ASEAN-Japan Transport Partnership

Guideline for Development and Utilization of Tsunami Disaster Management Map

For ASEAN AND INDIAN OCEAN TSUNAMI AFFECTED COUNTRIES

Version 1.0

Port Technology Group
ASEAN-Japan Transport Partnership

In cooperation with

Port and Airport Research Institute (PARI), Japan

The Overseas Coastal Area Development Institute (OCDI), Japan

Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan

Port Technology Group (PTG) under the ASEAN-Japan Transport Partnership Projects (AJMT-6) developed this guideline.

PTG Meetings " Tsunami Disaster Management Map Project "

- First meeting: March 1st, 2006
- Second meeting: February 14 th, 2007
- Third meeting: March 12th, 2008

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Foreword

Japan has suffered great damage in terms of both human life and infrastructures due to "Tsunami" attacks over the years. Among them the "Meiji Sanriku Tsunami" in 1896 killed over 22,000 persons on the Sanriku coast of northeast Honshu. Many countermeasures against tsunami attacks have been carried out for many years in Japan, and they are well recognized in the world. In fact, the Japanese word "tsunami", which means tidal wave in English, is now widely used throughout the world.

Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT prepared the Japanese manual for tsunami disaster management map. Advanced case studies have shown that the disaster management map is an effective evacuation measure.

This guideline aims to assist developing countries, particularly ASEAN countries, to develop and utilize tsunami disaster management maps. The exploratory committee on Guideline for Development and Utilization of Tsunami Disaster Management Map prepared a draft version of this guideline by arranging Japan's Tsunami and Storm Surge Hazard Map Manual.

The draft of this guideline entitled "Guideline for Development and Utilization of Tsunami Disaster Management Map for ASEAN AND INDIAN OCEAN TSUNAMI AFFECTED COUNTRIES" was submitted by Port and Airport Research Institute (PARI) and the Overseas Coastal Area Development Institute (OCDI) to Port Technology Group (PTG) at the 5th PTG meeting in March 2008. Thanks to all participants in the PTG project from ASEAN countries and Japan, this guideline was successfully finalized with fruitful results. All countries can share our knowledge described in this guideline on tsunami disaster management map.

Finally, we would like to thank the chair (Prof. Toshitaka KATADA of Gunma University), vice-chair (Dr. Takashi TOMITA of PARI), members of the exploratory committee, which was established in February 2007 and held 4 meetings in total, together with the committee's administrative staff, for their active discussions and hard work that led to the formation of this guideline. The Overseas Coastal Area Development Institute of Japan made great contributions in compiling this guideline.

It should be noted that this project started in 2006 as a part of the PTG Joint Research Project which aims at improving port technology in the framework of ASEAN-Japan Transport Partnership Program. Ports and Harbours Bureau of MLIT has demonstrated strong leadership in advancing this project.

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- First meeting: February 6th, 2007
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Guideline for Development and Utilization of Tsunami Disaster Management Map

CHAPTER.1 Introduction

1.1 Brief Overview

To reduce the magnitude of tsunami disasters in a region, a comprehensive approach involving the integration of land use planning, construction of coastal protection facilities and measures for increasing the people's self-protecting capability against disasters should be adopted based on the characteristics of the region. A tsunami disaster management map is a graphical presentation of necessary information to manage tsunami disasters and minimize damage in the region. The most basic information of the tsunami disaster management map is damage-prone areas with expected degrees of damage in case of possible tsunami attack, whose graphical presentation is generally called a tsunami hazard map or tsunami inundation map. The tsunami disaster management map is extremely valuable for evaluating necessary disaster prevention and reduction measures including the preparation of new protection facilities, reinforcement of existing structures, the identification of evacuation sites and routes to safer places and others, resulting in the establishment of a comprehensive disaster reduction system suitable to the region. Sharing the information on regional protecting capability against tsunami disasters with residents through the disaster management map also increases their self-protection capability.

To promote the preparation of tsunami disaster management maps in countries affected by the 2004 Indian Ocean Tsunami and ASEAN countries, this guideline clarifies the objectives, development, utilization and promotion of the maps.

<Explanation>

(1) Background

The 2004 Indian Ocean Tsunami which was generated by a magnitude 9.3 earthquake off the west coast of Northern Sumatra on 26 December 2004 propagated throughout the Indian Ocean, Bengal Bay and Andaman Sea resulting in devastating damage in Thailand, Sri Lanka, India, Maldives and other countries as well as Indonesia which was near the epicenter. In the Pacific Ocean, the Chilean Tsunami which was triggered by a magnitude 9.5 earthquake off the Chilean coast propagated in the Pacific Ocean and caused deadly damage in the Hawaii Islands and Japan and along the Chilean coast.

Tsunami risk reduction requires international cooperation to exchange information on tsunamis and the triggering earthquakes in order to establish international tsunami warning systems such as the Pacific tsunami warning system operated by the Pacific Tsunami Warning Center. The Center was realized thanks to the efforts of the International Coordination Group for the Tsunami Warning System in the Pacific which was established by the Intergovernmental Oceanographic Commission of UNESCO.

The tsunami warning provides the information required to determine whether an evacuation is necessary, which is an essential measure to save lives in the expected tsunami-affected areas. In fact, many residents in the Solomon Islands were able to save their lives by evacuating to higher places when the tsunami hit on April 2, 2007. Evacuation is helped further by adequate preparation of effectual evacuation sites and evacuation routes to safer areas. Minimizing the loss of individual and social properties is also important to facilitate rehabilitation and reconstruction in the aftermath of a disaster.

Comprehensive disaster prevention and reduction systems so as to save life and property from tsunami disasters are achieved by understanding tsunami hazards and the vulnerability of areas and communities to the expected tsunamis, and preparing adequate countermeasures among policy makers, disaster administrators and residents. The graphical presentation of the tsunami hazard, vulnerability and countermeasures in the region helps persons understand the tsunami risk in their region and particularly helps residents clearly understand what self-defense measures are required.

(2) Tsunami hazard map and tsunami disaster management map

Tsunami hazard map presents graphically the tsunami hazard and community vulnerability against tsunamis by indicating damage-prone areas with expected degrees of damage in case of possible tsunami attack, and allowing those concerned to understand the tsunami risk in the region. Tsunami disaster reduction activities are easily managed using a tsunami disaster management map as it indicates measures to provide disaster reduction as well as the tsunami hazard and vulnerability. For instance, the tsunami hazard map includes evacuation sites and routes.

As an example of the final product, one tsunami disaster management map of Japan is enclosed on the back cover of this guideline. Furthermore, website addresses which display several examples of tsunami disaster management map are given in the Appendix 1.

(3) Utilization of tsunami disaster management map

The tsunami disaster management map is a good tool for public education on tsunami disasters and raising awareness on self-protection activities. For instance, evacuation maps indicating the estimated tsunami inundation areas with tsunami shelters and evacuation routes is especially useful for the residents and general public to understand and decide upon an adequate evacuation scheme.

The tsunami disaster management map clearly indicates the effectiveness and weakness of structural measures. By examining the weakness revealed on the map, disaster administrators can improve countermeasures and enhance their capability of tsunami disaster prevention and reduction through the establishment of comprehensive disaster prevention and reduction systems.

An overview of the tsunami disaster management map is provided in Chapter 2 of this guideline.

(4) Preparation of tsunami disaster management map

The most basic information of the tsunami disaster management map is the possible tsunami inundation areas. The inundation due to a worst-case scenario tsunami in a region where tsunami disaster reduction activities are considered is estimated by means of numerical simulation. The inundation areas and damage caused by previous tsunamis is referred to draw tsunami-prone areas in regions where worst-case tsunamis cannot be predicted due to lack of bathymetric and topographical data. Natural disasters due to surges and floods may provide good information on the vulnerability of communities against coastal flooding due to tsunamis.

Figure 1.1 is a basic flow chart indicating how to prepare the tsunami disaster management map. Note that this flow explains the way to prepare the tsunami disaster management map by using numerical simulation. The detailed procedures to develop the tsunami disaster management map are introduced in Chapter 3.

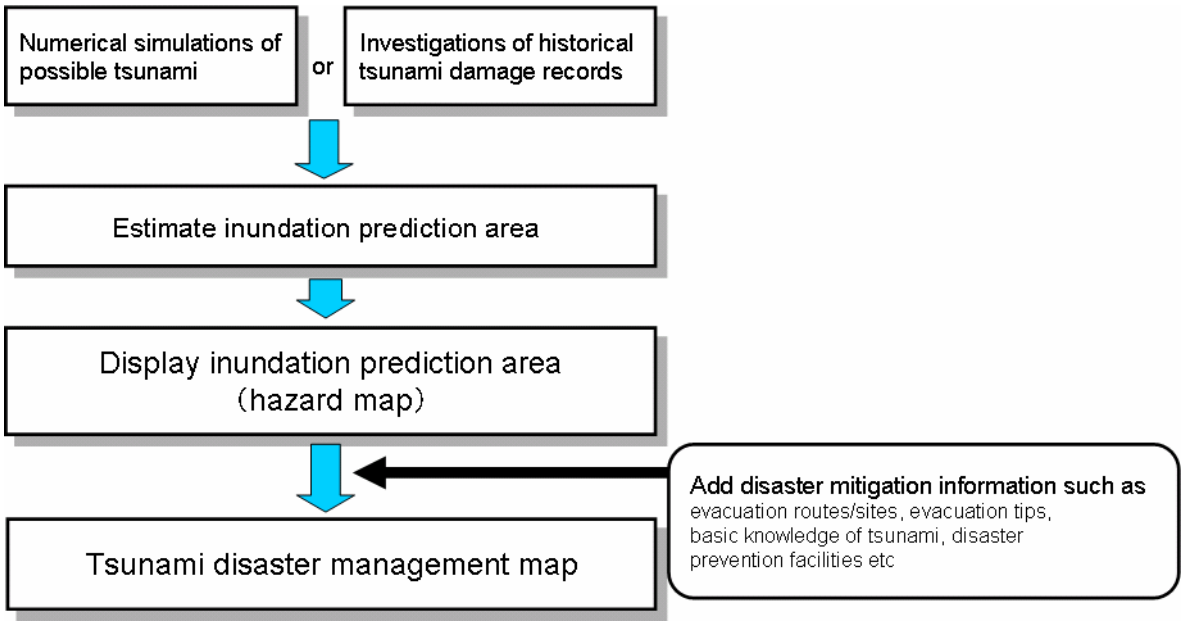


Figure 1.1 Flow of preparing tsunami disaster management map

(5) Intended users of this guideline

Intended users of this guideline are administrative persons who will prepare the tsunami disaster management map, or who will give the disaster management map to community leaders or directly to the public and explain the purpose and contents of the map to them.

(6) Contents of this guideline

This guideline consists of four chapters. Chapter 1 introduces the role of the tsunami disaster management map in regional tsunami disaster reduction activities. Chapter 2 describes the objectives and examples of tsunami disaster management map. Chapter 3 introduces the fundamental procedure to prepare the tsunami disaster management map. In the Appendix, characteristics of tsunamis are briefly explained. Chapter 4 introduces various applications of the tsunami disaster management map with several examples.

This guideline has been prepared by revising the contents of the manual for tsunami and storm surge hazard maps prepared in March 2004 by Cabinet Office (in charge of Disaster Management) of Government of Japan, Rural Development Bureau and Fisheries Agency of Ministry of Agriculture, Forestry and Fisheries, River Bureau and Ports and Harbors Bureau of Ministry of Land, Infrastructure and Transport, and adding new descriptions for the tsunami disaster management map in developing countries.

National Committee on the guideline for tsunami disaster management map in the Countries Affected by the 2004 Indian Ocean Tsunami and ASEAN Countries was established to prepare the draft of this guideline with Professor Toshitaka Katada, Gunma University as the chairperson. This guideline was finalized at Port Technology Group meeting in Transport Partnership Program of ASEAN-Japan Comprehensive Economic Partnership.

(7) Possible application of this guideline to the analysis of storm surges hazards and to the analysis of effects of sea level rise due to global warming

This guideline could be used to prepare the storm surge hazard map and to analyze the effects of sea level rise due to global warming.

1) Applicable analysis for coastal hazards and vulnerability due to storm surges

The estimation results of tsunami hazards and vulnerabilities in the community are also applied to the analysis of the hazards and community vulnerabilities due to storm surges. Although coastal flooding by storm surges has basically different

characteristics from tsunamis inundation, low-lying coastal areas are vulnerable against both tsunamis and storm surges because the seawater flooding on land flows finally into lower areas.

If numerical models to calculate fluid motion in the sea generated by tsunamis are available, they can be applied to analyze the storm surge generated by tropical storms with slight modification. It should be noted that the storm surge is caused through the rise in sea level resulting from depression of atmospheric pressure and the sea water volume pushed to coastal areas by high winds blowing above the sea surface, which are main generation factors of storm surges by tropical storms. The sea water flooding on land by storm surges is calculated in the same way as the calculation of tsunami inundation.

2) Applicable analysis for tsunami hazards and disasters under the condition of sea level rise by global warming in the future

Using the numerical simulations to analyze the tsunami hazards and disasters, the effects of sea level rise due to global warming on tsunami hazards and disasters are estimated in the same way as the consideration on tide level at the time of tsunami striking. Although the qualitative increase of vulnerability in coastal areas can naturally be expected as the sea level rises, the numerical simulations can quantitatively indicate hazards and vulnerabilities.

1.2 Concept of tsunami disaster management

1.2.1 Three elements for disaster management

Establishment of comprehensive measures in a region starts from understanding the hazard in the region, community vulnerability and countermeasures.

<Explanation>

(1) Understanding of tsunami hazard

To understand the tsunami hazard in a region, the tsunamis striking the region are estimated through analysis of previous disasters and numerical simulations of the previous and future tsunamis using bathymetric and topographical data.

For instance, tsunami arrival time after the occurrence of the triggering earthquake, inundation areas and duration time of tsunami excitation are essential data for judging the necessity of evacuation, setting up evacuation procedures, evacuation routes and arranging tsunami shelters. The height of tsunamis is also essential information when constructing defense facilities.

(2) Understanding of vulnerability

Even if the tsunami hazards are similar along the same coastal line, local variations in population, economy and land-use create different levels of community vulnerability. The community vulnerability is assessed in physical and social aspects. In the physical aspect, tsunami-prone areas are vulnerable to disasters. Coastal low-lying areas are generally vulnerable to tsunamis. In the category of social vulnerability are persons who require support in the case of evacuation such as children and the elderly.

(3) Understanding of countermeasures

Tsunami disaster reduction measures are divided into two categories: Structural and non-structural measures. To minimize the disaster in the region, they have to be integrated into a reasonable comprehensive system based on the local characteristics of hazard and vulnerability.

Breakwaters and coastal embankments are structural measures used to prevent intrusion of tsunami and to reduce tsunami height. Such structures also have the function of delaying arrival of the tsunami which has critical height and inundation depth.

Tsunami shelters and evacuation stairs to higher places, which support quick and secure evacuation of the residents, are also in the category of non-structural measures because they have no functions to control or reduce tsunamis.

1.2.2 Considerations in tsunami disaster management

Considerations in tsunami disaster management consist of i) promoting and raising disaster awareness, ii) providing and sharing information of tsunami disaster prevention, iii) reinforcing communication between administrators and residents, and iv) compiling a menu of countermeasures against tsunami disasters.

