Tsunami and Storm Surge Hazard Map Manual

March 2004

Cabinet Office (Disaster Management)
Rural Development Bureau of the Ministry of Agriculture, Forestry and Fisheries
Fisheries Agency of the Ministry of Agriculture, Forestry and Fisheries
River Bureau of the Ministry of Land, Infrastructure and Transport
Ports and Harbours Bureau of the Ministry of Land, Infrastructure and Transport

Foreword

Japan lies on the boundary of tectonic plates, and is prone to tsunamis during earthquakes that occur in submarine trenches. These have caused serious damage. Tsunamis are predicted to occur during earthquakes along the Japan Trench and Kuril Trench and during Tokai, Tonankai, and Nankai earthquakes. The country is also in the path of typhoons, and has frequently suffered storm surge damage. Rises in sea level due to climatic changes and increases in the scale of typhoons will probably increase storm surges. Thus, measures against tsunamis and storm surges must quickly be taken in Japan.

Advanced case studies have shown that hazard maps are an effective evacuation measure, and various attempts have been made to prepare hazard maps for tsunamis and storm surges. However, preparation of hazard maps that cover the entire country is at a standstill. This is probably because:

1) The staff of municipal governments in charge of disaster prevention and preparing hazard maps have no clear concept of tsunami and storm surge hazard maps,

2) The staff has no understanding of for whom tsunami and storm surge hazard maps are to be prepared, nor how to use such maps, and

3) Preparation of tsunami and storm surge hazard maps is technically difficult and expensive.

This manual aims to promote preparation of tsunami and storm surge hazard maps that cover the whole of Japan, and to assist the people in charge of preparation by providing information on 1) basic concepts of tsunami and storm surge hazard maps, such as the purposes of preparation, role allotment (support from national and prefectural governments), and utilization policies, and 2) standard methods for preparing tsunami and storm surge hazard maps, such as methods for identifying inundation risk areas, determining details to be stated on the maps, expressing those details, and utilizing the maps.

The manual assists in preparing and utilizing tsunami and storm surge hazard maps and shows essential points of technological systems and utilization methods. The methods described in this manual are merely a summary at today’s technical levels, and need to be revised along with technological development. New technologies, which are being constantly developed, should be actively incorporated according to the purposes of this manual.

Finally, we would like to thank the chair (Prof. Yoshiaki Kawata of Kyoto University) and members of the Study Committee on Tsunami and Storm Surge Hazard Maps, which was established in November 2002 and held 5 meetings in total, together with the committee’s administrative staff, for their active discussion and hard work that led to the formation of this manual.

March 2004

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People from administrative organizations (Fire and Disaster Management Agency, Meteorological Agency, Japan Coast Guard, and municipal governments) also participated.

Meetings held on:
November 22, 2002
February 25, 2003
May 1, 2003
June 17, 2003, and
December 16, 2003

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References

Introduction

> Tsunami and storm surge hazard maps show areas on which inundation is anticipated, the degree of inundation and, when necessary, disaster prevention information, such as evacuation sites and routes. Their purpose is to assist administrative bodies in deciding evacuation of residents during tsunamis and storm surges, and in the construction of disaster prevention facilities.
>
> This manual aims to promote the nation-wide preparation of tsunami and storm surge hazard maps. It states basic concepts such as the objectives of preparation, bodies in charge of preparation, roles of national and prefectural governments, and utilization methods, and summarizes the presently available standard information concerning tsunami and storm surge hazard maps, such as methods for predicting inundation, items to be included in hazard maps, expression methods, and methods for utilizing the maps.

(1) Definition of tsunami and storm surge hazard maps

Hazard maps	・In this manual, maps that show predicted inundation risk areas and, when necessary, information related to disaster prevention are called “hazard maps”. ・This manual describes “hazard maps for residents”, which should be used by residents for evacuation, and “hazard maps for administrators”, which should be used by administrative bodies to investigate disaster prevention measures.
Inundation risk area	・In this manual, an area where inundation is predicted when an assumed external force (tsunami and storm surge) occurs is called an “inundation risk area”.
Assumed external force	・In this manual, external forces of the following three levels are considered as assumed external forces. Details of the methods for setting the external force conditions are described in *3.2 (2) Setting external force conditions*. 1) External force level 1: External force that occurs at frequencies that can be sensed 2) External force level 2: Designed external force of a facility, consistent with its protection goal 3) External force level 3: External force that causes the worst degree of inundation

(2) Anticipated readership of the manual

This manual is for bodies in charge of preparing tsunami and storm surge hazard maps and those who support such preparation (See *2.3 Bodies in charge of preparing tsunami and storm surge hazard maps and their roles*, for information about bodies in charge of preparation and supporting bodies).

(3) Scope

This manual describes the preparation and utilization of tsunami and storm surge hazard maps. It should be used in conjunction with existing plans and manuals, such as regional disaster prevention plans and the Manual for Developing Measures Against Tsunamis.

This manual summarizes the presently available knowledge and should be appropriately revised in accordance with future technology development.

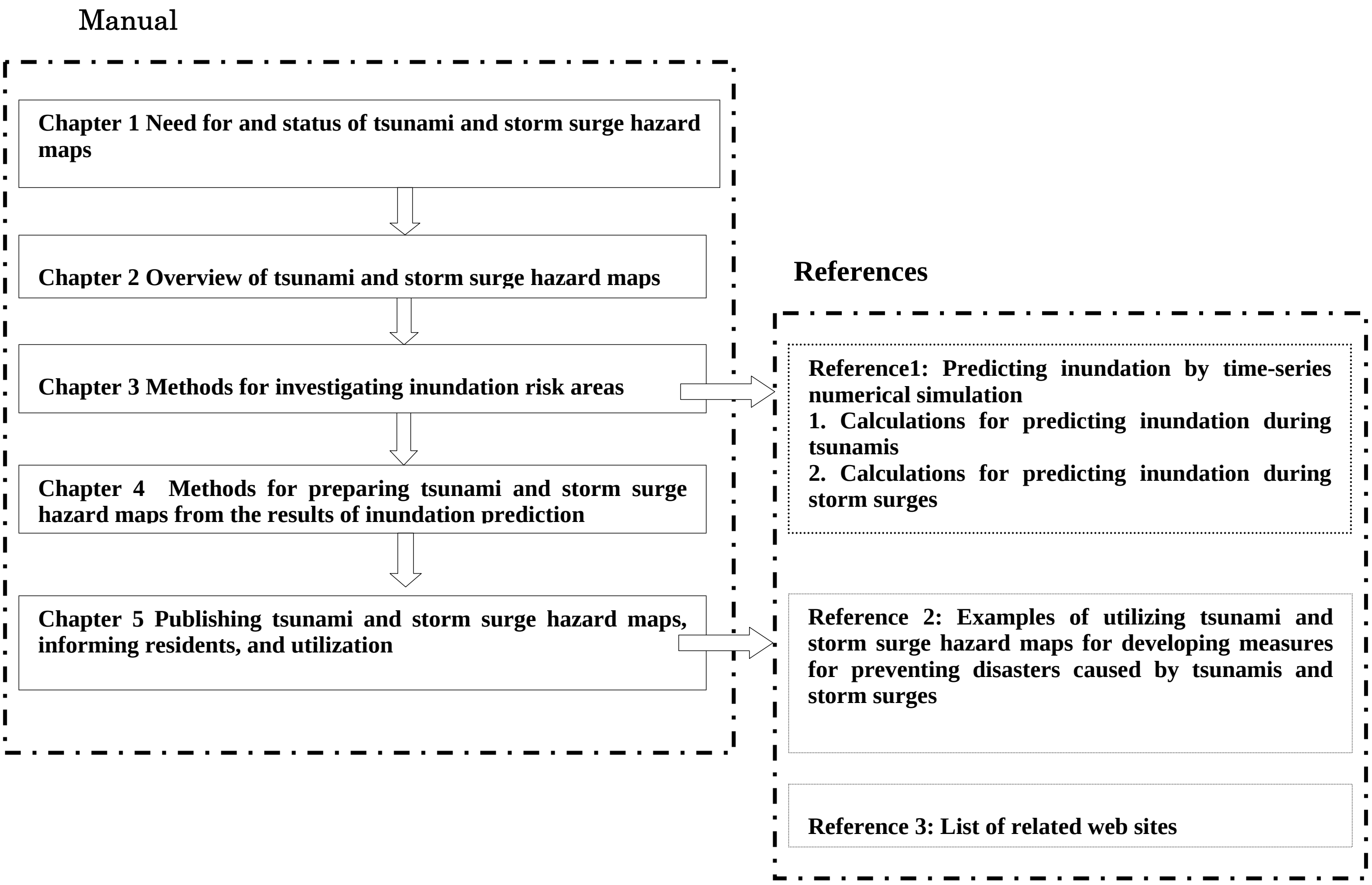
Reference　Existing manuals related to tsunami and storm surge measures

Disaster	Manual (date of issue)	Body in charge
Tsunami	Manual for enhancing measures against tsunamis in regional disaster prevention plans (March 1998)	Investigation Committee on Disaster Prevention Plan Methods against Tsunamis along the Pacific Coast during Earthquakes (National Land Agency, Agricultural Structure Improvement Bureau and Fisheries Agency of the Ministry of Agriculture, Forestry and Fisheries, Ministry of Transport, Meteorology Agency, Ministry of Construction, and Fire and Disaster Management Agency)
	Manual for Predicting Tsunami Disasters (March 1998)	Investigation Committee on the Manual for Predicting Tsunami Disasters (National Land Agency, Fire and Disaster Management Agency, and Meteorological Agency)
	Manual for Developing Measures against Tsunamis (March 2002)	Investigation Committee on the Manual for Promoting Measures against Tsunamis (Fire and Disaster Management Agency)
Storm surge	Manual for Enhancing Measures against Storm Surges in Regional Disaster Prevention Plans (March 2001)	Study Committee on Storm Surge Disaster Prevention Information (Cabinet Office (in charge of disaster prevention), Fire and Disaster Management Agency, Rural Development Bureau and Fisheries Agency of the Ministry of Agriculture, Forestry and Fisheries, River Bureau and Ports and Harbours Bureau of the Ministry of Land, Infrastructure and Transport, Meteorological Agency)

(4) Organization of the manual

This manual consists of the main chapters (1-5) and references. The main chapters summarize the basic concepts of significance and methods for preparing and utilizing tsunami and storm surge hazard maps. The references describe recommended methods for predicting inundation to prepare tsunami and storm surge hazard maps and examples of using such hazard maps.

