (greater than 5-10 meters). Nevertheless, specially engineered evacuation structures such as a hill or mosque can provide protection to inhabitants if realistic warning and evacuation times are utilized. In addition, the evacuation measures should be able to support all the people that need to be moved. In this zone, flexible siting measures become more important because of the possible need to reduce density to accommodate the evacuation system.

At even greater water depths, it may possible that evacuation is no longer possible (e.g., the costs to build evacuation hills or a mosque to such a height are too great). For this zone, an increased emphasis on siting and resettlement should take place. It is unlikely that it will be possible to require everyone to move, as many of the local population derive their living from the sea. Nevertheless, density could be reduced and other measures considered such as roads and canals leading away from the coastline that serve as access routes to the ocean and evacuation routes during a tsunami. Incentives by the local government can also be provided, including financial packages, or a land swap that exchanges coastal land for areas at a higher elevation.



Increasing Wave Height

Siting Strategies – avoid or resettle if cannot evacuate!

Siting Strategies & Evacuation – density reduction - flexible light handed approach – green belts – smart growth

Wave Measures & Evacuation – elevate – piers & columns

Flood Measures & Evacuation – elevate – vent entry – exit water

Figure 7-1 – Role of Construction and Siting Measures with Increasing Wave Height – As wave height increases (to right on blue triangle, or from bottom to top of diagram), the mix of appropriate hazard mitigation measures also changes from one emphasizing construction to one with increased emphasis on siting.

Given the wave heights encountered from the December tsunami, many of the countries can provide improved hazard mitigation with solely a tsunami warning system and better construction techniques. For countries that have a wider range of tsunami wave heights, increased emphasis on siting measures are recommended, with the emphasis increasing with anticipated water levels.

It is also very important that certain designs to create escape hills, escape mosques or to elevate structures to vent flood or wave damage are very dependant on anticipated wave or water heights. A design for a 5 meter water level, may not work for a 10 meter water level. This is why it is important to determine inundation limits by mapping, and to design structures for the particular area based on anticipated water levels. If mapping is not complete, local knowledge of the extent of inundation, based on water depths indicated on nearby landmarks can be used.

Mitigation measures may be modified by factors such as recurrence interval and the local, social, economic and cultural environment. Nevertheless, hazard standards should be established, and even if they are not strictly followed, they can serve as a design goal that communities and individuals can decide to follow after being properly educated of all possible risks.

It is encouraged that countries consider using a light-handed flexible approach to implementation based upon guidance, well written policy, and providing materials, finances or incentives so that individuals and communities can redevelop with the utmost respect for the forces of nature.

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