<Explanation>

(1) Promoting and raising disaster awareness

Since evacuation is essential for saving human lives, it is important that the awareness of tsunami disaster is promoted and raised among residents and the general public, allowing them to increase their self-protection capability. Local administration should provide tsunami disaster management maps, which can indicate tsunami hazard and community vulnerability, as a means to promote and raise awareness of tsunami disasters.

(2) Providing and sharing information of tsunami disaster prevention

For tsunamis triggered by an earthquake which occurred near the community, the residents in the community have less time to evacuate to safer places because the tsunami will arrive at the coast of the community almost immediately. In such a case, quick evacuation is a crucial measure to save human lives.

For distant tsunamis generated far from the community, the residents and general public have time enough to move to safer places. They require tsunami warnings and information, however, because they can feel no ground motion by the distant earthquake. Therefore, early tsunami warning system is a necessity, ideally one that involves international cooperation.

(3) Reinforcing communication between administrators and the residents

Reinforcing communication between administrators and the residents is important for the administration to gather information on tsunami disasters and to provide information to the community that can mitigate the effects of the tsunami. Partnerships with related authorities are also necessity for disaster prevention and mitigation when the tsunami strikes.

(4) Compiling a menu of countermeasures against tsunami disasters

A tsunami with a height greater than the design specifications of protection facilities can overflow the facilities, resulting in inundation in the hinterland of the facilities. For the planning of tsunami disaster reduction, therefore, the largest possible tsunamis striking each community should be predicted and comprehensive systems integrating various measures against the tsunamis are considered to reduce the tsunami disasters in the community.

1.2.3 Comprehensive disaster prevention and reduction system integrating structural and non-structural measures

Seawalls, embankments and others can prevent tsunamis from overtopping structures. The structural measures offer limited protection, however, as tsunamis with a greater height than the protective structures still have the potential to cause damage. Therefore, the integration of structural measures and non-structural measures is crucial.

<Explanation>

(1) Structural and non-structural measures

Structural measures such as breakwaters, seawalls, and embankments improve the degree of disaster prevention and reduction capability in the community. Non-structural measures redeem the limitation of the disaster reduction ability of structural measures. They include providing information on tsunami hazard and disasters to the residents before and after the occurrence of disasters, the setting up of tsunami shelters and evacuation routes, disaster education and others. Table 1.2.3 gives examples of structural and non-structural measures.

Table 1.2.3 Examples of structural and non-structural measures

Structural measures	- Measures for prevention and reduction of tsunami intrusion - Breakwaters, seawalls, embankments, water-gates and others with suitable operation and maintenance - Houses of reinforced concrete and steel-reinforced concrete
Non-structural measures	- Measures for supporting evacuation - Tsunami shelters, and evacuation sites/routes - Facilities to provide tsunami warning and others - Measures for reduction of tsunami disasters - Coastal vegetation - Improvement of land-use plan - Providing of tsunami warning and others - Tsunami disaster management map - Tsunami awareness through disaster education and others - Evacuation drill

(2) Necessity of the integration of structural and non-structural measures

The relationship between structural and non-structural measures is shown in Figure 1.2.3. As a strategy for tsunami disaster management, the damage caused by a certain level of tsunami, which is used to plan and design protection structures, can be prevented by structural measures. However, for tsunamis higher than the design specifications of protective structures, non-structural measures are also required to

minimize disasters and keep construction costs and time at a manageable level.

Even for a tsunami with a magnitude that has been accounted for in the tsunami disaster prevention strategy, it can still cause damage in the areas where there has been a delay in establishing protective structures. Besides, if the structures are unable to function normally to prevent tsunami inundation, non-structural measures such as evacuation is more effective in saving human lives.

Considering rehabilitation and reconstruction in the aftermath of disasters, it is of overriding importance to reduce the degree of tsunami disasters by increasing disaster prevention capability as much as possible.

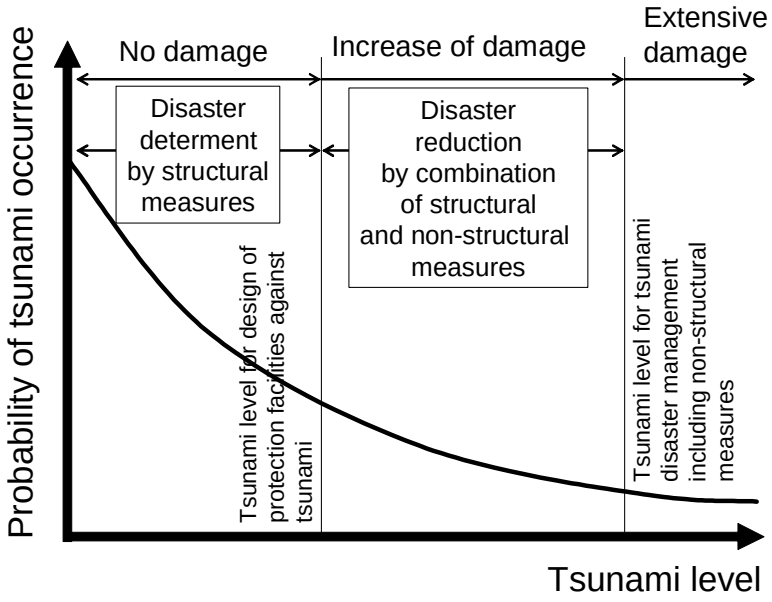


Figure 1.2.3 Relationship between structural and non-structural measures
Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Tsunami and Storm Surge Hazard Map Manual", 2004

(3) Procedure of integration of structural and non-structural measures

An example integrating structural and non-structural measures in a community is given as follows:

i) Specify the largest possible tsunamis (Setting of tsunami scenarios)

ii) Determine the protection capability of the existing structures against the tsunamis

iii) Estimate disasters by means of numerical simulations and analysis of previous disasters

iv) Set the level of disaster prevention

v) Improve land-use to minimize the disasters occurring

vi) Consider the order of priority to conduct measures such as reinforcement of the function of the existing structures, construction of new facilities, improvement of

gate operation, plantation of coastal vegetation and others so as to prevent and reduce the tsunamis, depending on evaluation of the expected tsunami disasters

vii) Determine the limitation of measures to prevent tsunami disasters

viii) Consider measures to assist in evacuation such as making tsunami disaster management map, arrangement of tsunami shelters, setting evacuation routes, and establishment of dissemination system of tsunami warning and evacuation advisory

1.3 Role of tsunami disaster management map

Tsunami disaster management map is a basic tool to analyze disaster prevention and reduction strategy and plan in a community, to develop the practical integration of structural and non-structural measures, to disseminate and provide information of the expected tsunami disasters and adequate evacuation procedure to the residents, general public and related authorities, to cultivate residents' awareness of tsunami disasters, to create risk communication with the residents, and others.

<Explanation>

(1) Importance of self-support and mutual support between regional residents

There are limitations to the tsunami disaster prevention measures prepared by central and local governments and authorized organizations. When faced with the possibility of a tsunami attack, it is of critical importance that persons make the decision to proceed with evacuation. In addition, mutual-support among regional communities is more effective in reducing the disasters. For instance, in the Solomon Islands Earthquake Tsunami on 2 April 2007, most persons in a village of the Solomon Islands evacuated the area (thus saving their lives) before authorized organizations issued a tsunami warning. Someone in a neighboring area alerted the residents that a tsunami would likely strike.

(2) Tsunami disaster management map as an awareness tool

i) Provide the information of tsunami hazards and tsunami disasters to the residents in the community

ii) Share the information of tsunami hazards and tsunami disasters among the administrative organizations and provide the information of tsunami hazards and tsunami disasters to the related authorities

iii) Create risk communication of tsunami between disaster administrators and the residents

(3) Analysis and investigation tool to support the establishment of structural measures

i) Analyze and investigate new structural measures and reinforcement of the existing structural measures to increase the capability of tsunami disaster prevention in the community.

ii) Analyze and investigate the location of evacuation sites and routes

iii) Analyze and investigate the procedure of recovering and rehabilitating activities

Table 1.3 Representative roles of tsunami disaster management map

Intended users	Objective measures	Role of disaster management map
Residents	- Awareness of disaster - Disaster study (education) - Disaster drills - Risk communication among the residents - Self and family protection plan - Mutual support plan	• Providing the tsunami risk and disaster information to residents • Risk communication tools between residents and disaster administrators
Disaster administrators	-Disaster prevention plan -Evacuation plan -Rescue plan -Development of disaster warning and evacuation information system -Constructing disaster prevention facilities and evacuation sites -Operation procedure of mobile structure measures such as a water gate	• Providing the tsunami risk and disaster information to the disaster administrators • Support disaster administrators to examine disaster prevention measures such as constructing disaster prevention facilities and evacuation shelters. • Risk communication tools between residents and disaster administrators

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Tsunami and Storm Surge Hazard Map Manual", 2004

1.4 Strategy for the development and utilization of tsunami disaster management map

1.4.1 Clarifying purpose, users and utilization manners of tsunami disaster management maps

Tsunami disaster prevention and reduction are achieved by the integration of various activities. Tsunami disaster management maps support effective and practicable combination of measures and estimate their effectiveness. It is important, therefore, to develop the tsunami disaster management maps based on practical strategies in which their purpose, users and ease of utilization are considered.

<Explanation>

(1) Purpose

Final purpose of the tsunami disaster management maps is tsunami disaster prevention and reduction. Various types of tsunami disaster management maps are developed which can assist in managing disasters. For instance, an evacuation map indicating tsunami shelters and evacuation routes is used to manage and support the residents' and general public's escape from tsunamis. Other administrative objectives are the development of regional disaster management plan, investigation of comprehensive arrangement of various measures, the analysis of the effect of protection facilities against tsunamis, and the identification of areas where evacuation is difficult.

(2) Users

Users of the tsunami disaster management map vary by purpose. The main users of the map, for instance, are the residents and general public because the map can be of great assistance during the evacuation process. Disaster administrators also use the map to develop regional disaster prevention and reduction plan in their community as do policy-makers who decide the regional disaster management plan.

(3) User-friendly layout

It is important that the tsunami disaster management map is easily understandable, according to its purpose and users. Excessive information on a map will make it difficult to be followed by users. Data indicated on the map, therefore, should be examined carefully so that users can grasp its purpose and essential information.

1.4.2 Step-by-step development of tsunami disaster management map

Tsunami disaster management maps can be developed step-by-step, depending on available technology and data. The essential information on the tsunami disaster management map is tsunami hazard. It is estimated in a community through tsunami numerical simulation based on bathymetric data, topographic data, and tsunami scenarios including the occurrence of tsunami generation and magnitude of tsunami. Even if no data are available, however, the tsunami hazard could be estimated by analyzing historical tsunami inundation records in the community. Social, economic or other necessary data is combined with such tsunami hazard information to create the tsunami disaster management map.

<Explanation>

Tsunami hazards such as the height of striking tsunami, inundation areas and so on, which is the most basic information on a tsunami disaster management map, are well estimated by tsunami numerical simulation based on bathymetric and topographic data and tsunami scenarios including where the tsunami occurs and the magnitude of the tsunami. Such data, however, is not widely available in many developing countries. Even if no data are available, however, the tsunami hazard can be estimated by analysis of historical disasters. According to technology, available data and necessity, therefore, tsunami hazard can be developed step-by step. Social, economic or other necessary data are combined with such tsunami hazard information to create the tsunami disaster management map.

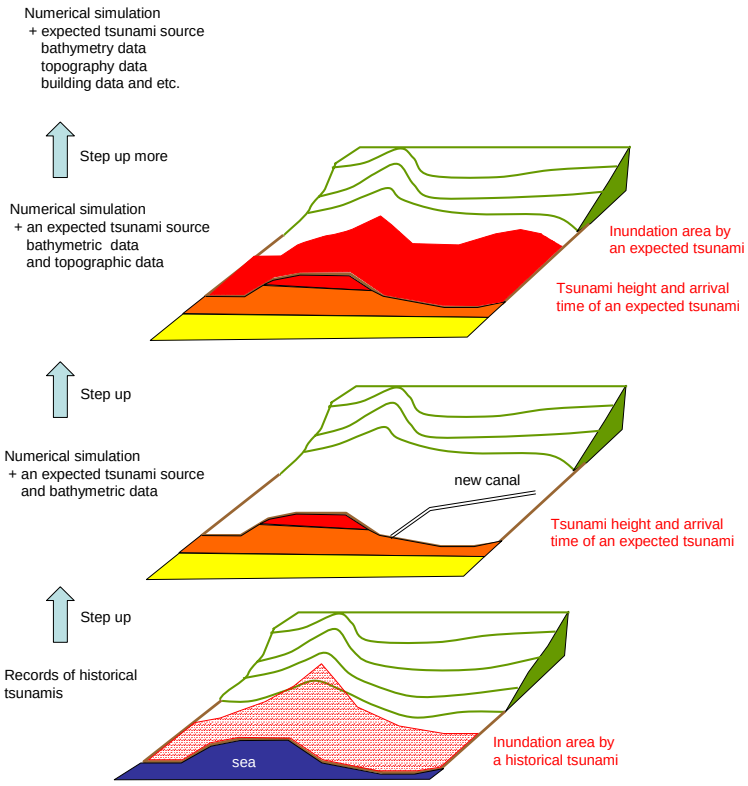


Figure 1.4.2 Step-by-step development of tsunami disaster management map

CHAPTER 2 Outline of tsunami disaster management map

2.1 Definition of tsunami disaster management map

A tsunami disaster management map is a map that graphically provides information on inundation area and disaster information. The disaster information includes evacuation information, evacuation tips, basic knowledge of tsunamis, and information for disaster mitigation measures such as evacuation plan and construction plan of disaster facilities.

<Explanation>

Tsunami hazard map shows the predicted inundation areas. Tsunami disaster management map shows the predicted inundation areas and information on evacuation. Tsunami disaster management map is completed by adding disaster information such as evacuation routes/sites, evacuation tips and basic knowledge of tsunami to the hazard map.

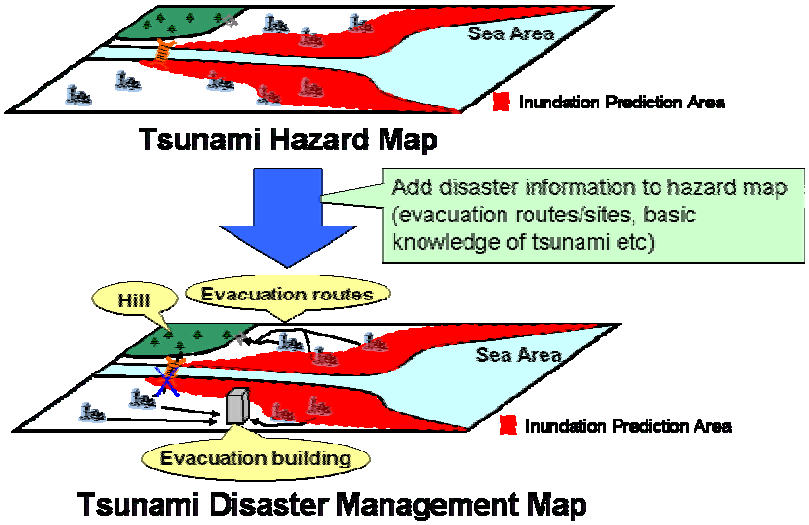


Figure 2.1 Definition of the tsunami disaster management map

2.2 Purpose of preparing a tsunami disaster management map

The purpose of preparing a tsunami disaster management map is to provide residents with necessary information for evacuation and to assist administrative bodies in carrying out their duties such as devising and taking disaster prevention measures.