Since tsunami hazard maps and storm surge hazard maps have much in common, the common information is first described and second the phenomenon and operation methods that differ between tsunamis and storm surges are described separately.



Constitution of the manual

Chapter 1　Need for and roles of tsunami and storm surge hazard maps

1.1 The present state of measures for preventing disasters caused by tsunamis and storm surges

(1) History of measures for preventing disasters caused by tsunamis and storm surges

> Conventional disaster prevention measures, which mainly rely on facility construction, have sharply reduced damage by tsunamis and storm surges. However, the level of coastal safety is still insufficient.

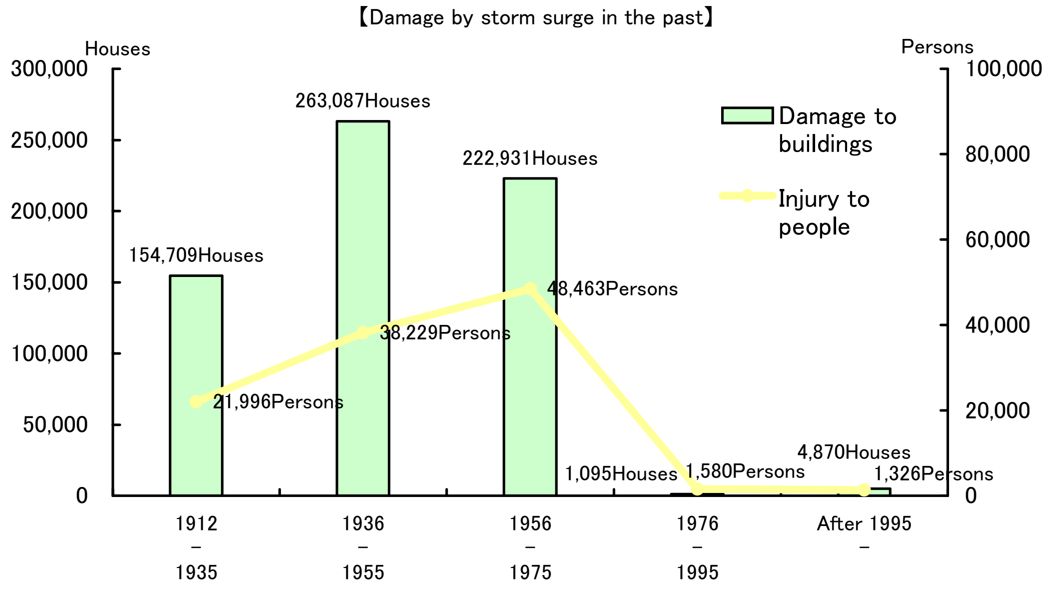
Measures for coastal protection against tsunamis and storm surges have changed as described below. These measures have sharply reduced damage.

(1) After World War II, Japan suffered serious damage from tsunamis and storm surges. Ways to protect coasts at that time mainly consisted of restoration activities.

(2) The Coast Law was enacted in 1956, around which time the construction of structures, such as banks, revetments, groins, and parapets, started to protect coastlines under the concept of "the linear protection method".

(3) After 1975, projects based on the concept of "the area protection method" started, including constructing two or more structures (detached breakwaters, submerged breakwaters, artificial reefs, and sandy beaches) to gradually reduce external forces such as waves.

(4) Subsequently, more advanced structural measures were taken by employing earthquake resistant structures and anti-liquefaction structures. Non-structural measures were also taken by constructing tsunami and storm surge disaster prevention stations.



* Source: Announcement (Dec. 31, 2002) by the Fire and Disaster Management Agency. "Injury to people" denotes the total number of people killed, injured and missing. "Damage to buildings" denotes the total number of buildings destroyed, semi-destroyed, and washed away.

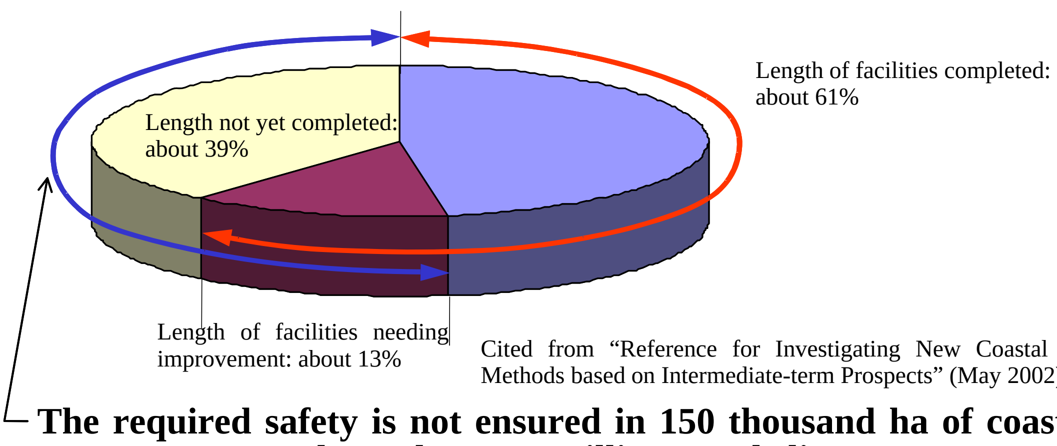
Figure 1.1.1　Reduction of storm-surge damage by disaster prevention measures

However, the present protection levels far from satisfy the indices for protection, information transmission, erosion and earthquake resistance, which are shown in Table 1.1.1.

Table 1.1.1 Present protection levels of coastal protection

Class	Outcome index	Present level
Protection	Population and area of districts where a certain level of safety is not ensured against tsunamis and storm surges	3.9 million people 150 thousand ha
	Population and area of districts where there is risk due to insufficiency of facilitie	1.4 million people 50 thousand ha
	Number and percentage of districts where it takes too long to close water gates and prepare against tsunamis, etc.	180 districts 17%
Information transmission	Number and percentage of districts where necessary tsunami and storm surge hazard maps have not been prepared	Tsunami: 1,200 districts 62% Storm surge: 1,500 districts 88%
	Number and percentage of districts where necessary information facilities for coastal risk management are insufficient	1,000 districts 43%
Erosion	Length and percentage of eroded/eroding coasts where erosion control facilities have not been completed	750 km 24%
	Percentage of coasts which need to be restored but have not yet	45%
Earthquake resistance	Population and area of districts protected by insufficient facilities	1 million people 40 thousand ha
	Population and area of zero-elevation districts that are prone to floods by earthquakes	200 thousand people 12 thousand ha

Cited from "Report on New Coastal Protection Methods based on Intermediate-term Prospects" (February 13, 2003, Investigatory Committee on New Coastal Protection Methods based on Intermediate-term Prospects)



Cited from "Reference for Investigating New Coastal Protection Methods based on Intermediate-term Prospects" (May 2002)

The required safety is not ensured in 150 thousand ha of coastal area to protect, where about 3.9 million people live.

Figure 1.1.2 Completion state of coastal protection facilities

Figure 1.1.2 Transition of coastal protection concept

(Period)	(Laws)	(Projects)	(Concepts of coast protection)	(Disasters)	(Background)
1945-1954		Storm surge prevention project (1949)	Restoration of damage	Many typhoons struck Japan (1948 to 1951)	
		Erosion prevention project (1952)			Rapid progress of coast engineering
		Local improvement project (1952)			
		Disaster restoration support project (1952)		Typhoon No. 13 (1953)	
		Disaster related project (1954)			
1955-1964	Coast law enacted (1956)		Main structural measures: banks, groins, revetments, and parapets	Kanogawa typhoon(1958)	Restoring exhausted country was the first priority
		Ise Bay storm surge countermeasures project (1959-1964)		Isewan typhoon(1958)	
				Chile earthquake tsunami(1960)	
	Structure standards prepared (1958)	Chile earthquake tsunami countermeasures project (1960-1966)		Dai-2 Muroto typhoon(1961)	
		Projects under direct control of the national government started (1960)	Linear protection method		
	Committee for coast protection administrative central office liaison established (1963)				
1965-1974				Typhoon No. 26 struck Shizuoka (1966)	
		First detached breakwater		Tokachioki earthquake tsunami (1968)	Increasing demand for seaside recreation
		Five-year project started (1970)			
				Typhoon No. 10 struck Kochi (1970)	
		Environment improvement project (1973)	Protecting merely at coast lines is insufficient.	Typhoon No. 16 struck Kochi (1974)	Ilegal disposal of oil drums at Osaka Bay (1971)
1975-1984		Coast cleaning project (1975)	↓		Advancing coastal erosion
		Seawall construction projects for public land reclamation (1976)		Typhoon No. 20 struck Kochi and Shizuoka (1979)	
		Repair project (1978)	Combination of various countermeasures to protect coastal "areas"		Rapid economic growth Promoting high-quality infrastructure development
		Gentle-slope revetments constructed.			
	Coast law agreement (1982)				
				Nihonkai Chubu earthquake tsunami (1983)	
1985-1988		Artificial reef constructed	Area protection method		Coastal erosion observed in many areas
		Okinotorishima protection project (1987-1993)			
		Headland defense works developed		Typhoon No. 19 struck Kochi (1987)	
		CCZ project (1987)			
					Enhanced awareness of the natural