<Explanation>

Tsunami disaster management map is prepared to provide residents with necessary information for evacuation in an easy-to-understand manner. It also assists administrative bodies in carrying out their duties such as devising and taking disaster prevention measures. For example, such map helps disaster administrators draw up evacuation plans and construction plan of disaster facilities such as breakwaters, seawall, and water gate.

2.3 Inundation prediction methods for preparing tsunami disaster management map

The main part of a tsunami disaster management map is the predicted inundation areas. The predicted inundation area is prepared based on the result of inundation prediction in case of a possible tsunami attack. There are mainly four kinds of inundation prediction methods as follows.

a. Numerical simulation method.
b. Level filling method.
c. Method based on historical inundation records.
d. Estimation based on ground elevation

Basically, the prediction should be based on a numerical simulation method. However, when a numerical simulation is difficult to conduct, inundation area could be estimated by using historical tsunami inundation records.

<Explanation>

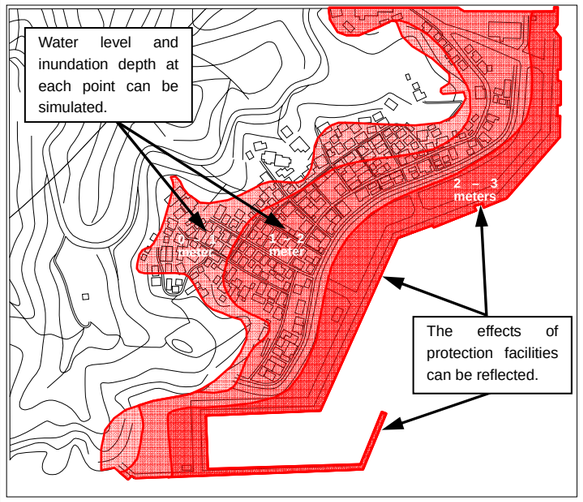
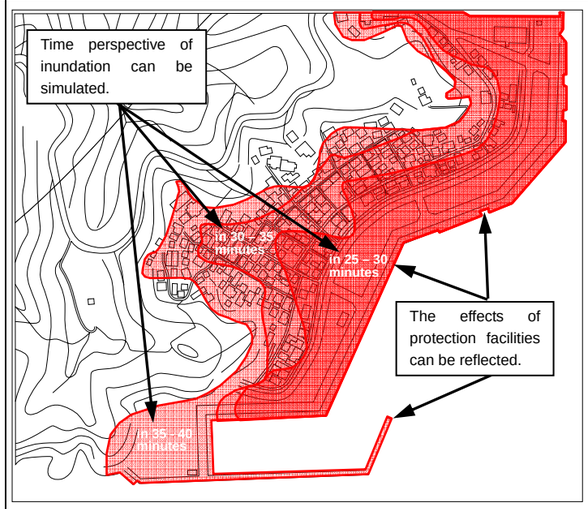
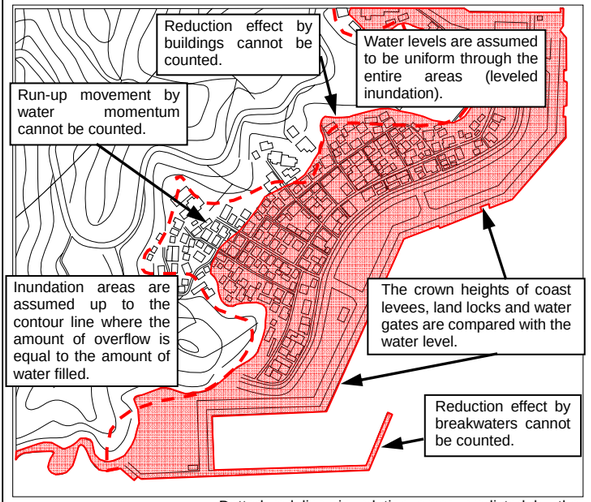
Inundation prediction must be conducted by a method that appropriately reflects external force conditions and structure conditions. The method must also have precision suited to the purpose of preparing a tsunami disaster management map and to the characteristics of the target district. Basically, prediction should be based on a numerical simulation method, because it precisely estimates the data necessary for preparing a tsunami disaster management map and it can reflect the effects of protection facilities. When a numerical simulation method is difficult to conduct, simpler alternatives are available for inundation prediction. For example, inundation area could be estimated by using historical tsunami inundation records (c. Method based on historical inundation records).

Four types of inundation prediction methods are outlined as follows;

a. Numerical simulation method is the method which predicts inundation areas based on numerical simulations using a numerical model of tsunami propagating through the ocean and flooding coastal areas.
b. Level filling method provides estimation of inundation areas in which inundation depth on the ground is calculated based on water volume intruding from coasts by a tsunami. The tsunami is calculated using a numerical model of tsunami propagating through the ocean.
c. Method based on historical inundation records is to indicate inundation areas of historical tsunamis.
d. Estimation based on ground elevation determines inundation areas under the tsunami height which is predicted from a tsunami numerical simulation.

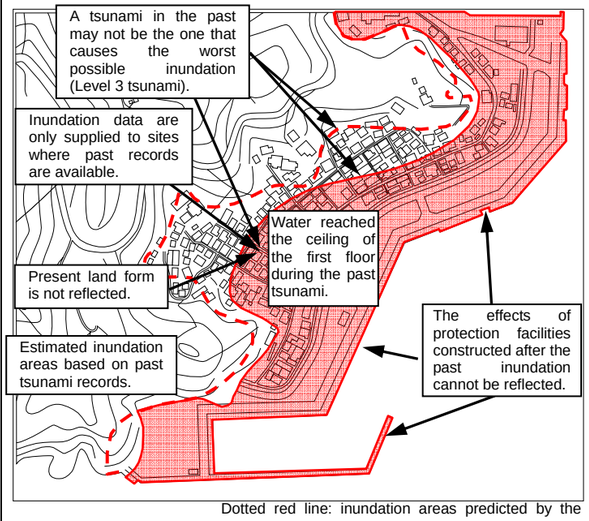
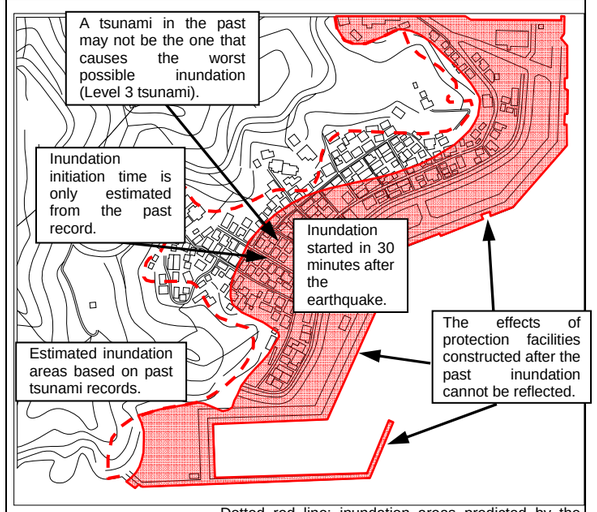
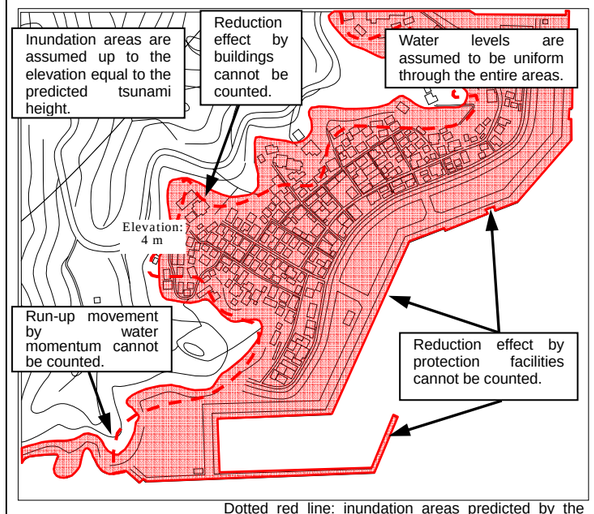
The characteristics of each method are shown in Table 2.3.

Table 2.3-1 Characteristics of each inundation prediction method

Method	Outline of the method	Advantages (A) and Disadvantages (D)	Prediction image for tsunami hazard	
			<Inundation areas and depths>	<Time perspective>
Numerical simulation method	Numerical simulation method is the method which predicts inundation areas based on numerical simulations using a numerical model of tsunami propagating through the ocean and flooding coastal areas.	(A) Can precisely estimate the data necessary for preparing a tsunami hazard map. (A) Can reflect the effects of protection facilities. (D) Requires skills and cost.		
Level filling method	Level filling method provides estimation of inundation areas in which inundation depth on the ground is calculated based on water volume intruding from coasts by a tsunami. The tsunami is calculated using a numerical model of tsunami propagating through the ocean.	(A) Requires no special skills. (A) Has a certain calculation basis for determining the amount of flood water volume and inundation areas predicted from the external force level. (D) Cannot count reduction effect by buildings (overestimates inundation areas) and run-up movement by water momentum (underestimates inundation areas). (D) May result in unrealistic estimations depending on the topographic situations, such as showing an enclave in the inundation area, since the water flow is ignored. (D) Can predict only final inundation areas. Cannot predict the speed and time perspective of inundation.	 Dotted red line: inundation areas predicted by the numerical simulation	- Only final inundation areas can be predicted. The speed and time perspective of inundation cannot be predicted. - Retarding effects by breakwaters, coast levees, land locks and water gates cannot be evaluated.

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, “Tsunami and Storm Surge Hazard Map Manual”, 2004

Table 2.3-2 Characteristics of each inundation prediction method

Method	Outline of the method	Advantages (A) and Disadvantages (D)	Prediction image for tsunami hazard <Inundation areas and depths>	Prediction image for tsunami hazard <Time perspective>
Method based on historical inundation records	Method based on historical inundation records is to indicate inundation areas of historical tsunamis.	(A) Is simple and inexpensive. (D) Cannot be applied to regions that have not ever suffered inundation. (D) May underestimate inundation areas, inundation depths and inundation initiation time because the external force level of the past inundation may not be the worst. (D) Cannot reflect the effects of protection facilities constructed after the past inundation. (D) Cannot provide data that were not monitored during the past inundation.	 Dotted red line: inundation areas predicted by the numerical simulation	 Dotted red line: inundation areas predicted by the numerical simulation
Estimation based on ground elevation	Estimation based on ground elevation determines inundation areas under the tsunami height which is predicted from a tsunami numerical simulation.	(A) Is simple and inexpensive. (D) Cannot count reduction effect by buildings (overestimates inundation areas) and run-up movement by water momentum (underestimates inundation areas). (D) Cannot reflect the effects of protection facilities because inundation areas are predicted only from the height of a tsunami and the ground elevation. (D) Can predict only the final inundation areas. Cannot predict the speed and time perspective of inundation.	 Dotted red line: inundation areas predicted by the numerical simulation	- Only final inundation areas can be predicted. The speed and time perspective of inundation cannot be predicted. - Retarding effects by breakwaters, coast levees, land locks and water gates cannot be evaluated.

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, “Tsunami and Storm Surge Hazard Map Manual”, 2004

3. Procedure to prepare tsunami disaster management maps

3.1 Different types of tsunami disaster management map for different purposes

A tsunami disaster management map should be prepared corresponding to its purpose and intended users. This guideline shows two examples of how to make the tsunami disaster management map. The first is an evacuation map whose users are not only administrative persons responsible for disaster management but residents and general public including non-residential workers and tourists. The second map is mainly for administrative use such as investigating and planning tsunami disaster prevention and reduction.

<Explanation>

Various types of tsunami disaster management maps can be prepared, depending on their purpose and intended users. To optimize its utility, the tsunami disaster management map should be user-friendly.

The users of the tsunami disaster management map can roughly be divided into administrative personnel and the general public which includes residents, non-residential workers and tourists. The most common tsunami disaster management map for both of them is an evacuation map. This guideline shows how to make an evacuation map as the first example of a tsunami disaster management map. Secondly, maps for other administrative uses to prevent and reduce tsunami disasters are introduced.

According to the necessity of disaster management in communities, other maps are prepared. For instance, a company may develop a map to control and manage the tsunami disasters which could otherwise affect its ability to continue doing business, or a fishery community may develop a map to indicate tsunami hazard in their sea and evacuation procedure for their fishing boats.

Tsunami disaster management map is a good tool to create risk communication against tsunamis between the authorities and the community, in which hazard and disaster information can be mutually shared.

3.2 Tsunami hazard as basic information on tsunami disaster management maps

3.2.1 Significance of tsunami hazard in tsunami disaster management maps

The most basic and crucial information of a tsunami disaster management map is tsunami hazard expected in a community. Indication of tsunami hazard such as the inundation area together with disaster prevention and reduction measures provides relevant parties with an understanding of the necessity of disaster prevention and reduction activities.

<Explanation>

(1) Significance of tsunami hazard information

A tsunami disaster management map that does not indicate tsunami hazards results in less understanding of the need to adopt disaster prevention measures and less awareness of the significance of tsunami disasters among relevant persons. Indicating tsunami inundation areas, tsunami-prone areas and vulnerability of the community against the tsunamis clearly on the map will raise awareness of the impact of tsunami disasters and prompt administrators to take the necessary measures to minimize such disasters.

(2) Various types of tsunami hazards

The most vital information is tsunami inundation areas, which are vulnerable to the tsunamis and would require evacuation in the event of an attack. The inundation area is estimated using records of past tsunami disasters and numerical simulation results of the expected tsunamis. Based on the numerical simulation results, water depth of the inundation areas is also estimated and clarifies the degree of risk levels against the tsunamis.

There are other factors which need to be considered in developing measures against tsunamis. Tsunami arrival time is an important factor for planning the evacuation process, while tsunami fluid velocity is an index to gauge the required speed of evacuation when a tsunami strikes several minutes after an earthquake. Tsunami destruction is, furthermore, estimated by tsunami wave force and fluid velocity.

(3) Estimation of tsunami hazards

As described in Section 2.3, there are several ways to estimate tsunami hazards, in particular tsunami height along coasts and inundation. If a community has experience of tsunami disasters in the past, historical records will indicate vulnerable areas and it will be possible to roughly predict inundation areas. However, the topography and bathymetry may have changed since these past disasters took place. In such a case, the characteristics of the tsunami striking the community would vary depending on these changes, resulting in the appearance of different inundation features. To understand the tsunami hazards at present and in the future, therefore, it is recommended that analysis and estimation using numerical simulations be conducted in the present and future situations.

If the community has no experience with tsunami disasters but seismological studies indicate that tsunamis can be expected in the future, past coastal flooding disasters due to storm surges serve as a good reference for predicting areas vulnerable to tsunamis.

3.2.2 Numerical simulation to estimate tsunami hazard

Numerical simulations can yield tsunami hazard and vulnerability of the community against tsunamis under various conditions. Numerical simulations, in particular, have the capability to estimate disaster risk due to the expected tsunamis which will strike in the community. To establish comprehensive measures to prevent and reduce the expected disaster risk, numerical simulations are also a crucial tool to evaluate and analyze the effect of each measure and combination and integration of measures on disaster prevention and reduction.

<Explanation>

(1) Recommended numerical simulation procedure to estimate tsunami hazards

A recommendable estimation method of tsunami hazards is a numerical simulation with a time-marching model, or time-integrated model which solves fluid motion driven by tsunamis and mass conservation of fluid. Such a model can analyze tsunami inundation spreading step by step.

(2) Necessary data for numerical simulations of tsunami disaster estimation

The time-marching numerical simulation of tsunami requires bathymetric and topographic data as shown in Figure 3.2.2-1. If bathymetric data and the configuration of coastal lines are available but topographic data on land is not, the tsunami heights and arrival time along coasts can at least be calculated. If the topographic data is available, inundation features can be estimated. Data of structures including houses and buildings can also be used to evaluate the degree of damage in case of a tsunami attack. It should be noted that the accuracy of numerical simulation results depends on the spatial resolution and accuracy of the bathymetric and topographic data.

One-minute grid oceanic bathymetry data is available from a web site of the General Bathymetric Chart of the Oceans (GEBCO, http://www.ngdc.noaa.gov/mgg/gebco/). To consider tsunami wave transformation in shallow water and the effect of protection facilities such as breakwaters in harbors, water depths in shallow water should be read from available nautical charts.

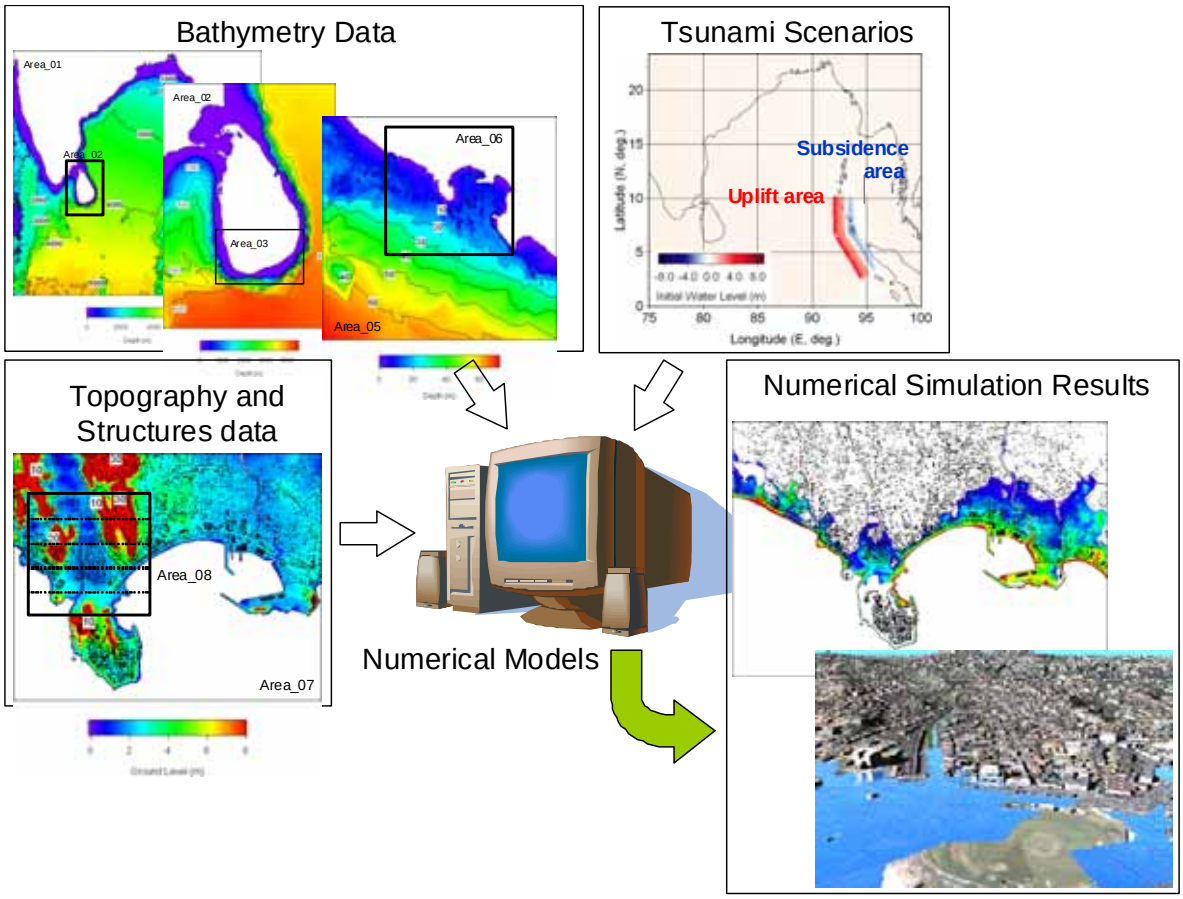


Figure 3.2.2-1 Estimation of the tsunami hazard area with numerical simulations

(3) Setting of tsunami scenarios

A tsunami scenario which determines the original condition of tsunami, the level of astronomical tide at the time of tsunami arrival and the conditions of structural measures including destruction of protective structures against tsunamis and operation states of mobile structures such as a water gate is also necessary to execute the numerical simulation of tsunami hazards.

The original condition of tsunami means the initial profile of tsunami which strikes a community and which can be usually calculated by means of a fault model of earthquake generating the tsunami. In general, tsunamis for the estimation of hazards are essentially the largest tsunamis which are expected to strike the community. However, the magnitude of tsunami should be selected corresponding to the purpose of the disaster management map. Table 3.2.2 indicates examples of tsunamis corresponding to various purposes. For example, a tsunami with a return period of 10 years is adopted for studying the structural measures required to protect a community against tsunami intrusion even though the largest tsunami that can be expected has a return period of well over a hundred years. This is because the structural measures

required to correspond to such a powerful tsunami are prohibitively large and in any case structural measures alone without non-structural measures would not significantly reduce the degree of disaster.

Table 3.2.2 Example of tsunami level corresponding to purpose

Tsunami level	Definition	Purpose of estimation
Level 1	Tsunami perceived to be realistic	Possible damage to activities related to fishery products, but not to the land
Level 2	Design tsunami as the protection goal	Design of structural measures which prevent and reduce disasters
Level 3	Largest tsunami causing the maximum damage	Development of comprehensive measures to reduce disasters

The tide level at the time of tsunami arrival is an important factor affecting the vulnerability of community against the tsunami. If higher tide is assumed in the simulation, the vulnerability level against tsunamis becomes higher, and in particular the inundation areas and depths are generally wider and deeper. The estimation of tsunami inundation, therefore, is conducted generally under the condition of high tide. On the other hand, the low tide condition is sometimes used to estimate the hazards affecting vessels on the sea. Receding tsunami during the low tide is hazardous because the vessel bottom hits the sea bed.

Facility conditions to be set before conducting the numerical simulations are destruction patterns and operational status of facilities. Damage to facilities is caused by earthquake motion and tsunami action. Thus, it is recommended that the stability of a facility against quake motion and tsunami wave force be inspected. Another fatal factor is the smashing of vessels, cars and other large bodies into the facilities, resulting from action of their collision forces with tsunami forces. For operational states of facilities such as a water gate and land lock which have opening spaces for access to the sea and sea fronts, actual data should be used as much as possible, including capability of their operations to close their opening space before a tsunami strikes.

The tsunami scenarios including the facility conditions should be adjusted to the characteristics of disasters, the map purpose, and regional characteristics. It is important that tsunami hazards are estimated to develop countermeasures against tsunamis using current knowledge and technologies. Even if the current knowledge and technologies are not always enough to estimate the hazards in detail, necessary knowledge and technologies will be accumulated and developed in the future.

It should be also noted that disasters occur possibly under conditions other than those presented in this section. In order to get necessary information, such as destruction patterns of facilities, an appropriate method should be selected by referring, for example, to "Coastal Facility Design Handbook" (November 2000, Japan Society of Civil Engineers) and "Technical Standards and Commentaries for Port and Harbour Facilities in Japan" (January 2002, OCDI).

(4) Indication of tsunami hazards

Inundation areas estimated through the numerical simulations are used to indicate tsunami risk areas on the tsunami disaster management maps. The most basic and essential indication procedure of tsunami hazards is that of coloring the inundation areas on the map. Red is usually used to represent the inundation areas on the map. When inundation depth is predicted by the numerical simulation, the depth is indicated by the strength of the red. Such a map clearly indicates tsunami inundation areas, raising peoples' awareness of the need to evacuate from tsunami-prone areas. A more advanced map on which the inundation areas are color-coded depending on inundation depth and/or on which tsunami arrival time and inundation initiation time are superimposed creates deeper understanding of the hazards with their risk degrees.

According to development of numerical simulation technology and acquirement of detailed bathymetric and topographic data, fluid velocity and wave force of tsunami will be estimated and indicated on the map as well as inundation areas and depths. However, too much data on the map can defeat the purpose of the map. If many types of risk data are required on the map, it is recommended to develop electronic map (E-map) with the geological information system (GIS) and to create inventive ways to describe them.

(5) Advanced tsunami hazard estimation

Advanced numerical simulation models are being developed to estimate fluid velocity and wave force of tsunami and tsunami destruction of structures as well as inundation area and depth. Since the fluid velocity and wave force of tsunami depend on the existence of structures as well as microscopic changes of bathymetry and topography, detailed bathymetric and topographic data and arrangement data of structures including houses and buildings are necessary to estimate such physical values. If there are design data of a structure and suitable numerical models, tsunami-induced destruction and fatal damage of the structure would be evaluated.

According to the development phase of tsunami numerical models and the availability of detailed data on bathymetry, topography and structures, the prediction of tsunami

hazards will become more sophisticated and can be utilized to formulate measures against tsunamis as shown in Figure 3.2.2-2.

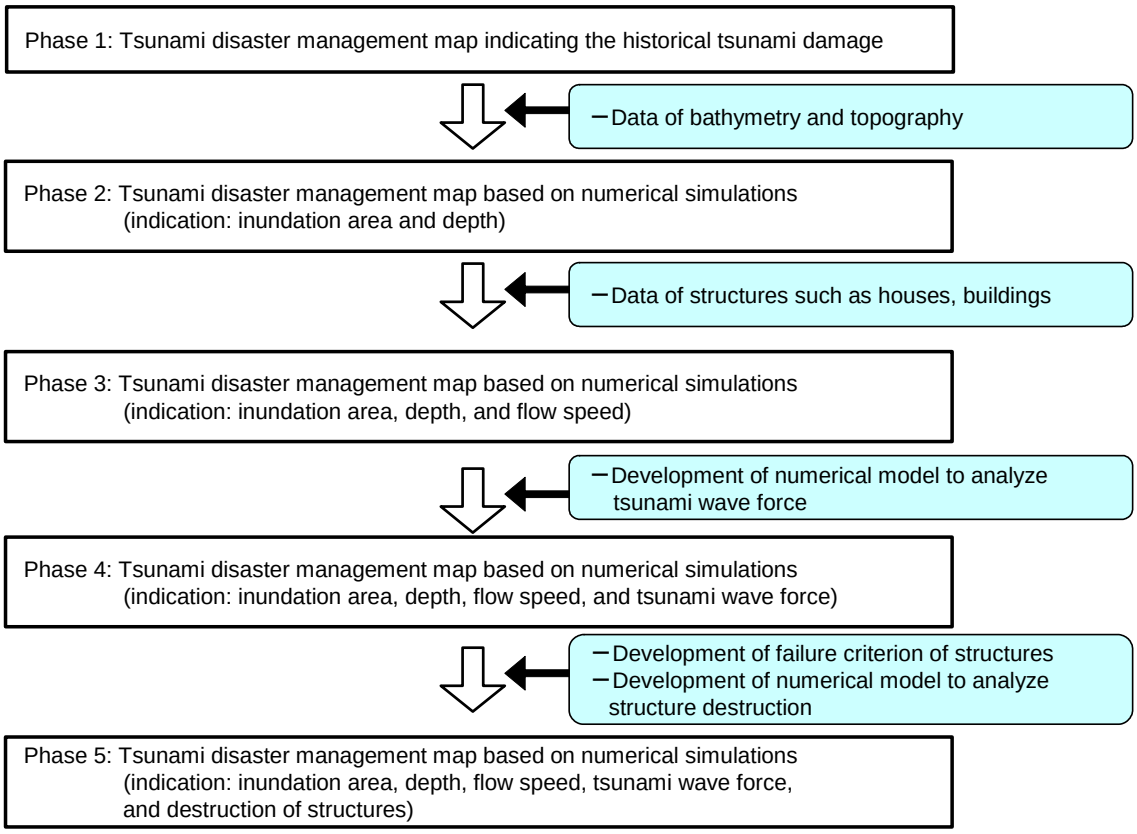


Figure 3.2.2-2: Example of step-by-step progress of tsunami disaster management map

3.3 Indication items on maps for peoples' evacuation

3.3.1 Information for evacuation activities and raising disaster awareness

Necessary information for adequate and smooth evacuation of people including residents, non-residential workers and tourists is divided into information for evacuation and raising disaster awareness. The information for evacuation consists of tsunami inundation areas, locations of evacuation sites/routes, and evacuation tips. For raising disaster awareness, the maps could include basic knowledge of tsunami, the information on historical tsunami disasters which affected the community in the past.

<Explanation>

(1) Basic information

Other than the information on tsunami hazards, necessary information for peoples' evacuation from tsunamis is classified into information for evacuation and information on the nature of tsunami disasters.

Evacuation sites and routes are essential and necessary information when facing a tsunami crisis. The basic information for evacuation includes the locations of evacuation sites/routes, tsunami evacuation tips, and tsunami inundation areas. If tsunami arrival time, tsunami striking direction and inundation depth are estimated, it is easier to study an effective evacuation procedure in the tsunami-prone areas. Information on buildings that are higher than the inundation depth is also beneficial when seeking refuge.

Related to information for peoples' evacuation, evacuation tips are important information for tsunami disaster management map. Table 3.3.1 shows an example of tsunami evacuation tips on a tsunami disaster management map. Also, tsunami safety rules can be downloaded from the ITIC's website.

Table 3.3.1 Example of evacuation tips

Evacuation Tips (Example of Uchiura, Numazu city, Japan)
• When the shaking stops, evacuate as quickly as possible.
• Move quickly to higher ground away from the coast.
• Return home only after local officials give the "All Clear" notice.
• A tsunami does not always start with the ebb tide.

Source:Uchiura, Numazu city, Japan

Basic knowledge of tsunami is effective in increasing people's self- and mutual defense capabilities when a tsunami actually strikes. The basic knowledge includes evacuation tips as well as that related to tsunamis such as tsunami generation mechanism. Examples of evacuation tips are as follows:

- As soon as the shaking of earthquake is over, move to high ground and tsunami shelters; do not wait for an official warning as a local tsunami which is generated near a coast can propagate to the coast within a few minutes.
- Remain in a safe place or site as tsunami waves repeatedly strike in general, depending on topography and bathymetry.

Historical tsunami disasters in a community also make people aware how vulnerable their community is to tsunamis. An area which is vulnerable to tsunamis, for example, a low-lying coastal area with no protection, generally suffers disasters repeatedly.

(2) Other important information

The map should also provide significant information corresponding to specific problems or needs in the community. For instance, in a community where many foreigners live, information in the prevalent foreign language would help such people to understand the map.

3.3.2 Displaying map

The tsunami disaster management map should be displayed in a simple and easy-to-understand language. The amount of information should be limited to the information which is indispensable for evacuation. For example, the crucial information on an evacuation must be able to be understood immediately. A simple map indicating inundation areas in the community is useful for all residents and general public regardless of their knowledge levels of tsunami features and disasters.