					environment
1989-1993	Basic environment law enacted		Coastal spaces with diverse values ↓	Typhoon No. 11 struck Kagoshima (1989) Typhoon No. 19 struck many areas of Japan (1990) Hokkaido Nansei-oki earthquake tsunami (1993) Hyogo-ken Nanbu earthquake	
1995	Long-term vision for the coast	Measures for restoring seaside and green environments	Harmonizing disaster prevention, public use and environment		Promoting administrative/financial reform Promoting decentralization of power
1996		Sixth seven-year project (to 2002) Eco-coast project Constructing healthy seaside and green areas	↓		
1997	Environment assessment law enacted Comprehensive soil control subcommittee report	Nagisa project (sand bypass) *Iki-iki umino-ko hama-zukuri* project		Petroleum leak from a ship, Nakhodka	
1998	Law on prevention of marine pollution and accidents revised Proposal from the Coast management investigation committee				
1999	The Coast law revised	Direct control of Okinotorishima Island	Comprehensive coastal management	Tyhoon No.18 caused storm surge damage to western part of Japan	
2000	Revised coast law enacted Basic coast protection policies drawn up	Project for constructing marine and forest environments rich in nature Urgent projects against large driftwood, etc. during disasters			
2001		Tsunami and storm surge disaster prevention stations Comprehensive grant-aid system for repairing damage		Typhoon No. 11 caused storm surge damage	
2002	Investigatory committee on the implementation of a new medium-term coastal protection	Advanced coastal risk management project Integration of the grant-aid systems for seawall construction projects for public land reclamation			

Reference: Takeshi Koike, "Past, Present and Future of Coast Disaster Prevention Measures" (September 2002, 2002 Summer Meeting on Water Engineering, Japan Society of Civil Engineers)

Manual

2) Present safety against tsunamis and storm surges

Even districts where facilities to counter tsunamis and storm surges are completed may still suffer damage when the levels of tsunamis and storm surges exceed the assumed levels, and may not be always safe.

Recent technology has improved prediction accuracy and has revealed that external forces exceeding the present protection level can possibly occur, and may thus cause tsunami and storm surge damage.

Even districts where protection facilities are completed may still suffer damage by external forces exceeding the assumed levels. These include such places as Okushiri Island, which suffered tsunami damage during the Hokkaido Nansei-oki Earthquake in 1993, and Kumamoto Prefecture, which suffered storm surge damage in 1999.

Recent progress of technology has improved the performance of computers and the precision of measurements (such as reduced grid sizes for ground elevation measurements) and enabled floods and resultant damage to be predicted accurately. The improvement of accuracy has changed the calculated scale of external forces of tsunamis and storm surges even when the calculations are made using the same conditions. The new estimated values exceed the present protection level at some sections of coast, revealing the true risk of tsunamis and storm surges.

Even areas where structures are completed, as well as those where structures are not completed, are not always safe against tsunamis and storm surges.

1.2 Issues of disaster prevention measures against tsunamis and storm surges

(1) Urgency of disaster prevention measures against tsunamis and storm surges

Japan has been frequently struck by earthquakes and has suffered damage caused by tsunamis triggered by large submarine earthquakes. Tsunamis caused by distant earthquakes, such as the Chile Earthquake, have also struck Japan, and damage by future tsunamis is a concern. A large earthquake is predicted to occur at any time soon in the Tokai Area, and Tonankai and Nankai earthquakes are predicted to occur in the first half of this century. Large earthquakes in the Japan and Kuril Trenches are predicted to cause large-scale tsunamis.

Comprehensive measures for preventing disasters and mitigating damage during tsunamis must be urgently and systematically established.

Damage caused by storm surges is recently increasing. Although anti-storm-surge facilities have been steadily constructed since the Isewan Typhoon, there are still districts affected by storm surges.

1) Time urgency of measures against tsunamis and storm surges

Japan is located on the boundary of tectonic plates that has been frequently struck by earthquakes and tsunamis, the latter arising when large earthquakes occur under the sea. Many large-scale ocean trench type earthquakes are known to repeatedly occur at certain intervals, and they are predicted to cause tsunamis.

Tokai, Tonankai and Nankai Earthquakes are predicted to occur at intervals of about 100 to 150 years, and have caused serious damage not only by their strong seismic motions but also by accompanied tsunamis. Coastal areas suffered serious tsunami damage during the Meiji Sanriku Earthquake, Showa Sanriku Earthquake, and Tokachioki Earthquake, all of which occurred along the Japan and Kuril Trenches, and during earthquakes that occurred along the eastern edge of the Sea of Japan, such as the Nihonkai Chubu Earthquake and Hokkaido Nanseioki Earthquake. Moreover, the Chile Earthquake, which occurred far from Japan, also caused serious tsunami damage.

Especially, a Tokai Earthquake is predicted to occur at any time soon, and Tonankai and Nankai earthquakes are predicted to occur in the first half of this century. A large-scale earthquake will also occur off the coast of Miyagi Prefecture in the next 30 years. These earthquakes are imminent.

Conventional technologies cannot accurately predict the time and place of an earthquake, and other earthquakes may also occur soon.

The imminence of major earthquakes and major earthquake disasters during and after the Showa Period are shown in Tables 1.2.1 and 1.2.2, respectively.

Recent earthquakes include the Tottori-ken Seibu Earthquake (October 6, 2000, M7.3), the Geiyo Earthquake (March 24, 2001, M6.7, killed 2), the earthquake off the cost of Miyagi Prefecture (May 26, 2003, M7.0), the earthquakes in the northern part of Miyagi Prefecture (July 26 to 28, 2003, M5.1 to 6.4), and the Tokachi-oki Earthquake (September 26, 2003, M8.0). Especially, the Tokachi-oki Earthquake caused tsunami damage.

Table 1.2.1 Imminence of earthquake

Predicted earthquake	Imminence and probability	Magnitude	Note
Tokai Earthquake	Soon	M8.0	1)
Tonankai Earthquake	In the first half of this century	M8.2	2)
	Within 30 years 50%	-	3)
Nankai Earthquake	In the first half of this century	M8.6	2)
	Within 30 years 40%	-	3)
Inter-plate earthquake along a trench (Sanriku-oki to Boso-oki) (tsunami-causing earthquake)	Within 30 years 20%	M8.2	4)
Miyagi-ken Oki Earthquake	Within 30 years 90%	M7.5	4)

Notes:
1) Central Disaster Prevention Council, "Research Committee on Measures against Tokai Earthquakes" (December 2001)
2) Central Disaster Prevention Council, "Research Committee on Tonankai and Nankai Earthquakes" (December 2003)
3) Center for Earthquake Studies, "Long-term evaluation of Nankai Trough Earthquakes" (September 2001)
4) Earthquake Investigatory Committee of the Center for Earthquake Surveys (September 2002)

Table 1.2.2 Major earthquakes since the Showa Period

Date	M*	Name	Deaths**	Tsunami
March 7, 1927	7.3	Kita Tango Earthquake	2,925	○
November 26, 1930	7.3	Kita Izu Earthquake	272	
March 3, 1933	8.1	Showa Sanriku Earthquake	1,522 1,542	○
September 10, 1943	7.2	Tottori Earthquake	1,083	
December 7, 1944	7.9	Tonankai Earthquake	998	○
January 13, 1945	6.8	Mikawa Earthquake	1,961	○
December 21, 1946	8.0	Nankai-do Earthquake	1,330 113	○
June 28, 1948	7.1	Fukui Earthquake	3,769	
May 23, 1960	9.5※	Tsunami by Chili Earthquake	122 20	○
May 26, 1983	7.7	Nihonkai Chubu Earthquake	104	○
July 12, 1993	7.8	Hokkaido Nansei-oki Earthquake	201 29	○
January 17, 1995	7.3	Hyogo-ken Nanbu Earthquake	6,432 3	○

* Scale of the earthquake (magnitude), provided, moment magnitude for the Chile Earthquake
** The upper figure denotes the number of people killed. The lower denotes the number of people missing. (Data cited from Usami, "Nihon Higai Jishin Soran" (Earthquake damage in Japan, in Japanese), reference by the Fire and Disaster Management Agency)

Reference: Website of the Meteorological Agency

On the other hand, coastal improvement works have avoided suffering serious damage from storm surges since the late 1960s in Japan. However, the country is frequently struck by typhoons and is still prone to serious storm surge damage. For example, Typhoon No. 18 in 1999 affected Kumamoto and

Yamaguchi prefectures, and killed or injured many people. The risk of storm surges is possibly increasing due to rises in sea levels and increases in the size of typhoons due to climatic changes. Major damages occurred by storm surges are shown in Table 1.2.3.

Table 1.2.3 Major storm surge disasters during and after the Showa Period

Date	Principal affected area	Injury to people			Damage to buildings			Typhoon
		Killed	Injured	Missing	Destroyed	Semi-destroyed	Washed away	
1934/09/21	Osaka Bay	2,702	14,994	334	38,771	49,275	4,277	Muroto
1942/08/27	Shubonada	891	1,438	267	33,283	66,486	2,605	
1945/09/17	Southern Kyushu	2,076	2,329	1,046	58,432	55,006	2,546	Makurazaki
1950/09/03	Osaka Bay	393	26,062	141	17,062	101,792	2,069	Jane
1959/09/26	Ise Bay	4,697	38,921	401	38,921	113,052	4,703	Isewan
1961/09/16	Osaka Bay	185	3,879	15	13,292	40,954	536	Muroto II
1985/08/30	Ariake Bay	3	16	0	0	589	—	No. 13
1999/09/24	Sea of Yashiro	12	10	0	52	102	—	No. 18

Reference: Website of the Cabinet Office (in charge of disaster prevention)

2) Urgency of disaster prevention measures against tsunamis and storm surges

Clearly, tsunamis and storm surges can occur at any time. However, the implementation of structural countermeasures requires a huge amount of expense and time, and comprehensive countermeasures should be developed by incorporating non-structural countermeasures, so that damage can be minimized.

The Central Disaster Prevention Council investigated measures against tsunamis that may occur by large earthquakes, such as Tokai, Tonankai and Nankai Earthquakes, and reported.

Extract from the “Outline of Measures against Tokai Earthquakes”

Urgent execution of measures for assisting evacuation during tsunamis

National and regional public bodies shall urgently prepare tsunami hazard maps of coastal area based on the predicted damage, etc., ensure that all people have sufficient knowledge of tsunamis, draw up plans for evacuation of each region during tsunamis, and promote systems for evacuation during tsunamis.

Evacuation sites and routes shall be quickly constructed in coastal areas by appropriately utilizing projects of various kinds and giving priority to areas of the greatest need. Also, facilities for quick evacuation, such as evacuation signs, shall be quickly installed. In areas where evacuation sites are difficult to construct, evacuation sites shall be quickly ensured by utilizing private buildings and other structures that have enough resistance to predicted tsunamis.

Quick transmission of tsunami warnings, etc., is very important to appropriate evacuation from tsunami regions. Thus, regional public organizations shall urgently install radio transmission systems and form a network of such systems. For appropriate evacuation of tourists, such as sea bathers, information transmission systems shall be developed, and signs of various kinds shall be posted to establish consciousness among them of the need for evacuation from tsunamis.

Reference: “Outline of Measures against Tokai Earthquakes” (May 29, 2003, Central Disaster Prevention Council)

Extract from the “Outline of Measures against Tonankai and Nankai Earthquakes”

Establishing disaster prevention systems against tsunamis

Tonankai and Nanaki earthquakes may occur in the first half of this century and cause serious damage over large areas. Comparing this with the damage by the anticipated Tokai earthquake, the damage could be more serious, especially by tsunamis. Thus, facilities must be systematically and steadily improved by inspecting anti-tsunami installations, such as coastal and river banks, for earthquake resistance and reinforcing them.

To mitigate damage caused by tsunamis, appropriate evacuation is important. The damage predicted by investigatory committees also shows that injury to people can be sharply reduced if residents are highly aware and take quick evacuation action of tsunamis. Intensive education is very important in districts where there is risk of large tsunamis. Measures against tsunamis, both structural and non-structural, must be developed; for example, constructing evacuation sites and studying evacuation routes in advance.

Reference: “Outline of Measures against Tonankai and Nankai Earthquakes” (December 16, 2003, Central Disaster Prevention Council)

(2) Issues concerning tsunami and storm surge disaster prevention in coastal areas

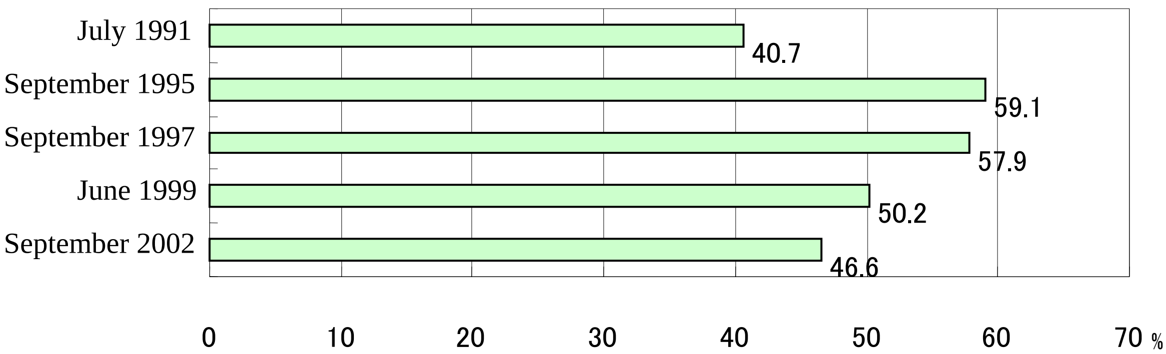
While the urgency and importance of disaster prevention during tsunamis and storm surges are recognized, there are three issues to be resolved in disaster prevention during tsunamis and storm surges in coastal areas: 1) reduced self-defensive capability of residents due to lack of awareness, 2) coastal characteristics prone to disasters, and 3) difficulty of identifying areas that need evacuation.

There are following three issues of disaster prevention during tsunamis and storm surges in coastal areas:

1) Reduced self-defensive capability of residents due to lack of awareness

A person must always be aware of the danger of disasters in order to defend himself from the danger. People’s awareness of tsunamis and storm surges rose a great deal after the tsunami during the Hokkaido Nansei-oki Earthquake, the Hyogo-ken Nanbu Earthquake, and storm surge disasters during Typhoon No. 18 in 1999. However, such awareness level is rapidly decreasing as the years pass by.

【Decreasing awareness level of disaster prevention】



Cited from the 2003 disaster prevention white paper “Public Opinion Poll on Disaster Prevention” (September 2002, Cabinet Office)

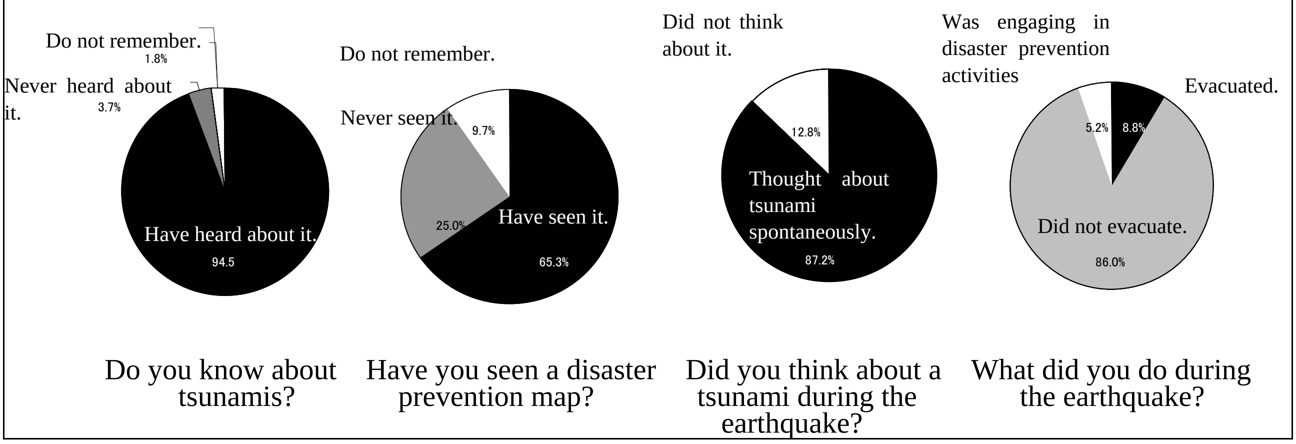
Figure 1.2.1 Decreasing awareness level of disaster prevention

To minimize damage to people during tsunamis and storm surges, they themselves need to appropriately evacuate dangerous areas based on information from administrative bodies and the mass media. Thus, residents need to be always aware of the danger of tsunamis and storm surges, be prepared for disasters, and know the norms of actions to take. However, their awareness of disaster prevention is fading as the years pass by after the Hokkaido Nansei-oki Earthquake, the Hyogo-ken Nanbu Earthquake and the storm surge during Typhoon No. 18 in 1999. Various projects which steadily improves protection for coastal areas also help accelerate such tendancy.

Administrative bodies, which are to support residents in evacuation and undertake regional disaster prevention activities, should bear important roles since local communities lack strong relationship among their residents, but the number of administrative staff who have actually experienced disasters is decreasing. Local residents and administrative bodies need to cooperate in flood fighting activities, but a great concern is declining self-defensive capability, due to the residents' decreasing awareness of the risk and the decreasing number of capable staff in local governments.