<Explanation>

The evacuation map for people including residents, non-residential workers and tourists should include the minimum amount of information indispensable for evacuation, since the map size is limited and users of the map have various levels of the knowledge on tsunamis. Information should be displayed in a simple and easy-to-understand language.

The basic function of a disaster management map is to present the areas inundated by the expected and past tsunamis. To promote awareness of tsunami risk, it is recommended that the inundated areas be colored in red.

For raising awareness of disaster preparedness and disaster education, a large amount of information may be required. In such a case, the necessary information is distributed in different forms such as leaflets, separately from the evacuation map. If personal computers are available, an electronic map (E-map) with GIS technology is effective in showing a large volume of information easily.

3.4 Indication items on maps for other administrative uses

The tsunami disaster management maps can be utilized for various purposes as well as evacuation: for instance, planning of preventative measures, evaluating the effects of structural measures and others. According to the purposes, the necessary data are indicated on the map together with tsunami hazard data.

<Explanation>

The tsunami disaster management map for disaster prevention should include the expected number of people exposed to the forecast tsunami disasters and its distribution as well as locations and capacities of evacuation sites including tsunami shelters. If there is an area in which some persons cannot escape from tsunami inundation, tsunami shelters for such persons may be newly constructed or selected from among solid and high buildings existing in the area. In addition, construction of new protective structures and enhancement of protection function of existing structures can delay the initiation time of the inundation, resulting in more time for evacuation.

The tsunami disaster management map for coast management should include facility information such as locations and types of facilities, facilities that are prone to damage, and evaluation results of stability of facilities against quake motion and tsunami wave force including liquefaction of the structure basement. Table 3.4 shows examples of information that should be included so as to accomplish the intended purpose of the map in consideration of the users.

Table 3.4 Basic information to be included in the tsunami disaster management map

Category of information	Information (to be layered in the tsunami disaster management map)
Hazard	· **Inundation risk areas (depth and time)** The following information could be included in the map. · Inundation area records based on historical tsunamis · Inundation depth due based on the expected tsunamis · Inundation depth records based on historical tsunamis · Initiation time of inundation based on the expected tsunamis · Initiation time of inundation based on historical tsunamis · Fluid velocity and wave force of the expected tsunamis · Others
Evacuation	· **Evacuation sites or tsunami shelters** · **Evacuation routes** The following information could be included in the map. · Population distribution in day and night times · Facilities for those who require some assistance for evacuation · Elementary schools and kindergartens · Others
Disaster awareness-rising and disaster study	· **Basic knowledge of tsunamis** · **Evacuation tips** The following information could be included in the map. ・Characteristics of historical tsunamis and their induced disasters · Others
Other disaster managements	· **Telephone number of authorities related to disaster management** The following information could be included in the map. ・Protection line · Land use · Disaster prevention centers · Emergency transportation routes · Police, fire department, hospital and other authorities related to disaster control · Life lines such as power, gas and water supply facilities, and sewerage facilities · Coast protection facilities such as breakwater, tide wall, and water gate) · Others

CHAPTER 4 Applications of tsunami disaster management map

4.1 Dissemination of tsunami disaster management map

To utilize tsunami disaster management maps for residents effectively, it is important that residents be thoroughly informed of the maps. Tsunami disaster management maps can be provided to residents by distributing printed materials, setting up bulletin boards, using the Internet, etc. Disseminating methods should also be devised for disaster-vulnerable people, such as the handicapped, elderly, and children as well as for foreigners and tourists.

<Explanation>

(1) Importance of dissemination

Mere distribution of tsunami disaster management maps to residents does not serve their fundamental purposes. It is important for residents to understand the risks of disasters and ways to seek safety such as evacuation procedures. Thus, educating residents about disaster management maps is essential.

(2)Methods to disseminate tsunami disaster management maps

1) Tools for disseminating tsunami disaster management maps

a) Printed Disaster Management Maps:

Distributing a tsunami disaster management map to each household is the most basic way to inform residents. However, careful attention should be paid to the size of the map and the way it is distributed. The best size may be just large enough to post on a refrigerator.

b) Bulletin boards:

Bulletin boards are useful in posting tsunami disaster management maps. It is possible to set up such boards specifically for disaster prevention, or it is also possible to use already existing community bulletin boards. Posting tsunami disaster management maps at bus stops, railway stations, and other public spaces, is also effective in informing tourists and visitors.

c) The Internet:

Due to the recent rapid spread of personal computers for home use, a large number of people are now able to acquire various information through the Internet and CATV on a daily basis. Many municipal governments are opening and operating websites. Posting the map on the website urges administrators to update the map frequently because website audience could easily access the map and check whether the map is appropriately updated or not. Thus, distributing tsunami disaster management maps to residents through those media is effective.

Unlike information printed on paper, which requires time and cost for revision and redistribution, information through the Internet and CATV can be updated frequently and delivered immediately. Tsunami disaster management maps and related video contents that meet individual needs can be provided through the interactive communication of the Internet and CATV, which is almost impossible with maps printed on paper. Through the Internet, more detailed information on inundation, such as GIS data, can also be provided. When these latest communication technologies are used, measures should be devised to assist the elderly, who may not be accustomed to such technologies.

2) Considerations for disseminating tsunami disaster management maps

Tsunami disaster management maps must be prepared so as to be easy for the handicapped, elderly, and children to understand and use. Use of the maps by people who cannot read and write should also be considered. Universal design, such as pictograms, should be used for signs on maps, because it ensures easy understanding for all sorts of people.

4.2 Ways to promote understanding of residents

Tsunami disaster management maps should not be unilaterally prepared by governments and distributed to residents, but should be prepared together with residents. Thus, residents' participation should be encouraged in order to reflect local information in tsunami disaster management maps and to promote their understanding of inundation areas, evacuation sites, and use of the maps. A community leader plays an important role in the residents' participation in developing countries. Accordingly, it is effective to ask for the cooperation of an existing community leader so that the map sprouts roots in the community.

Workshops are effective for encouraging residents to participate in preparing tsunami disaster management maps, so that local information can be incorporated into the maps. Providing learning opportunities about disasters are also effective in promoting the residents' understanding of tsunami disaster management maps.

<Explanation>

(1) Residents' participation

Local evacuation plans during tsunamis must be appropriate to the actual conditions of the region, and should be drawn up by collecting opinions of residents who know a great deal about the region. Residents' participation in preparing the maps is also effective in promoting their understanding and use of the maps.

Therefore, encouraging residents to voluntarily participate in map preparation through workshops between residents and administrative bodies is essential for promoting the use of tsunami disaster management maps. Participants should represent various groups, such as communities, chambers of commerce and industry, and youth associations. Since women play an important role in protecting the family, it is recommended to involve female participants to include the viewpoint of women.

Other ways to promote the understanding of residents include:
- Holding local study meetings,
- Preparing interactive electronic Disaster Management Maps and making them available through the Internet, and
- Preparing disaster prevention education tools (videos, etc.).

(2) Workshops

Workshops are effective for encouraging residents to participate in preparing tsunami disaster management maps, so that local information can be incorporated into the maps. Workshops can also help residents understand the significance of the maps, the information included in the maps, and evacuation methods.

1) Holding workshops

Some local information is known only to residents, and disaster management maps unilaterally prepared by governments may miss such important information. To prepare truly effective tsunami disaster management maps requires residents' voluntary participation in local disaster prevention activities. Workshops can be such useful opportunities.

Core members for workshops can be those shown in Table 4.2-1. Experts and public representatives express their opinions regarding what should be included and how they should be displayed on maps from different points of view.

Experts on tsunamis must be present at workshops. Also officials of the national and local governments in charge of disaster prevention and coastal areas should be requested to participate when necessary.

At a workshop, the administrative side should explain the purpose of the workshop, details about tsunami disaster management maps, and ways to distribute and use them. Then, participants express their opinions on the information presented to them. Workshops should be held several times in order to correctly reflect the opinions of residents in maps.

Tours can be made to visit inundation areas and check the necessary time for their evacuation. To prevent participants from gaining fixed ideas, it should be explained that tsunami disaster management maps merely show model cases.

Table 4.2-1 Examples of members of workshop

Class	Member	Viewpoint/Roles
Chair	Expert, local government official, or consultant	Expediting the proceedings, consolidating and summarizing opinions
Core Members	Expert in tsunamis, coastal engineering	From a technical viewpoint
	Representative of a community planning association	Viewpoint from a urban planner
	School teacher	Viewpoint from the safety of students
	Representative of the elderly	Viewpoint from the elderly
	Representative of residents	Viewpoint from local residents
	Representative of local tourism industry	Assisting tourists' evacuation
	Representative of local company employee	Assisting employee evacuation
	Representative of fire fighters	Local disaster prevention
	Representative of voluntary disaster prevention organization	Local disaster prevention
	Representative of welfare organization	Assisting the handicapped and the elderly
Secretariat	Disaster administrators (local government official)	Arranging meeting place, preparing and presentation materials

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Tsunami and Storm Surge Hazard Map Manual", 2004

2) Example of workshop

For a workshop, the appropriate number of participating residents is about 30. Each resident shall be asked to participate in the workshop through the existing voluntary disaster prevention organization. Alternatively, the municipal authority shall directly ask each resident to participate. At the workshop, evacuation plans during tsunamis are usually drawn up for each district in a region - the region should be divided into 4 to 5 districts in advance - and at least several participants should be present from each district. The time and frequency of holding workshops should be determined based on the regional conditions. Photo 4.2 shows scenes of discussing evacuation plans in a workshop.

Photo 4.2 Discussing evacuation plans at a workshop (Susaki City, Kochi Prefecture)
Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Disaster prevention for a tsunami and storm surge -Example of preparation and utilization of tsunami and storm surge hazard map-", 2005

The venue should be large enough to accommodate all participants, and an overhead or liquid-crystal projector, a white board, large-size paper, and other necessary items should be prepared. Tables that are large enough for spreading maps should be set for each group. Examples of necessary references and tools are shown in Table 4.2-2.

Table 4.2-2 References and tools to be prepared for workshop

	References and tools to be prepared (examples)
Maps	Tsunami hazard maps showing inundation areas (results of simulation analyses and areas inundated in the past)
References for disaster prevention	References of evacuation sites, evacuation sites, and evacuation routes designated by the local government
Other tools	Pencils, pens, oil-based markers, transparent plastic sheets,

During the workshop, the chair should speak clearly and explain in an easy-to-understand manner for the participants. The chair should encourage as many residents as possible to ask questions, so as to make them feel that it is their own issue. People tend to consider a large-scale disaster as unrealistic because they have never experienced it in their life. With this in mind, information to be shown on maps and expression methods used should be selected carefully to inform correctly the participants of inundation areas and evacuation sites.

Displaying inundation prediction results using Web GIS during a workshop is also effective in making matters clear to residents.

(3) Educational opportunities for residents

Providing learning opportunities about disasters are effective in promoting the residents' understanding of tsunami disaster management maps. Such opportunities can be provided in voluntary disaster prevention organizations and at school. Information technology (IT) can be used to enhance residents' understanding. Training residents to become tsunami advisors is also effective.

1) Holding follow-up workshops

Holding follow-up workshops is effective in promoting the residents' understanding of the tsunami disaster management map. The follow-up workshops should not be considered as a one-time event. Holding follow-up workshops several times a year contributes to enhancing residents' awareness of disaster prevention against tsunamis and establishing the importance of the map within the community.

2) Learning in voluntary disaster prevention organizations

It is effective in promoting the residents' understanding to use a tsunami disaster management map as a tool for learning disasters within a voluntary disaster prevention organization established in each district.

It will be very effective to recognize the risk in each district and to review each evacuation route at meetings of a voluntary disaster prevention organization, which knows the district very well. The members can prepare more precise tsunami disaster management maps for the district by investigating details that could not be discussed at workshops.

3) Learning at school

Tsunami disaster management maps can be used in learning disaster-related issues at school. By teaching children about tsunami disasters management maps from elementary school, a system can be developed to continuously educate people about disasters and related issues from childhood. Educational opportunities at school like this may provide a chance for family members to talk about disaster prevention.

Considering teaching materials for elementary schools, the content should be described and displayed in a way that can be easily understood by children.

The training seminar for teachers is also recommended to enhance teaching skills.

4) Use of information technology (IT)

To encourage residents to understand and use tsunami disaster management maps,

measures should be taken to make people feel that tsunamis are their own concern. However, tsunami disaster management maps showing an entire city on one or several sheets of paper may not be convincing enough to enhance their concern to that level.

Information technology (IT) can be helpful in presenting information that is tailored to personal needs. For example, an interactive tsunami disaster management map system can be constructed in which a user can see his or her risk, appropriate evacuation sites and routes, and video clips, just by clicking on his or her house.

5) Training programs

Since damage by tsunamis varies depending on conditions of each region, experts can be trained as long-term advisors on tsunami disaster prevention. Tsunami disaster management maps will be useful tools for the advisors to teach children about tsunamis, and to supervise school teachers in giving disaster prevention classes. Such activities will be effective in increasing public understanding of tsunami hazards.

4.3 Utilization of tsunami disaster management map in taking measures against tsunamis

Tsunami disaster management maps for residents can enhance the self defense ability of residents and their smooth evacuation. Tsunami disaster management maps for administrators can be used to make evacuation plans for residents and to make plans for improving disaster prevention facilities. Tsunami disaster management maps can also be used for risk communication between governments and residents on future disaster prevention measures.

<Explanation>

Tsunami disaster management maps can be utilized for comprehensive disaster prevention measures from structural and non-structural aspects (see Figure 4.3). In the next section (Section 4.4), examples of utilizing tsunami disaster management maps in Japan are introduced.