[Column: Disaster prevention awareness and evacuation behavior]

Kesennuma City was struck by tsunamis during the Sanriku and Chile Earthquakes. The area has been very conscious of tsunami disaster prevention, and tsunami disaster prevention maps have been distributed to the residents. During the Sanriku Minami Earthquake on May 26, 2003, approximately 90% of the residents spontaneously thought about the possibility of a tsunami. However, only 10% took evacuation action and the majority did not evacuate but stayed at home collecting information through TV, etc. until an announcement declared no tsunami 12 minutes after the earthquake. Even people who are very conscious of disaster prevention do not always take evacuation action, which clarifies that methods for enhancing people's awareness level and for giving them information regarding evacuation should be improved to bridge knowledge and action.



Reference: May 26, 2003, "Survey report on evacuation of Kesennuma citizens from tsunami during the Sanriku Minami Earthquake"
(September 2003, Katada Laboratory, Department of Civil Engineering, Faculty of Engineering, Gunma University)

2) <u>Coastal characteristics prone to disasters</u>

Japan is surrounded by sea and has coastal characteristics prone to damage from tsunamis and storm surges. Compared to European and North American countries, Japan has long coasts in relation to its area. Thus, it needs a vast amount of time and expense to construct coast protection facilities.

Especially, large cities, in which population and assets of various kinds are concentrated, have recently expanded toward the sea, including residential areas and districts covering various city functions, and becomes a concern for great damage by tsunamis and storm surges. On the other hand, in districts where the mountains are close to the sea, villages are scattered in a narrow strip of lowland. Protection of these villages from tsunamis and storm surges is a difficult but important issue. Coastal erosion has been noticed in various parts of Japan since the late 1950s, and non-experienced areas of tsunamis and storm surges could be struck by such disasters in future.

In lowlands, where the elevation is almost zero, storm surges and tsunamis are known, from the past inundation record, to cause large areas to inundate. Thus, even sites far from the coast are not always safe.

When a large earthquake occurs near the coast, the resultant tsunami will reach the coast very fast, and there will be little time to evacuate. Storm surges, which can be predicted to a certain extent, may cause serious disasters if a levee breaches and allows water to flash inland.

Thus, especially in lowlands, disaster prevention measures must be developed based on thorough understanding of the flood properties of each area.

3) Difficulty of identifying areas that need evacuation.

When damage by tsunamis or storm surges is predicted, the mayor of a city must issue evacuation orders to residents in areas to be affected. Although the decision standards are to be stated in regional disaster prevention plans, etc., some plans state no such standards, and others state standards which are not specific enough. When a large earthquake occurs near the coast, the resultant tsunami will reach the coast very fast, and there will be little time of decision of evacuation order. When a levee breaches during a storm surge, the resultant flood spreads unexpectedly fast. Thus, it is difficult to identify areas over which evacuation orders and advice are to be issued.

1.3 Direction of development of measures to prevent disasters by tsunamis and storm surges

(1) Considerations for disaster prevention measures against tsunamis and storm surges

Disaster prevention measures against tsunamis and storm surges should include education for residents, providing and sharing information, and enhancing cooperation and measures for mitigating damage.

Disaster prevention measures against tsunamis and storm surges should consider the followings:

1) Educating residents to increase awareness of disaster prevention

Residents should be educated so that they can collect information by themselves and voluntarily exercise caution and take evacuation actions. Administrative bodies should provide them with disaster prevention information on a regular basis, explain the limits of disaster prevention facilities, and make efforts to raise residents' awareness level toward disaster prevention.

Table 1.3.1 Useful knowledge about tsunamis

1. When strong earthquake motion is felt (seismic intensity of over 4) or when earthquake motion is weak but long, evacuate from the coast to a safe place at once. 2. Even when no earthquake motion is felt, evacuate from the coast to a safe place at once when a tsunami warning is issued. 3. Collect accurate information through radio, TV and municipal information cars. 4. Do not bathe or fish when a tsunami advisory is issued, because there is still some risk of a tsunami reattack. 5. Tsunami strikes come repeatedly. Stay alert until the tsunami warning or advisory is called off.

Cited from: "Thorough understanding of tsunami warnings in coastal areas" (July 1999, Communication Council of Tsunami-related Ministries and Agencies)

2) Providing and sharing information for disaster prevention

When a large earthquake occurs near the coast, the resultant tsunami reaches the coast very fast and there will be very little time to evacuate. Thus, evacuation action needs to be taken quickly. The need of evacuation from a storm surge during a typhoon depends on its route. Thus, disaster prevention information, such as tsunami warnings and storm surge warnings, must be provided in real time and be shared among administrative bodies and residents. Municipal governments and related organizations must establish systems for sharing information with residents, and must construct a disaster-resistant information network.

3) Enhancing cooperation

Local communities, which have become weak, should be reconstructed, and cooperation among municipal governments and related organizations should be enhanced to smoothly collect and transmit information. Especially, disaster-vulnerable people, such as the elderly who live alone, will possibly have difficulty evacuating by themselves during disasters, and administrative bodies and local residents need to cooperate in evacuation activities.

4) Enhancing measures for mitigating damage

Measures for mitigating damage need to be investigated in advance by assuming inundation, since tsunamis and storm surges that exceed the assumed scale of the facilities can possibly occur. Measures for mitigating damage include those that are taken before and during a tsunami (storm surge), and also include stuctural and non-structural measures. All the measures must be developed by considering the characteristics of the coast and possible inundation.

(2) Direction of development of countermeasures to prevent disasters by tsunami and stormsurge

Tsunamis and storm surges must be counteracted by taking structural measures up to certain external force levels (the design protection level). Forces exceeding the level are difficult to deal with only by structures, since they require a huge amount of expense, and thus non-structural measures should be developed as well. Non-structural measures are effective even when external force levels are within the designed range.

The structural and non-structural measures for preventing disasters need to be coordinated so as to minimize the damage, improve the protection standards by constructing appropriate structures, enhance the self-defense capability of residents through non-structural measures (for example, sharing disaster prevention information),and, as a result, mitigate damage.

1) Structural and non-structural measures for preventing disasters during tsunamis and storm surges

Structural measures for preventing disasters denote those for improving the protection level using tsunami and storm surge control structures and damage prevention structures. Non-structural measures denote those against tsunami and storm surge disasters that cannot be controlled by structures alone, and include provision of disaster information before, immediately before, immediately after, and after the disasters, construction of evacuation sites, and development of systems and facilities for mitigating damage. Preparation of hazard maps is one of the non-structural measures.

Typical structural and non-structural measures for preventing tsunami and storm surge disasters are shown in Table 1.3.2. Note that some non-structural measures involve structural factors (such as construction of evacuation routes).

Table 1.3.2 Examples of structural and non-structural measures for preventing tsunami and storm surge disasters

Class	Objectives	Measures	
		Structural	Non-structural
Structural	Control tsunamis and storm surges	・Breakwaters against storm surges and tsunamis ・Tide embankments, banks, and revetments ・Water gates and land locks ・Seaside forest ・Reinforced concrete, and steel reinforced concrete, buildings	・Maintaining and inspecting facilities ・Checking the functions of the facilities ・Effective and efficient operation of the facilities
Non-structural	Mitigate damage during tsunamis and storm surges	・Evacuation routes and sites ・Information communication facilities	・Establishing land use plans ・Measures to encourage voluntary evacuation of residents when a typhoon approaches and after an earthquake ・Issuing tsunami and storm surge warnings ・Sharing knowledge on past tsunamis and storm surges ・Providing education on disaster prevention ・Executing evacuation drills ・Establishing self-defensive organizations ・Preparing tsunami and storm surge hazard maps ・Assuming damage and examining local disaster prevention plans

Reference: Yoshiaki Kawata "Coast Disaster Prevention as Risk Management" (in Japanese)
(September 2002, 2002 Summer Study Session on Water Engineering, Japan Society of Civil Engineers)

2) Coordination between structural and non-structural measures for preventing tsunami and storm surge disasters

The relationship between structural and non-structural measures for preventing disasters is shown in Figure 1.3.1. Up to a certain level (the design protection level), external forces should in principle be controlled by structures. Forces exceeding the design level are difficult to be controlled by the structures alone mainly due to high costs, and non-structural measures need to be implemented. non-structural measures are also effective against external forces below the design level for areas where structures are not yet completed and when the structures fail to function. However, the structures are indispensable for ensuring safety and must be steadily constructed and improved. Especially in areas where population and assets concentrate and the need of reducing risk is high, the protection level should be raised by improving protection structures so that the design level approaches the maximum permissible risk.

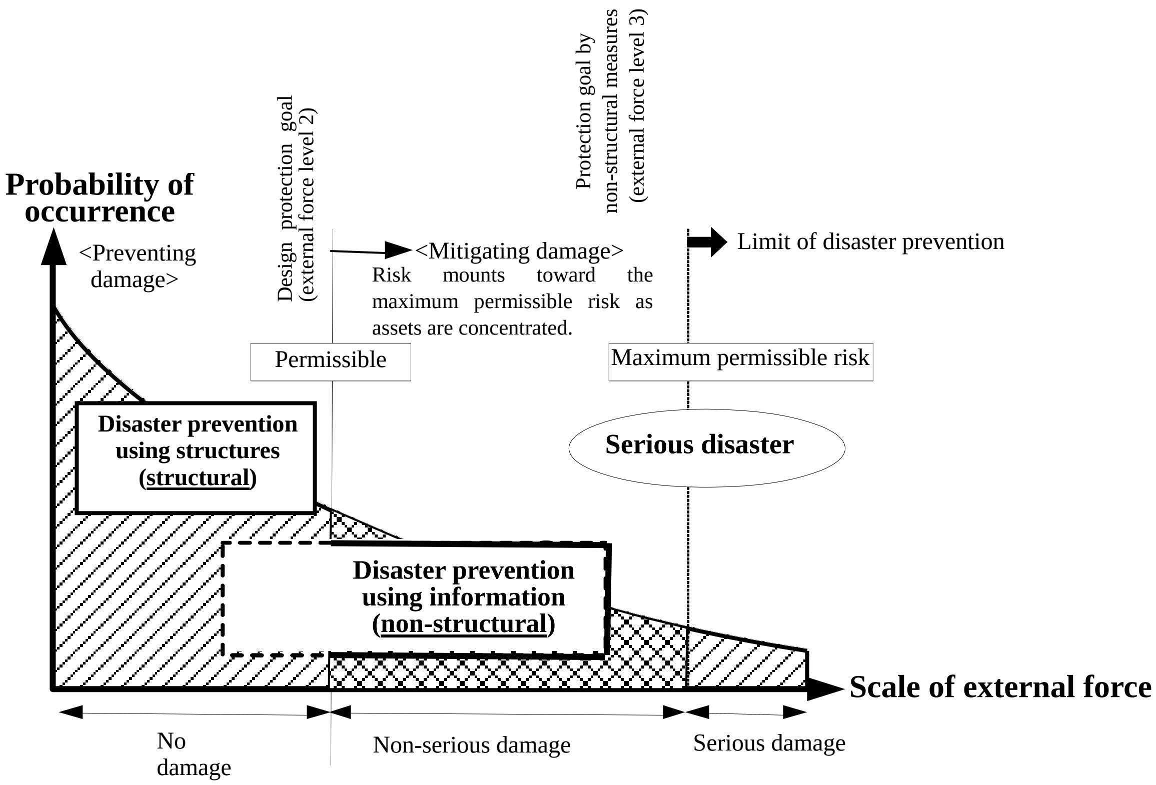


Figure 1.3.1 Relationship between structural and non-structural measures for preventing disasters

Reference: Yoshiaki Kawata "Coast Disaster Prevention as Risk Management (in Japanese)" (September 2002, 2002 Summer Study Session on Water Engineering, Japan Society of Civil Engineers)

As shown in Figure 1.3.2, the structural and non-structural measures for preventing disasters need to be coordinated so as to minimize the damage, improve the protection standards by constructing appropriate structures, enhance the self-defense capability of residents through non-structural measures (for example, sharing disaster prevention information) and, as a result, mitigate damage.

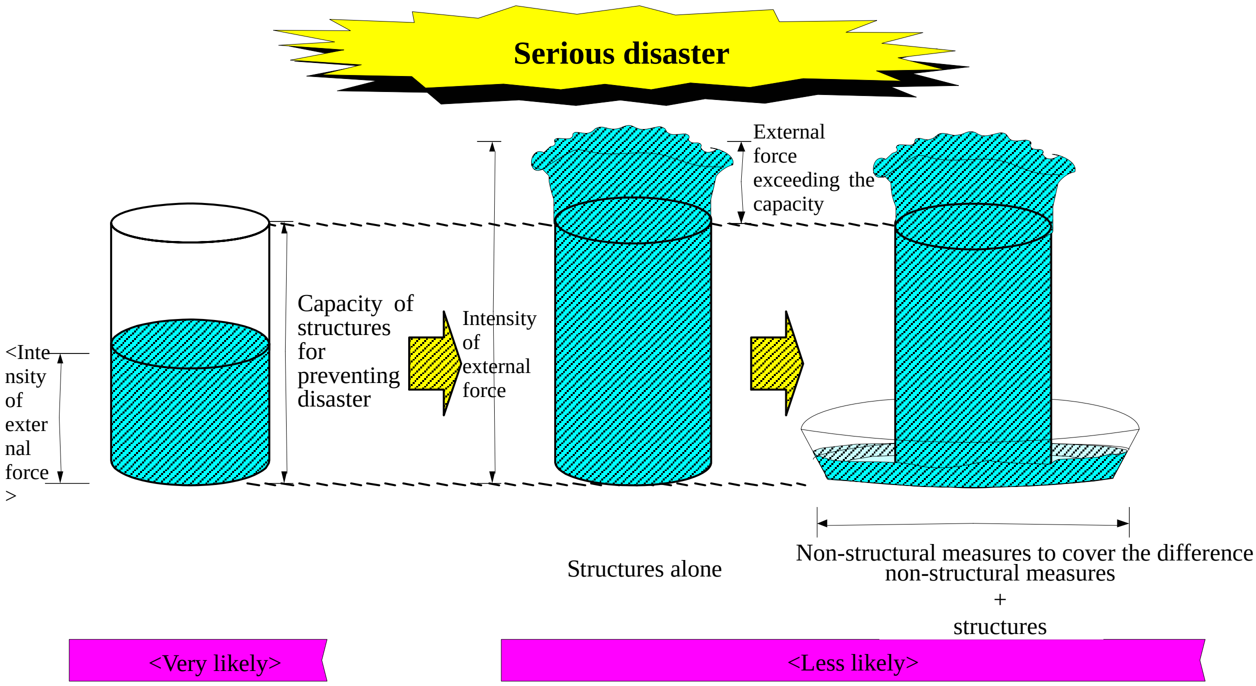


Figure 1.3.2 Schematic diagram of coordination between structural and non-structural measures for preventing disasters

Actual methods for coordinating structural and non-structural measures for preventing disasters include:

a) Understanding the performance of coast protection facilities in the area (crown height, earthquake resistance, etc.), estimating possible damage in the area, and assessing the present risk.

b) Deciding the permissible damage level and safety level.

c) Deciding priority for construction, improvement or repair of coast protection facilities, including installation of a remote control system for closing and opening water gates and land locks, based on the performance of coast protection facilities and risk assessments, and efficiently executing projects that are immediately effective for mitigating damage. (Structural measures)

d) Informing local residents about what external force would cause what degree of inundation at that site in that district based on the present status of facility construction, since constructing coast protection facilities requires expense and time.

e) Providing tsunami and storm surge hazard maps to residents so that they know the evacuation routes and evacuation sites during disasters, prepare against disasters and enhance their defensive capability. Roads and sites for quick evacuation are to be constructed. (Structural measures)

f) The priority should be given to constructing evacuation sites and various facilities in areas containing hospitals and other welfare facilities accommodating many people who cannot evacuate by themselves, densely populated districts, and areas that have wooden buildings prone to collapsing and blocking evacuation routes since residents in such areas and districts may have difficulty evacuating by themselves. Land use plans and land use regulations may also need to be revised for areas prone to serious damage. (Disaster prevention measures for enhancing further safety)

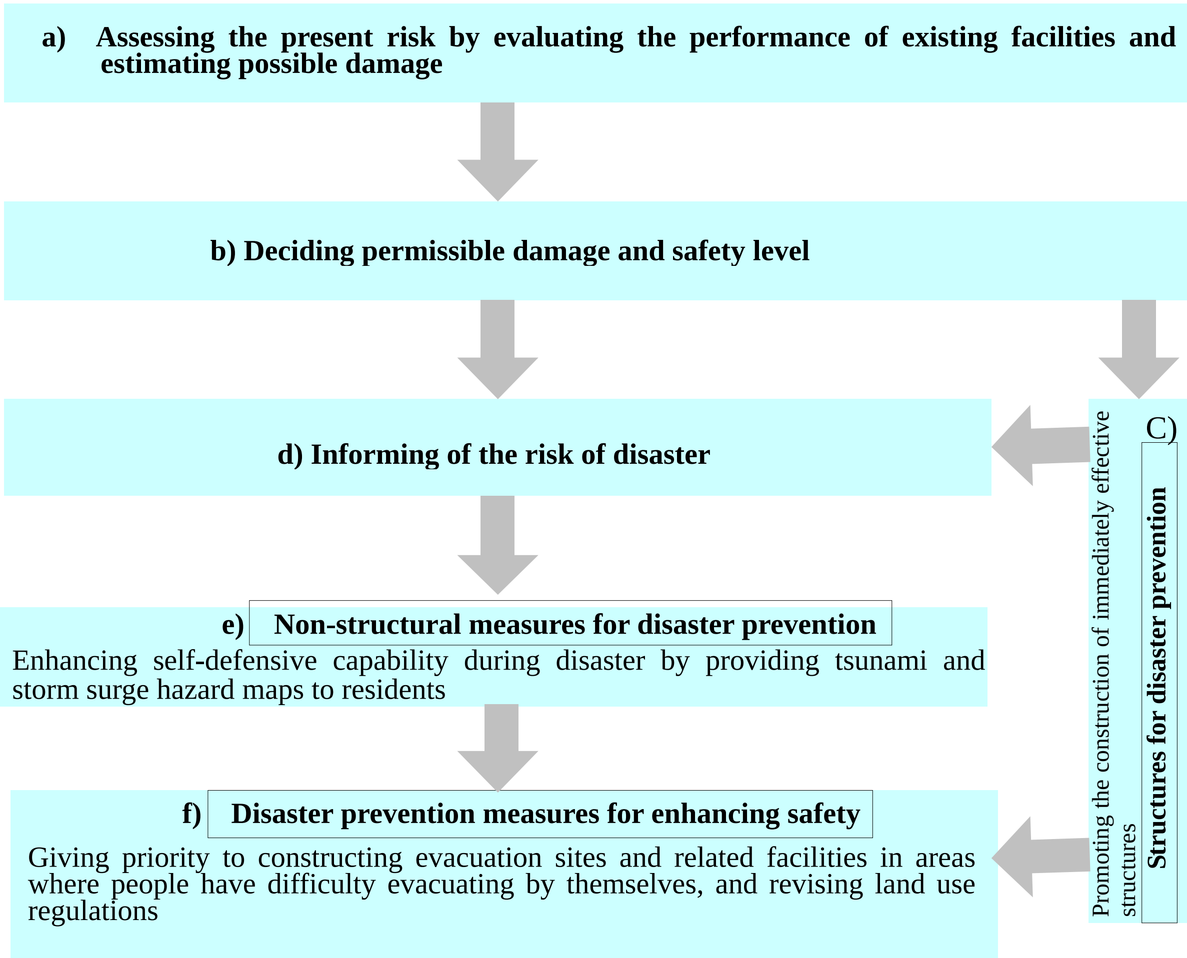


Figure 1.3.3 Coordination of flow between structural and non-strucutural measures for disaster prevention

As a reference, structural and non-sturucutural measures for preventing tsunami disasters and the position of hazard maps are shown in Figure 1.3.4.