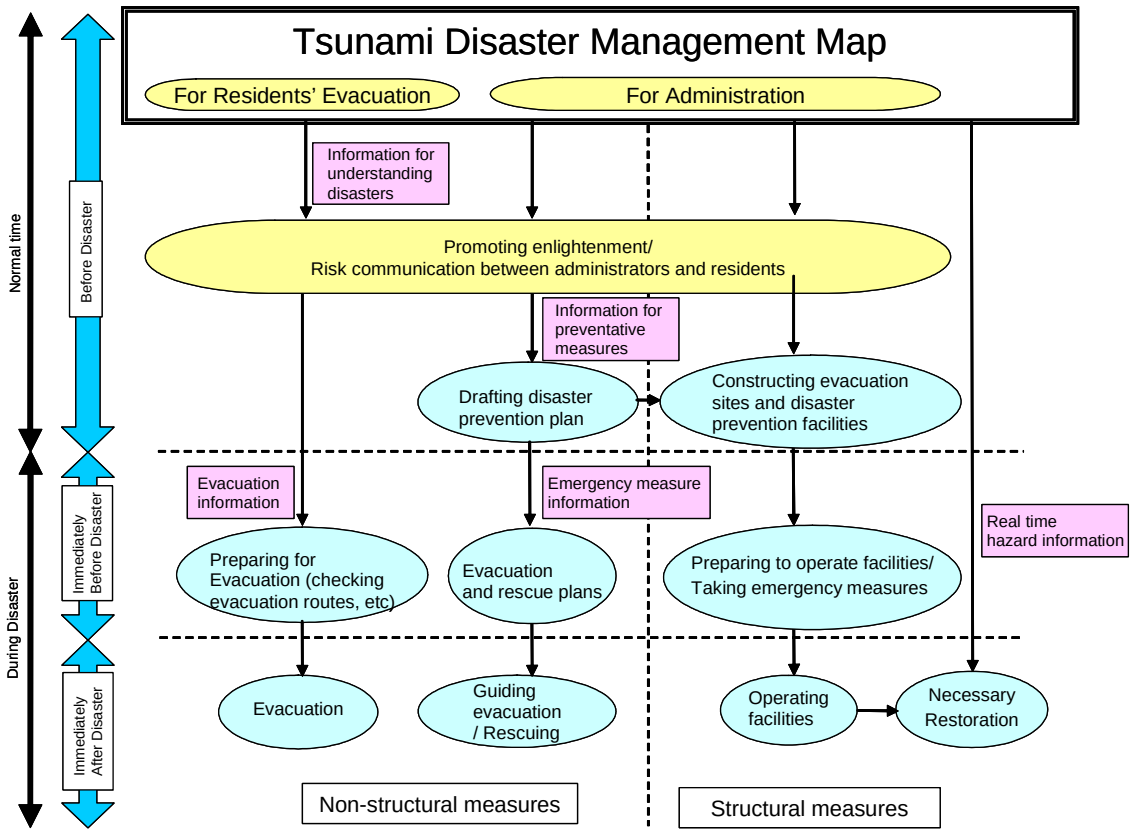


Figure 4.3 Utilization of tsunami disaster management map at each stage of disaster

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Tsunami and Storm Surge Hazard Map Manual", 2004

4.4 Examples of utilizing tsunami disaster management maps in Japan

Tsunami disaster management maps are utilized for enhancing residents' self defense capabilities and drawing up evacuation plans in Japan.

As examples of utilizing tsunami disaster management maps in Japan, workshops, evacuation drills, informative brochure, IT-based tsunami simulation, and tsunami evacuation guidance signboards are introduced in this section.

<Explanation>

(1) Holding workshops

(Susaki City, Kochi Prefecture)

Workshops are not only effective for encouraging residents to participate in preparing tsunami disaster management maps but also enable residents to understand the significance of the maps, the information in the maps and evacuation methods.

Susaki city developed the tsunami disaster management map by holding several workshops with local residents. Susaki city opened the map to the public in April 2004. At the workshop, the organizer of the workshop prepared a large hazard map which presented a predicted inundation area so that residents could discuss the tsunami disaster management in concrete terms. As a result, the residents added evacuation sites and routes to the original large map prepared by the organizer of the workshop. Thus, developing the tsunami disaster management with the participations of residents reflects residents' intentions.

Scenes at a workshop in a region are shown in Photo 4.4(1)-1, 4.4(1)-2 and 4.4(1)-3. Photo 4.4(1)-1 shows an expert explaining a draft tsunami disaster management map, Photo 4.4(1)-2 shows residents discussing evacuation sites and routes, and Photo 4.4(1)-3 shows a group of people investigating and confirming evacuation sites and routes on site respectively. In this region, after revising the draft map through workshops held twice, tsunami disaster management maps were distributed to residents and put in the region's official website.

Photo 4.4(1)-1 Explanation by an expert

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Tsunami and Storm Surge Hazard Map Manual", 2004

Photo 4.4(1)-2 Residents discussing evacuation sites

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Tsunami and Storm Surge Hazard Map Manual", 2004

Photo 4.4(1)-3 Investigating and confirming evacuation sites and routes on site

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Tsunami and Storm Surge Hazard Map Manual", 2004

(2) Evacuation drills conducted on the way back home from school

(Former Taiki Town, Mie Prefecture)

Because one never knows when a tsunami will occur, the evacuation action differs according to the conditions at the time of occurrence of a tsunami. It is important to implement evacuation drills according to various conceivable situations, like those conducted by elementary and junior high school students on the way back home from school in the area that was formerly Taiki Town in Mie Prefecture.

In the latter area, a disaster prevention committee consisting of representatives from various organizations in the town was established in 1995, which discussed the nature of the measures the town should implement for disaster prevention. During this discussion, a specific problem was pointed out, namely that the evacuation drills conducted at elementary and junior high schools were based on the assumption that an earthquake would occur when students would be in school, even though one never knew when a tsunami would occur. Therefore, it was decided to implement an evacuation drill on the way back home from school for elementary and junior high school students.

The sounding of a siren was scheduled during the journey home from school, which would summon students to evacuate to the nearest shelters indicated on hazard maps. In 2004, an evacuation drill was conducted on the 28th of October, in which a total of 138 students from two elementary schools and junior high schools respectively participated.

Photo 4.4(2) Evacuation drills conducted on the way back home from school

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Disaster prevention for a tsunami and storm surge -Example of preparation and utilization of tsunami and storm surge hazard map-", 2005

(3) Informative brochure

(Susaki City, Kochi Prefecture)

It is important for children who will take charge of disaster prevention in future to be continuously informed of new developments to enhance the disaster prevention ability of communities. In addition, knowledge concerning disaster prevention is expected to be disseminated among families through children. It is thought that the preparation and use of disaster-related teaching materials, in conjunction with integrated learning, like "Our Town and the Nankai Earthquake and Tsunami - Let's Learn about Tsunami, and Protect against Tsunami" prepared by the Susaki City Government in Kochi Prefecture, will be an effective means of promoting understanding among residents.

Susaki city in Kochi Prefecture was frequently affected by damage caused by tsunamis in the past. In response, it established the "Susaki City Review Committee on Measures against Tsunami" (Chairperson: Mr. Tomotsuka Takayama, Professor, Disaster Prevention Research Institute, Kyoto University), and conducted a study on municipal measures against tsunamis. Consequently, the importance of software-related measures combined with hardware-related measures was pointed out, as well as that of preparing and distributing tsunami disaster management maps, and enhancing residents' awareness of disaster prevention against tsunamis, as a key measure in providing information for prompt, safe and secure evacuation. Therefore, in Susaki City, the "Review Conference on the Informative Brochure on Tsunami" (Chairperson: Mr. Kunio Otoshi, Professor of Agriculture, Kochi University), which consists of persons involved in education (the Municipal Educational Research Institute, elementary and junior high school teachers, and PTA representatives), and tsunami specialists (persons having actually experienced a tsunami, and the Kochi Port and Airport Office, Shikoku Regional Development Bureau and the Ministry of Land, Infrastructure and Transport), conducted a study, prepared 1,000 copies of the informative brochure on tsunami for senior children at elementary schools, and distributed and utilized the same among elementary schools in the city.

Table 4.4(3)-1 Features of the brochure on tsunami "Our Town and the Nankai Earthquake and Tsunami"

・The brochure was targeted at elementary school students. ・Elementary and junior high school teachers are also members of a review committee (on children's tendency, the awareness of scenes for application, the use of an agate type for Chinese characters, etc.). ・The brochure was laid out using cartoon characters to explain the mechanisms of an earthquake and tsunami, as well as the presumed damage, and response to an earthquake and tsunami, so the brochure would become applicable for children (cartoon characters designed by Mr. Takashi Yanase were used (and provided by the Kochi Prefectural Government)). ・Consideration was given to the fact that the brochure would be used during a period of integrated learning. The brochure layout included a number of sections for children to investigate the history of local disasters by themselves. ・Memoranda and photos of disasters having previously occurred in Susaki City were placed so that readers could get an imminent feeling of disaster. ・Memoranda and photos of the Great Hanshin Awaji Earthquake were also included in order to emphasize the importance of mutual cooperation after the occurrence of a disaster. ・Consideration was given for the dissemination of knowledge on damage caused by tsunamis among families to whom the brochure would be introduced after it was taken home by children.

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Disaster prevention for a tsunami and storm surge -Example of preparation and utilization of tsunami and storm surge hazard map-", 2005

Table 4.4(3)-2 Contents of the brochure on tsunami, "Our Town and the Nankai Earthquake and Tsunami"

Contents		Objective of description
What is the Nankai Earthquake?	Nankai Earthquake	•To enhance understanding of why a tsunami occurs •To enhance understanding that the probability of occurrence of a tsunami is high
	The probability of the occurrence of the Nankai Earthquake over the next 30 years is 40%.	
	Mechanism of occurrence of the Nankai Earthquake	
Why does a tsunami occur?	What is a tsunami?	
	Mechanism of occurrence of a tsunami	
	A tsunami travels very fast.	
What happens if a tsunami occurs?	Damage previously caused by tsunamis	•To enhance understanding as to the nature of damage a tsunami would cause •To enhance understanding about damage caused by tsunamis in our town in the past, and expected damage in the event of the Nankai Earthquake in future
	Anticipated damage from a tsunami if the next Nankai Earthquake occurs	
What should we do to protect ourselves against tsunamis?	Efforts to protect us from tsunamis	•To enhance understanding as a means of protecting ourselves in the event of a tsunami •To enhance understanding about damage caused by tsunamis in our town in the past, and expected damage in the event of the Nankai Earthquake in future
	Evacuate immediately after the occurrence of an earthquake!	
What should we do if an earthquake occurs?	Action to be taken in an emergency	
	How to spend time in a shelter	
	In preparation for an earthquake and tsunami	
	Let's help each other when we have difficulties.	

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Disaster prevention for a tsunami and storm surge -Example of preparation and utilization of tsunami and storm surge hazard map-", 2005

Figure 4.4(3)-1 Front and rear covers

Source: Susaki City, Kochi Prefecture, "Our Town and the Nankai Earthquake and Tsunamis - Let's Learn about Tsunamis, and Protect against Tsunamis -"

Figure 4.4(3)-2 Description of the mechanism of occurrence of a tsunami

Source: Susaki City, Kochi Prefecture, "Our Town and the Nankai Earthquake and Tsunamis - Let's Learn about Tsunamis, and Protect against Tsunamis -"

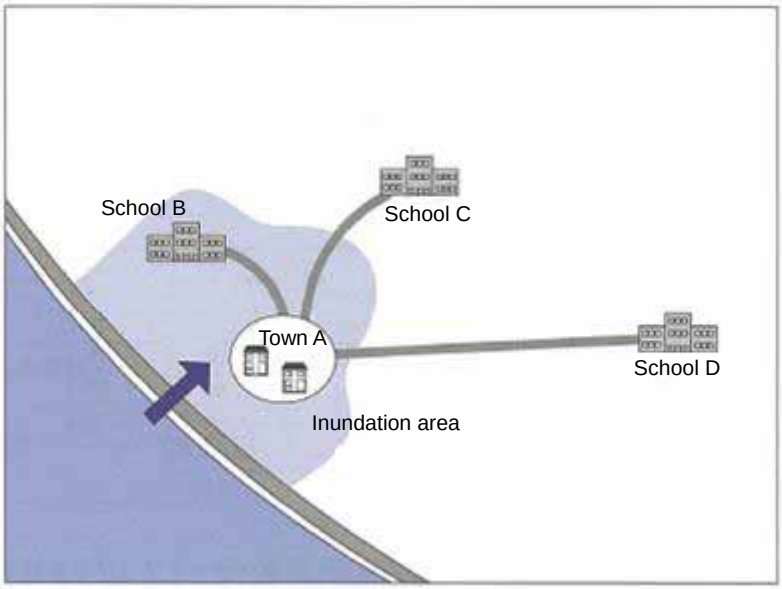
Figure 4.4(3)-3 Section for children to investigate the history of disasters in communities by themselves

Source: Susaki City, Kochi Prefecture, “Our Town and the Nankai Earthquake and Tsunamis - Let’s Learn about Tsunamis, and Protect against Tsunamis -”

(4) Drawing up evacuation plans

Information shown on tsunami disaster management maps, such as inundation sites, inundation depths, could be used to investigate evacuation routes and evacuation sites. In drawing up evacuation plans, the planner should consider the damage of the earthquake. For example, the planner should not select evacuation routes along which there are buildings in danger of collapsing. Simplified examples are shown below.

<Example: Selecting evacuation site from Town A>



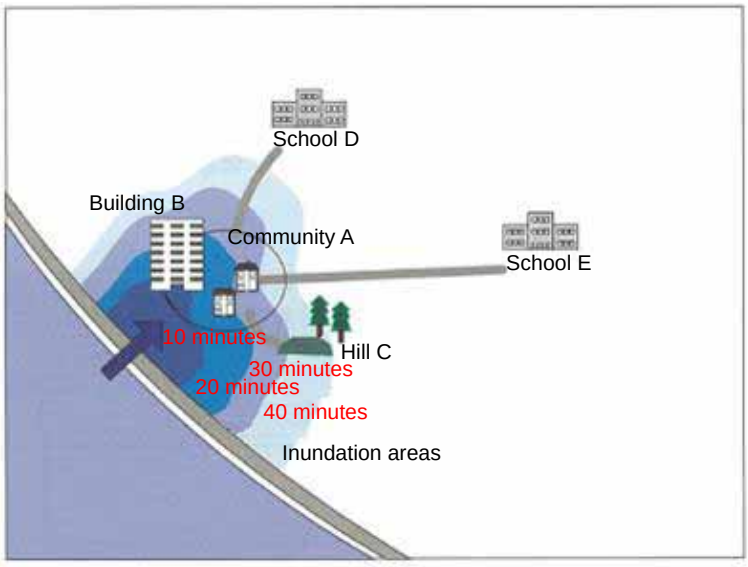
Candidate	Outside inundation area?	Distance	Judgment
School B	No. Inside the area	Near	N.G.
School C	Yes. Outside the area	Near	Priority evacuation site
School D	Yes. Outside the area	Far	N.G.

→ School C is chosen as the evacuation site

Figure 4.4(4)-1 Utilizing Disaster Management Map for selecting evacuation site

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Tsunami and Storm Surge Hazard Map Manual", 2004

<Example: Selecting evacuation site depending on time allowance>



Time allowance	Candidate	Outside inundation area?	Distance
Almost no time	Building B	No. Inside the area	Very near
Not much time	Hill C	No. Inside the area	Near
Sufficient time	School D	Yes. Outside the area	Rather far
Sufficient time	School E	Yes. Outside the area	Far

→ When there is little time to evacuate, Building B and Hill C should be selected as the evacuation site

Figure 4.4(4)-2 Utilizing Disaster Management Map for selecting evacuation site depending on time allowance

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Tsunami and Storm Surge Hazard Map Manual", 2004

Photo 4.4(4)- 1 Evacuation tower in the Shima City, Mie Prefecture

Photo 4.4(4)-2 Evacuation tower in the Taiki Town, Mie Prefecture

(5) IT-based tsunami disaster simulation

(The Port and Airport Research Institute, Japan and National Institute for Land and Infrastructure Management of MLIT, Japan)

An information technology (IT) based tsunami simulation can produce detailed images of tsunami disasters. Good visualization of numerical simulation results provides good images of tsunami. In particular, visual technology (such as movies) can be used to demonstrate the dynamic features of tsunami: tsunami destruction, interaction of tsunami with buildings and structures and others. The simulation results in an area where viewers live, moreover, promote understanding of what can happen in areas hit by tsunamis, leading to the establishment of suitable structural and non-structural measures. Investigation of successful evacuation is also conducted on the IT-based simulation. Figure 4.4(5)-1 is an example of an IT-based tsunami simulation to indicate tsunami features, and shows snapshots from a movie showing tsunami inundation in a coastal city. The tsunami flows on roads and a river because buildings and structures are considered in the simulation as obstacles to interrupt tsunami propagation. Tsunami fluid velocities on the roads are also estimated in such simulations. Figure 4.4(5)-2 shows snapshots of tsunami disaster simulation results. Red bars in the figures indicate tsunami damage to buildings, and the damage expands with time. The use of a three-dimensional numerical model can provide estimation of tsunami wave pressure and accurate fluid velocity. Figure 4.4(5)-3 shows a numerical simulation of the evacuation process under various conditions.

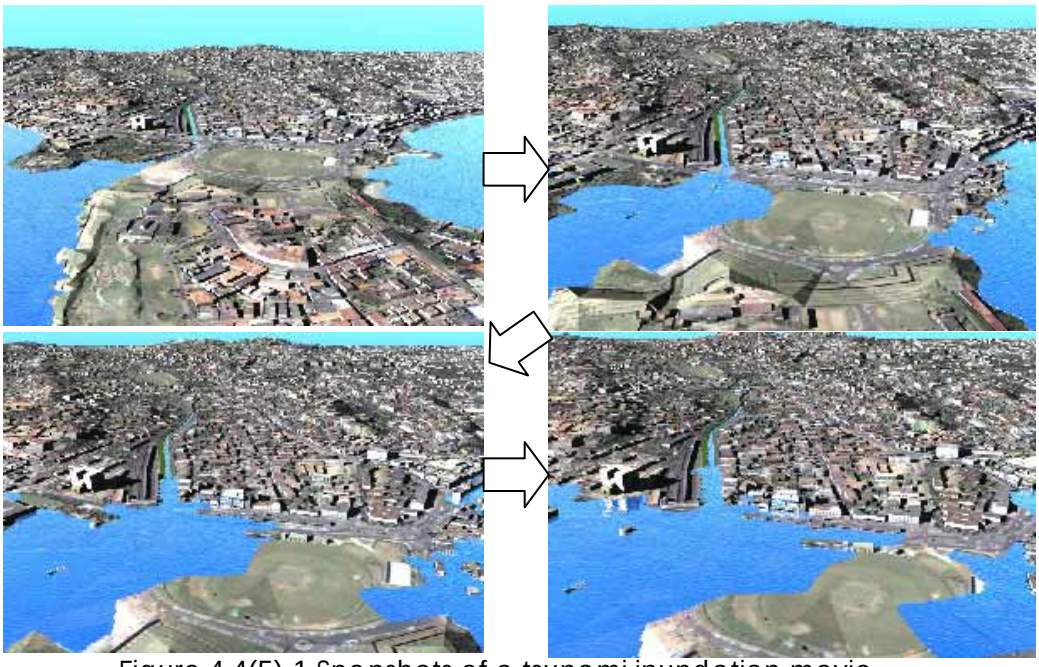


Figure 4.4(5)-1 Snapshots of a tsunami inundation movie

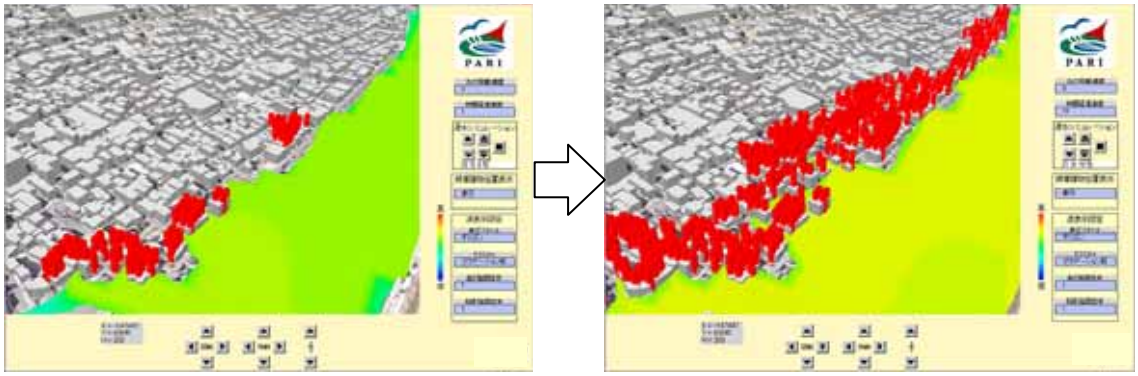


Figure 4.4(5)-2 Snapshots of tsunami disaster simulation of Dynamic Hazard Map

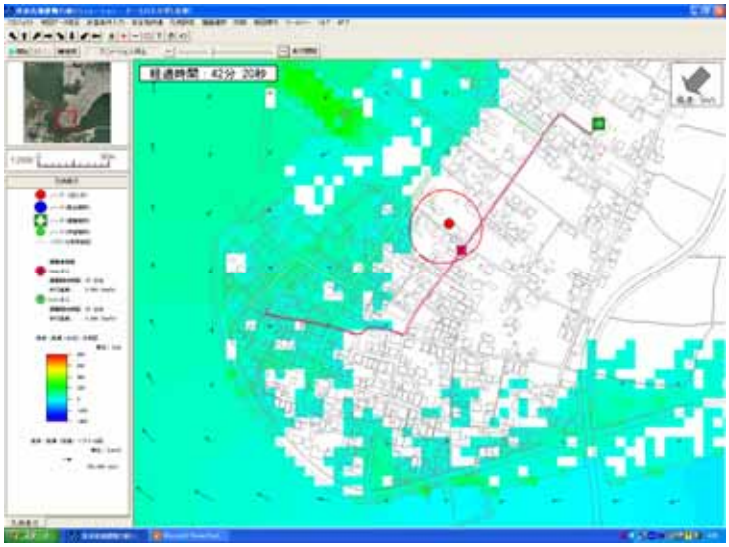


Figure 4.4(5)-3 Snapshot of evacuation simulation of Interactive Evacuation Simulator

(6) Investigating evacuation and rescue methods (during disasters)

During disasters, appropriate evacuation of residents (by specifying evacuation routes and evacuation sites) can be supported by judging the scale of the disaster, comparing the scale with those shown in tsunami disaster management maps, and revising the preliminary disaster prevention plans. Special care must be taken when the actual external force is different from those used to prepare the maps.

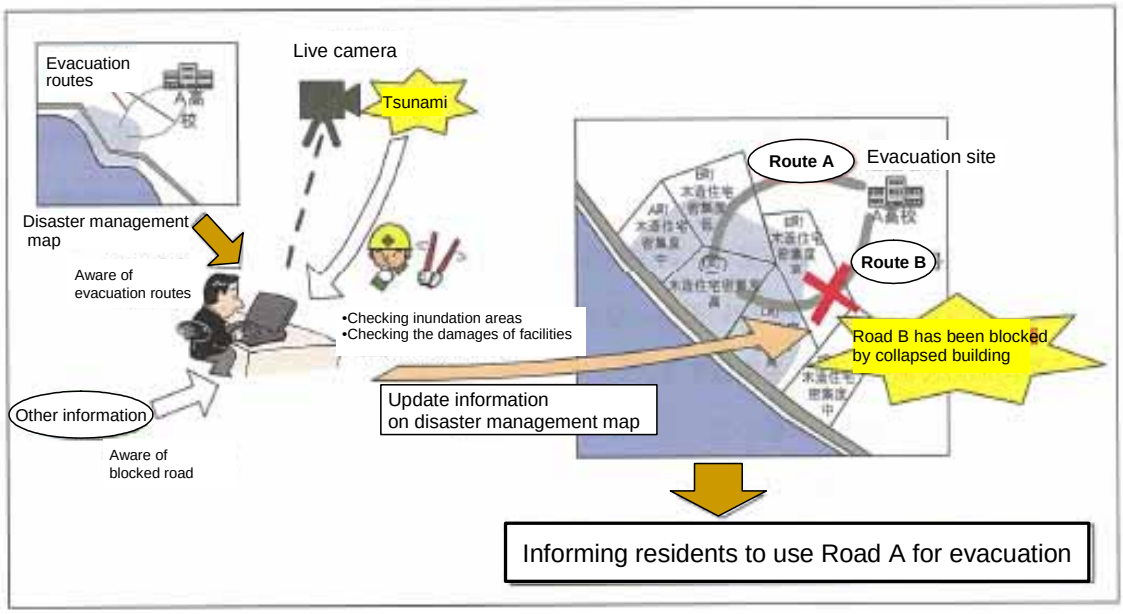


Figure 4.4(6) Utilization of disaster management map for evacuation directives

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Tsunami and Storm Surge Hazard Map Manual", 2004

(7) Tsunami warning and evacuation guidance signboards

(Yuki town, Tokushima Prefecture)

Installing tsunami warning signboards is effective for people to understand tsunami risks. And installing evacuation guidance signboards is useful for people to evacuate when a tsunami attacks. These signboards should be installed in coordination with tsunami disaster management maps, and their design should be standardized in a region.

Table 4.4(7)-1 Signboards for each purpose

Purpose	Function	Design
Signboard to show tsunami risks	Warning of tsunamis	
Signboard to show evacuation sites	Evacuation guidance (Information on evacuation sites)	

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Disaster prevention for a tsunami and storm surge -Example of preparation and utilization of tsunami and storm surge hazard map-", 2005

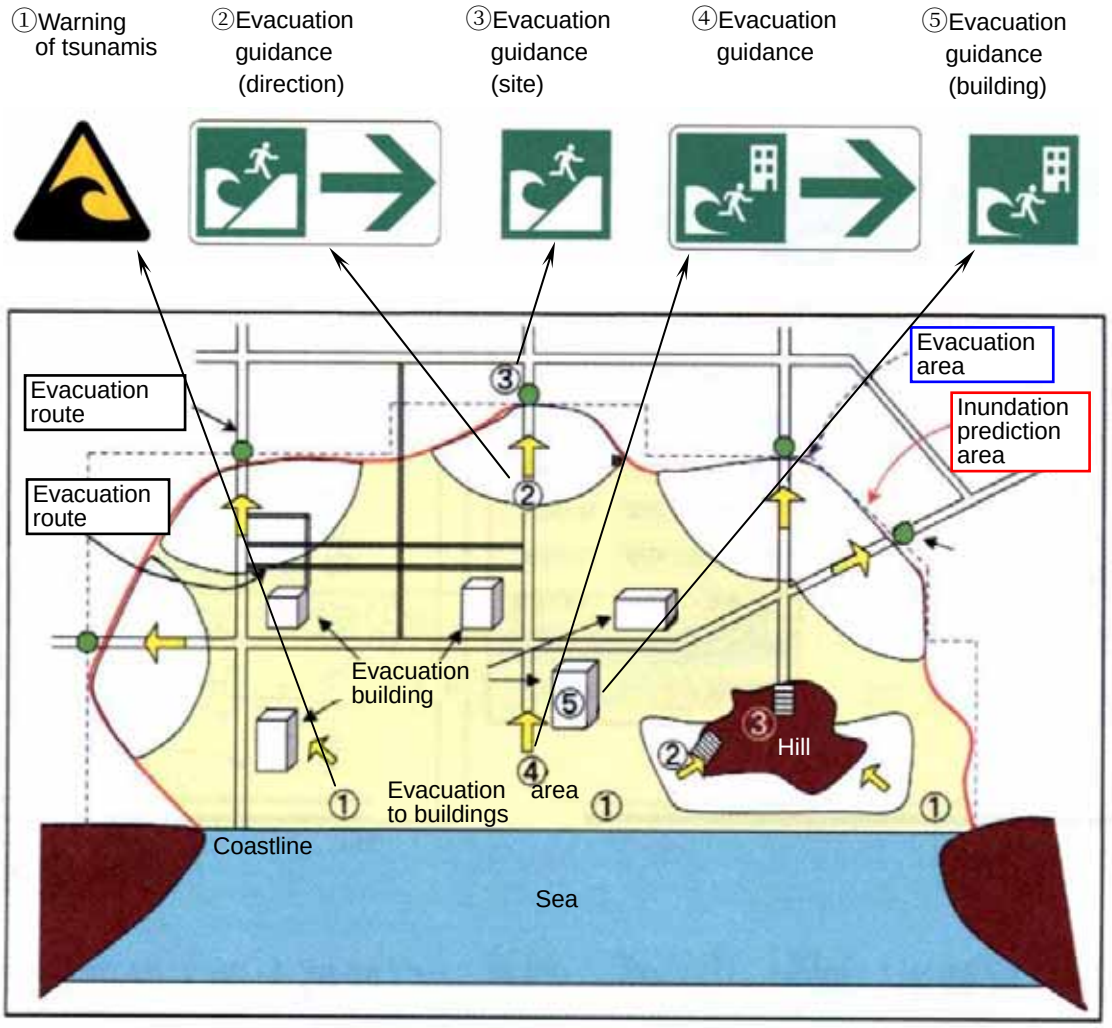


Figure 4.4(7)-1 Installation locations of signboards

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Disaster prevention for a tsunami and storm surge -Example of preparation and utilization of tsunami and storm surge hazard map-", 2005

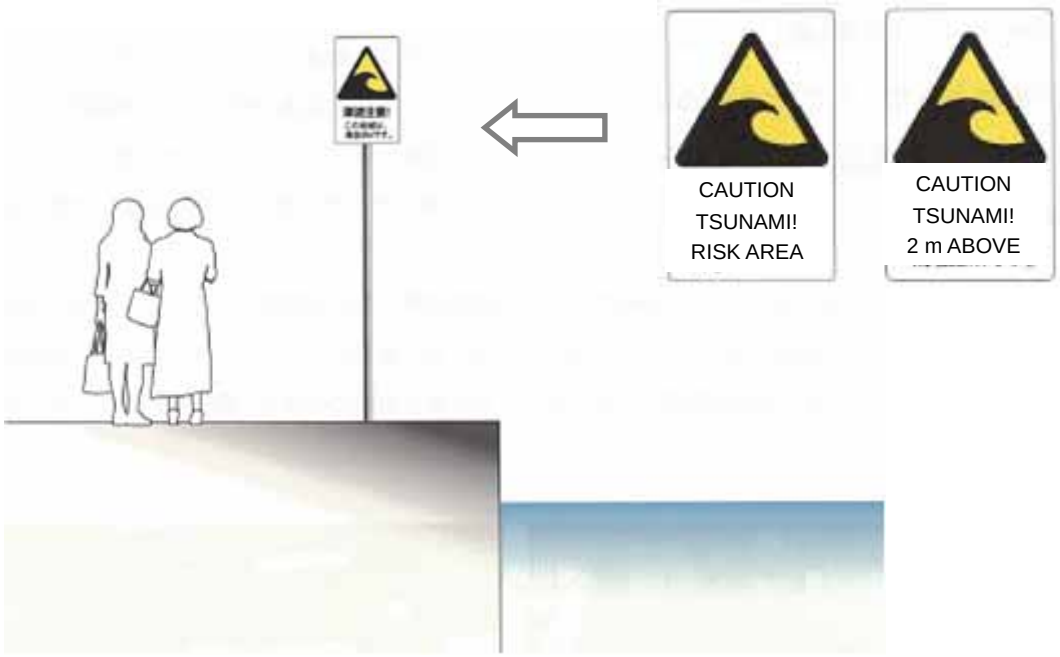


Figure 4.4(7)-2 Example of a signboard for tsunami warning

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Disaster prevention for a tsunami and storm surge -Example of preparation and utilization of tsunami and storm surge hazard map-", 2005

Marking past tsunami height with tape is also effective for residents to understand tsunami risks visually (Photo 4.4(7)).