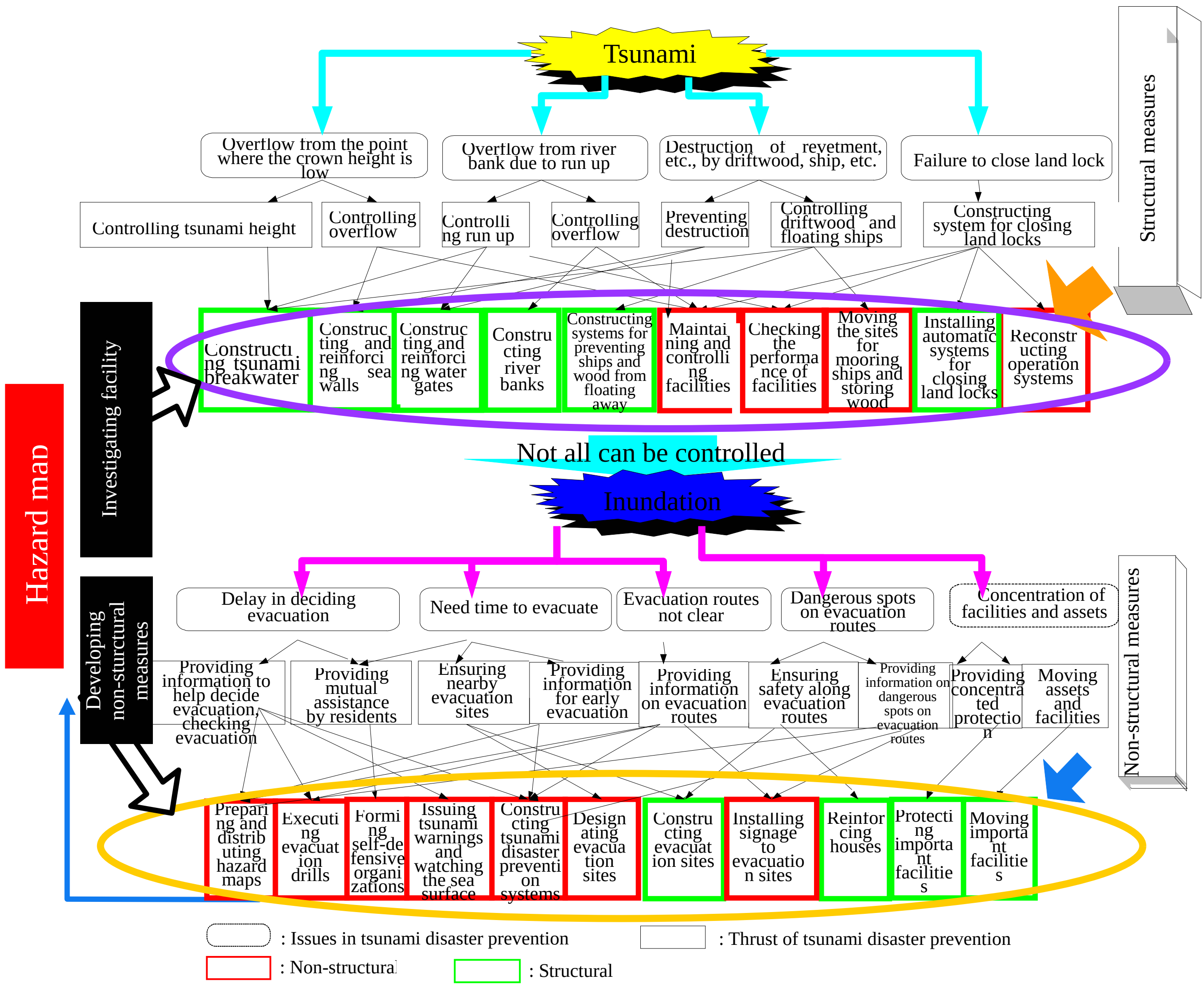


Figure 1.3.4 Position of hazard maps in structural and non-structural measures for preventing tsunami disasters

1.4 Roles of hazard maps as a measure for preventing disasters caused by tsunamis and storm surges

(1) Roles of tsunami and storm surge hazard maps

> Tsunami and storm surge hazard maps are tools for mitigating damage during tsunamis and storm surges, mainly in a self supportive and mutually supportive manner, and to help administrative bodies to draw up evacuation plans, provide education on disaster prevention, increase public awareness of disaster prevention, construct strong communities against disasters, and enhance communication with residents regarding risks.

1) Three support classifications of disaster prevention

Disaster prevention can be classified into "self support", "mutual support", and "public support" activities. National and regional public organizations have mainly promoted public support projects, such as construction of coast protection facilities. However, public support activities alone are insufficient for preventing disasters. Substantial mutual support systems, which involve cooperation with local residents, volunteer groups, and private companies, and self support activities to protect oneself are also needed. As the Hyogo-ken Nanbu Earthquake revealed, the majority of activities during the earthquake were either self support or mutual support in nature, as residents made their own escape from houses that collapsed during the earthquake and reconstructed new houses, but people in general still feel that disaster prevention is a role of governments, which proves a strong dependency of the public toward public support. Self support and mutual support activities are likely to be increasingly important especially during the period immediately after a disaster until public support activities start; one should naturally realize their further importance when considering the disaster-vulnerable population, which will become larger and larger as the aging society progresses. Of residents in areas prone to damage, some may be elderly and living alone, and some may need help to evacuate. To help these people, residents in high-risk areas need to be conscious of self support and mutual support activities for disaster prevention.

It is important to make the most of tsunami and storm surge hazard maps as tools to assist self and mutual support activities in coordination with evacuation plans, disaster prevention education, activities to increase public awareness of disaster prevention, construction of strong communities against disasters, and communication enhancement with residents about risks.

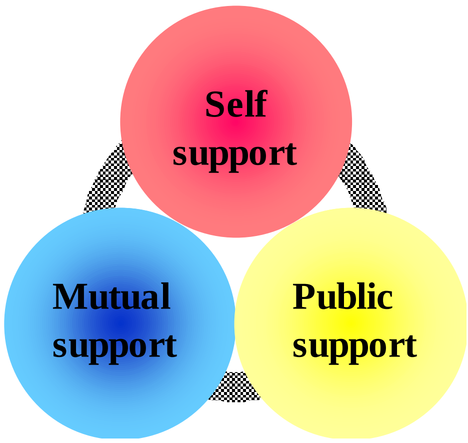


Figure 1.4.1 Three support classifications of disaster prevention

2) Role of hazard maps

The most important non-structural measure of information provision for preventing disasters during tsunamis and storm surges is tsunami and storm surge hazard maps. The maps will enable residents to quickly evacuate from dangerous areas, obtain knowledge about the predictable risks, and be aware of disaster prevention. They will also be effective to promote construction of strong communities against disasters.

The contents of and investment for projects against unexpected disasters should be decided by not only governmental advice but also communication with residents about degree of risk, costs involved. Tsunami and storm surge hazard maps can be used as a tool for risk communication, in which local residents and administrative bodies share information about disasters and jointly investigate countermeasures.

[Column: Risk communication]

All phenomena in this world, including scientific technologies, can be both useful and dangerous. Therefore, administrators and companies, which are the owners of certain information, should inform people of the usefulness and danger of the phenomena and discuss how to deal with it to save people from the risk. Disclosing not only the positive side of a subject but also all of its negative side, such as risks, in a fair manner, is called “risk communication”.

Regarding risk management in terms of the way for a group of people to confront risk, exchange of information, experience, sense and knowledge, and mutual understanding among people, are called “risk communication”. When people confront risks, many seek for strategic management to avoid, reduce, and mitigate damage and exercise risk communication by actively providing and exchanging information. Risk communication also denotes two-way communication among interested parties on risks and countermeasures by increasing the parties’ involvement. Here, communication is regarded as part of “management” in a broad sense, and both are interpreted together.

Reference: “Encyclopedia of Risk” (in Japanese) (2000, The Society for Risk Analysis, Japan-Section)

(2) Roles of tsunami and storm surge hazard maps

In disaster prevention during tsunamis and storm surges, tsunami and storm surge hazard map functions as non-structural measures for enhancing the self defensive capability and evacuation activities of residents, and also as structural measures for supporting the investigation of what facilities to construct to improve protection levels.