Photo 4.4(7) Marking historical tsunami height with tape

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Disaster prevention for a tsunami and storm surge -Example of preparation and utilization of tsunami and storm surge hazard map-", 2005

(8) Tsunami study meeting in conjunction with other events

(Yuki town, Tokushima Prefecture)

It is effective to hold a tsunami study meeting in conjunction with other events. Yuki town held tsunami study meeting in conjunction with a fitness seminar. The effort of Yuki town is an effective way to diffuse knowledge of tsunami disaster.

Since many residents in Yuki town tripped and fell when they participated in evacuation drill, one community group organized an event consisting of a tsunami study meeting and a fitness seminar in January 2005. The event started with the screening of a video of Asian tsunami. The participants recognized the horror of tsunami and recognized the need to be prepared for such disasters. Then, participants did a series of exercises.

Photo 4.4(8) tsunami disaster study meeting and fitness seminar

Source: Cabinet Office, Ministry of Agriculture, Forestry and Fisheries and MLIT, Japan, "Disaster prevention for a tsunami and storm surge -Example of preparation and utilization of tsunami and storm surge hazard map-", 2005

Appendix-1. Examples of Tsunami Disaster Management Map

- Hawaii Hazard
  http://www5.hawaii.gov/tsunami/

- USA (San Francisco and San Mateo counties)
  http://www.abag.ca.gov/bayarea/eqmaps/tsunami/

- USA(Crescent City Region)
  http://www.humboldt.edu/~geology/earthquakes/rctwg/toc.html

- USA(Oregon)
  http://www.coastalatlas.net/learn/topics/hazards/tsunami/index.asp

✧ Tsunami Information

✓ Pacific Tsunami Warning Center, National Oceanic and Atmospheric Administration(NOAA)
http://www.prh.noaa.gov/ptwc/

✓ West and Alaska Tsunami Warning Center, National Oceanic and Atmospheric Administration(NOAA)
http://wcatwc.arh.noaa.gov/

Appendix-2. Characteristics of Tsunami

A tsunami is a series of ocean waves generated by sea surface displacement which is produced by an earthquake, volcanic eruption, landside and others except for meteorological triggers. The tsunami can travel over the ocean easily and strike coastal areas. When the tsunami hit coastal areas, the height of tsunami is sometimes a few meters or more. Characteristics of tsunami depend highly on bathymetry and topography.

(1) Generation of tsunami

A tsunami is a series of ocean waves generated by sea surface displacement which is mainly produced by earthquake-induced sea floor displacement. Other triggers of the tsunami-generated sea surface displacement are a volcanic eruption, massive sediment inflow induced by a landside, falling of a meteor and other impacts except for meteorological triggers.

When an earthquake occurs under the sea or in a coastal area, parts of the sea floor are raised and subsided in a wide area depending on the fault mechanism of the earthquake (See Figure A2.1 which indicates tsunami generation caused by deformation of sea floor). The deformation creates a similar displacement on the sea surface above the sea floor, since the sea water depth, for example the mean water depth is 4,000 m in the Pacific Ocean, is much less than a horizontal scale of the displaced area which could reach some hundred kilometers, and the displacement is in an extremely-wide area of thousands square kilometers or more, resulting in less horizontal movement of sea above the displaced sea floor*). The sea surface displacement is an initial form of tsunami. The height of the displacement is, in general, a few meters or less in the initial form.

*) The propagation speed of tsunami is approximately 0.2 km/s in an ocean of 4000 through 5000 m deep, and the propagation speed of sea bottom deformation is a few km/s depending on the earthquake's rupture speed of 2 to 3 km/s. Less sea water volume can, therefore, move horizontally resulting in the sudden displacement of sea surface generated.

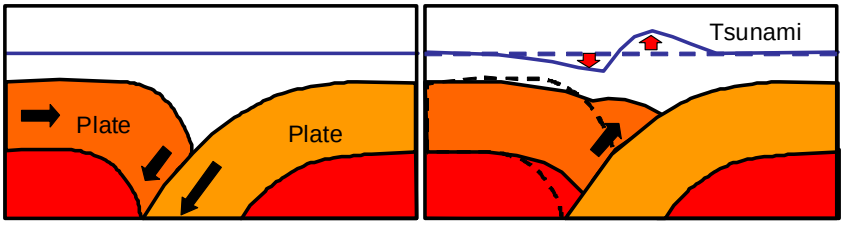


Figure A2.1 Tsunami generation mechanism

(2) Propagation of tsunami

The tsunami can travel over the ocean easily, since the energy of tsunami is diminished less through propagation like wind waves. Depending on the initial form of tsunami, the wave-length of tsunami is extremely longer than sea waves induced by winds, which is several tens of kilometers and more in general. The resultant wave frequency of such a lob wave becomes low. Since fluctuations with lower frequency are less diminished, the tsunami can propagate over a long distance easily. For example, the 1960 Chilean Tsunami was generated near the Chilean coast in the South America, and traveled over the Pacific Ocean resulting in hits on the Hawaiian and Japanese coasts. The 2004 Indian Ocean Tsunami generated by the earthquake off Sumatra Island could travel to the east coast of the Africa Continent.

The propagation speed of tsunami depends on the water depth, and is calculated by the following equation:

$$c = \sqrt{gd} \qquad (1)$$

in which

c (m/s): Propagation speed of tsunami

d (m): Water depth

g (m/s^2) Gravitational acceleration (=9.8m/s^2)

The tsunami comes earlier in the area which has wide-spreading deeper sea in its front.

In shallow areas with a comparable water depth to the tsunami height, the propagation speed is affected by the tsunami height, and calculated by the following equation:

$$c = \sqrt{g(d+\eta)} \qquad (2)$$

in which

c (m/s): Propagation speed of tsunami

d (m): Water depth

η (m): Water surface elevation by the tsunami

g (m/s^2): Gravitational acceleration (=9.8m/s^2).

(3) Distant tsunami and local tsunami

The tsunami can strike coasts which are fairly far from the area where the tsunami is generated, since the tsunami can travel long distances. Such a tsunami is called “Distant Tsunami” or “Teletsunami.” On the other hand, the tsunami that is generated near a coast hits the coast soon after the earthquake triggering the tsunami. Such a tsunami is called “Local Tsunami.”

In mitigation of tsunami disasters, there are some things to be considered against the distant tsunami and local tsunami, respectively. For instance, an international early warning system is important for the distant tsunami, because the earthquake motion far away from the epicenter cannot be detected by people even though a tsunami may be headed in their direction. For the local tsunami, a national early warning system is important, because the tsunami hits the nearby coasts quickly after the earthquake, and "evacuation to high places as quickly as possible after the tremors stop is essential." Tsunami reduction measures could be also effective in reducing the needed time for evacuation.

(4) Flooding tsunami or receding tsunami

The tsunami does not always start as a receding wave. According to location and tsunami generation condition, a flooding tsunami can come first at some areas. In Figure A2.1, the retreated tsunami comes first in the left-hand side of the figure, and the flooding tsunami goes to the right-hand side. In fact, the first wave of the 2004 Indian Ocean Tsunami struck the coasts of Thailand and Indonesia as a receding wave, and hit the coasts of India and Sri Lanka as a flooding wave. The tsunami, therefore, propagated to the east side as the flooding wave and to the west side as the receding wave.

(5) Numbers of tsunami striking

The number of tsunami striking a coast is generally not limited to one. The tsunami strikes as a series of waves, since tsunami are diffracted by islands or others and reflected by other shores. The first tsunami waves are sometimes the largest in the series, but not always; the second, third, or latter waves are sometimes the largest, depending on the location and horizontal scale of initial tsunami form.

(6) Enlargement of tsunami

Tsunami height is a few meters or less in offshore areas whereas the wavelength exceeds several tens of kilometers. The tsunami is, therefore, inconspicuous to a ship on the deep sea. The tsunami, however, enlarges its height and shortens its wave-length as it approaches to shallow water. The tsunami height, which is vertical length from the tsunami wave crest to the sea surface before the tsunami arrival, can reach 10 m or more depending on local bathymetry and topography.

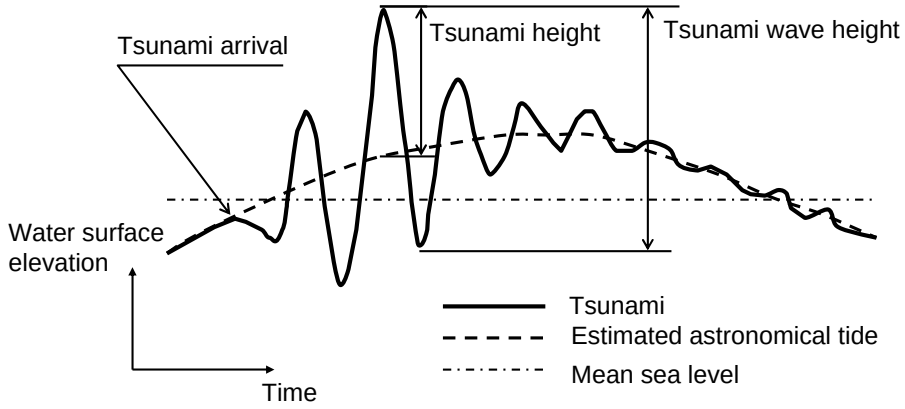


Figure A2.2 Tsunami height and tsunami wave height

Changing tsunami wave height, which is different from the tsunami height and is a wave height that is vertical length from a wave crest to trough, is roughly estimated by the following Green's Law which is derived from conservation of tsunami energy:

$$H_2 = H_1\left(\frac{d_1}{d_2}\right)^{1/4} \quad (3)$$

in which

H_1: Wave height in deep water depth

H_2: Wave height in shallow water depth

d_1: Water depth in the deep water area

d_2: Water depth in the shallow water area

Using the above equation, for instance, the tsunami height in shallow water of 10 m is 1.8 times that in deep water of 100 m.

In a V-shape basin, an incident tsunami is reflected from the shores of both sides of the basin and is concentrated in the innermost section of the basin, resulting in generation of higher tsunami than the incident tsunami.

The tip of a cape is also a dangerous area in which tsunami height is increased, since the tsunami energy is concentrated there due to wave refraction as shown in Fig A2.3. The wave refraction provides the change of tsunami propagation direction in the same way as lights refracted by an optical lens. The direction change results in the reduction of the width between adjacent wave rays, and then the wave height between the adjacent wave rays increased to conserve wave energy between the rays. A similar phenomenon appears around a shoal under the sea.

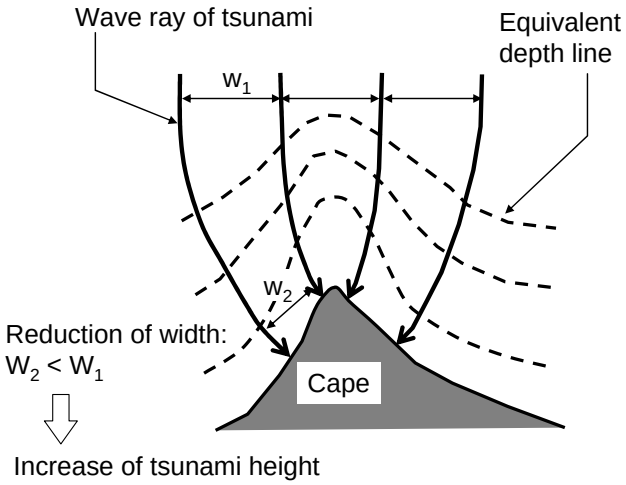


Figure A2.3 Increase of tsunami height around the tip of a cape

(7) Runup of tsunami

The tsunamis do not only inundate low-lying coastal areas but runup hill surface. For instance, the 2004 Indian Ocean Tsunami struck the western coast of the Sumatra Island with a height of approximately 10 m and then climbed hill slopes until reaching the level of 30 m above ground.

River sides are also vulnerable against tsunamis because tsunamis can run up rivers easily. For instance, the tsunami of the 1993 Hokkaido Nansei-Oki Earthquake (Okushiri Tsunami) climbed the Okushiri River in the Okushiri Island, resulting in the inundation of an elementary school beside the river.

(8) Fluid velocity of tsunami flooding on the ground

Fluid velocity of tsunami flooding on the ground depends highly on the topography and arrangement of structures including houses. According to geographical conditions and tsunami conditions, the fluid velocity on the ground could be twice as fast as tsunami propagation speed estimated by Eq. (2).

(9) Disasters due to tsunamis

A tsunami causes the follows various types of damage:

- Inundation **)
- Destruction of houses ***), roads, bridges, port and harbor facilities and other structures (Photo A2.1)
- Driftage of debris, timber, cars (Photo A2.2), containers, vessels +)(Photo A2.3, A2.4), and others++)(Photo A2.5, A2.6)
- Spreading oil and hazardous material leaked from storage tanks and pipes which

are damaged by the earthquake and tsunami, resulting in fires

- Erosion and deposition of coastal areas (Photo A2.7, A2.8)
- Others

Moreover, many human beings are killed or injured. Socio-economy and environment are also affected.

Photo A2.1 City Destruction in Indonesia by the 2004 Indian Ocean Tsunami

Photo A2.2 Destruction of car in Thailand by the 2004 Indian Ocean Tsunami

Photo A2.3 Driftage of fishing boat in Indonesia by the 2004 Indian Ocean Tsunami

Photo A2.4 Driftage of power generation ship Indian in Indonesia by the 2004 Indian Ocean Tsunami

Photo A2.5 Damage to train in Sri Lanka by the 2004 Indian Ocean Tsunami

Photo A2.6 Driftage of empty oil tanks in Indonesia by the 2004 Indian Ocean Tsunami

Photo A2.7 Erosion under a rail way by the 2004 Indian Ocean Tsunami

Photo A2.8 Erosion in Indonesia by the Indian Ocean Tsunami2004

**) In Banda Aceh, the northern city of Sumatra Island, the 2004 Indian Ocean Tsunami inundated the coastal area 4 to 5 km from the coast line; in particular, the low-lying area 2 to 3 km from the coastal line suffered devastating damage as most homes were completely destroyed.

***) Shuto (1993) summarized the degree of tsunami damage by tsunami height from historical tsunami damages in the world as follows: Wooden houses are destroyed by 2 m inundation depth, and partially destroyed by 1m and more inundation depth. For stone-built houses, records show that during the 1960 Chilean Tsunami a stone-built house in Japan survived the tsunami of 2.9 m inundation depth. RC Buildings were destroyed in Hawaii by the 1946 Aleutian Tsunami of 5 m inundation depth.

+) In the 1983 Nihonkai Chubu Earthquake Tsunami (Sea of Japan Tsunami), damage to fishing boats in ports as caused by the tsunami of 1 m in height.

++) The 2004 Indian Ocean Tsunami drifted empty oil storage tanks of 11 m in height and 17 m in diameter in the northern Sumatra Island and swept away train passenger cargoes in Sri Lanka.

(10) Tsunami-prone areas

Tsunami-prone areas in the world are along the most active seismic zone surrounding

the Pacific Ocean as well as the eastern edge of the Indian Ocean. The seismic zone in the Pacific Ocean is called the Circum-Pacific seismic belt and the “Ring of Fire.” Many earthquakes there have generated tsunamis.

Tsunami vulnerable areas are locally low-lying coastal areas and river side areas near the mouth. Even in areas where tsunamis will strike, however, areas with high altitude and areas sufficiently protected by structures are less vulnerable to tsunami disasters because tsunami inundation does not easily occur in such areas.