Typical structural and non-structural roles of tsunami and storm surge hazard maps include:

[Non-structural roles]

1) Providing residents with information about disasters, evacuation, etc.
2) Providing administrators with information about disasters and evacuation,
3) Serving as a tool for risk communication between residents and administrators.

[Structural roles]

1) Providing support for investigating about what facilities to construct (improve) to improve protection levels
2) Providing support for investigating about construction of evacuation sites, systems for monitoring coast protection facilities, and other counter-disaster systems, and
3) Providing support for investigating about post-disaster restoration measures.

Table 1.4.1 Roles of tsunami and storm surge hazard maps in disaster prevention

Class	Target	Example of measure	Role of hazard map
Non-structural	Residents	• Raising awareness	Providing information about disasters to residents
		• Providing evacuation information	
		• Evacuation drill	
	Administrators	• Measures for preventing disaster	Providing information about disasters to administrators
		• Disaster prevention activity plans	
		• Preparing for evacuation	
		• Evacuation plan, support plan	
		• Constructing counter-tsunami and storm surge systems	
		• Information about tsunami and storm surge warnings	
	Residents and administrators	• Risk communication between residents and administrators	Tool for risk communication
Structural	Administrators	• Constructing and improving structures for improving protection levels	Providing information about priority of facilities
		• Constructing disaster prevention stations	Providing support for investigation of construction of evacuation sites, systems for monitoring coast protection facilities, and other systems against disasters
		• Providing information about sites that must be urgently dealt with	
		• Constructing systems for operating and monitoring facilities (water gates, land locks, etc.)	
		• Restoration plan by understanding states of damage in real time	Providing supports to investigate post-disaster restoration measures

Chapter 2 Overview of tsunami and storm surge hazard maps

2.1 Purposes of preparing tsunami and storm surge hazard maps

Hazard maps for residents are prepared to provide residents with the information necessary for taking appropriate evacuation actions, such as the risks of tsunamis and storm surges, and evacuation sites and routes.

Hazard maps for administrators are prepared to assist administrative bodies in carring out their duties, such as devising and taking disaster prevention and emergency measures.

Hazard maps for residents are prepared to provide residents with the information necessary for taking appropriate evacuation actions, such as the risks of tsunamis and storm surges, and evacuation sites and routes, in an easy-to-understand manner.

Hazard maps for administrators are prepared to assist administrative bodies and management bodies in carrying out their duties, such as devising and taking disaster prevention measures and taking emergency measures. For example, such maps can help those in charge of disaster prevention to draw up evacuation plans and also support those of coast, ports and fishing ports to plan construction of facilities and safety measures for users.

Hazard maps for private companies are also effective to select locations appropriate for building offices and factories, to draw up evacuation plans from offices and factories located in inundation-prone areas, especially from factories and research facilities handling hazardous materials, and to investigate management of the hazardous materials.

2.2 Target disasters and range of tsunami and storm surge hazard maps

> Tsunami and storm surge hazard maps are to be prepared for each municipality, which is the unit of administrative rights and responsibility. Coordination with adjacent municipalities may be considered when it is necessary in terms of topography and evacuation.
>
> Tsunami hazard maps and storm surge hazard maps should in principle be prepared separately.

1) Range

Since the chief of a municipality is responsible for evacuation from the area (Article 60 of the Disaster Countermeasures Basic Law), tsunami and storm surge hazard maps are to be prepared for each municipality.

However, in areas that belong to different municipalities but which should be regarded as a single area in terms of topography (for example, an area surrounded by a large river), an inundation risk area should be identified regardless of municipal boundaries. It is important to keep consistency in terms of the setting of external forces among neighboring municipalities. Similarly, it should be noted that evacuation plans are also to be investigated regardless of municipal boudaries in some cases.

Evacuation sites and routes from the shore side of coast protection facilities must also be shown on hazard maps when there are possibilities of users and workers being in the zone. Foreshore reclaimed land, wharfs, marinas, beaches, coastal parks, etc., must be included in the maps, and evacuation sites and routes must be decided.

2) Target disaster

Both tsunamis and storm surges cause inundation, but are substantially different in cause, inundation pattern, and evacuation method. Thus, tsunami hazard maps and storm surge hazard maps should in principle be prepared separately.

For residents to use hazard maps, a comprehensive hazard map which contains information about storm surges, tsunamis, floods, and sediment-related disasters is desirable. However, the scope of this manual is for tsunami hazard maps and storm surge hazard maps, which are to be given priority over the preparation of a comprehensive map because:

a) Hazard maps for tsunamis and storm surges need to be urgently prepared, and

b) Individual maps are needed to prepare a comprehensive map.

This manual describes preparation of tsunami hazard maps and storm surge hazard maps as a preliminary process of preparing a comprehensive hazard map.

2.3 Bodies in charge of preparing tsunami and storm surge hazard maps and their roles

> Tsunami and storm surge hazard maps for residents should be prepared by municipal governments, which are responsible for evacuation of residents, and tsunami and storm surge hazard maps for administrators should be prepared by the appropriate administrative divisions with the support of prefectural and national governments.
>
> Municipal, prefectural, and national governments should bear appropriate roles in preparing tsunami and storm surge hazard maps for residents according to the areas covered by the maps. Hazard maps should be prepared by both administrative bodies and residents working together, not be prepared by administrative bodies alone and distributed to residents in a completed form. Residents' participation should be encouraged in preparation of the maps through workshops, etc., so that more regional characteristics can be incorporated into the maps, residents can be more aware of hazard maps and be more encouraged to utilize the maps.
>
> Prefectural and national governments should support municipal governments in preparing tsunami and storm surge hazard maps by providing data on inundation prediction and constructing a database for coastal topology.

1) Main body in charge of preparing hazard maps

Since the ultimate objective of hazard maps for residents is to assist them in evacuating quickly during disasters, the maps should be prepared by municipal governments, which are responsible for evacuation of local residents and carry detailed information around the target areas.

Hazard maps for administrators should be prepared by individual divisions depending on the purposes of the maps.

The basic concepts of role allotment for administrative bodies at each level are described in the following section, but prefectural and national governments should provide support flexibly based on regional characteristics and conditions.

2) Role allotment in preparing hazard maps for residents

Joint preparation of a integrated map for inundation-prone areas by neighboring municipalities is desireable in some cases so that they can avoid redundancy in calculations and ensure consistency in terms of external forces and damage. In such cases, prefectural and national governments assist municipal governments by providing the necessary data and conditions for prediction, conducting inundation prediction, and coordinating neighboring municipalities for cooperation. Constructing a coast database for the entire Japan will also a great contribution by prefectural and national governements to efficient preparation of tsunami and storm surge hazard maps.

Participation of residents in the preparation of tsunami and storm surge hazard maps is an effective way to incorporate regional characteristics into the maps, raise residents' awareness toward the maps, and encourage them to utilize the maps. Municipal governments should construct a system for enabling residents to actively participate in preparation of tsunami and storm surge hazard maps through workshops, etc.

Inundation-prone areas may need to be identified by prefectural and national governments depending on the financial conditions and technological capacities of individual municipal governments.

The concepts of roll allotment among residents, municipalities, and prefectural and national governments in preparing tsunami and storm surge hazard maps are shown in Table 2.3.1

Table 2.3.1 Roles of residents, municipalities, and prefectural and national governments in preparing tsunami and storm surge hazard maps

Body	Roles
Municipal government	1) Prepare tsunami and storm surge hazard maps • Establish preparation conditions appropriate to the region • Prepare maps, and predict inundation and assume damage in individual zones 2) Encourage participation of residents to devise original safety measures, enhance the consciousness of self-defense, and understand the risks
Prefectural government	1) Assist preparation of tsunami and storm surge hazard maps when the maps are to cover two or more municipalities or when municipal governments have difficulty preparing the maps independently • Identify external forces and inundation areas, and assume damage
National government	1) Provide technical assistance to prefectural and municipal governments when the area for which a hazard map is to be prepared extends over two or more prefectures or when prefectural governments alone have difficulty preparing the maps 2) Develop and reinforce administrative methods • Solve issues regarding preparing tsunami and storm surge hazard maps • Construct systems for supporting preparation of hazard maps 3) Provide and share knowledge and information • Prepare the manual for tsunami and storm surge hazard maps • Provide information to, and share the knowledge of risks with, municipal governments to promote preparation of hazard maps • Actively cooperate with bodies in charge of hazard map preparation 4) Construct databases on basic coast information • Improve the efficiency of hazard map preparation by constructing databases 5) Support disaster prevention activities of municipal governments by providing real-time information in connection with and by utilizing hazard maps
Residents	1) Participate in preparation of tsunami and storm surge hazard maps • Participate in hazard map workshops to help incorporate regional characteristics into the maps, enhance understanding of those characteristics, and promote more frequent use of the maps.

3) Roles of disaster prevention organizations and coast administrators

Both organizations related to disaster prevention and coast administrators should actively support bodies in charge of tsunami and storm surge hazard map preparation. This cooperation is expected to reinforce the consciousness of disaster prevention organizations and coast administrators about disaster prevention and about information sharing in the field of disaster prevention.

In practice, coast administrators should provide various kinds of information that are necessary for predicting inundation during tsunamis and storm surges to bodies in charge of preparing the maps. Information that should be provided includes the mechanisms of damage to coast protection facilities, water depth and elevation data used to predict inundation during tsunamis and storm surges, and areas that inundated during disasters in the past. Port management bodies and administrators of fishing ports should also provide various kinds of information concerning facilities in ports and fishing ports to bodies in charge of preparing the maps.

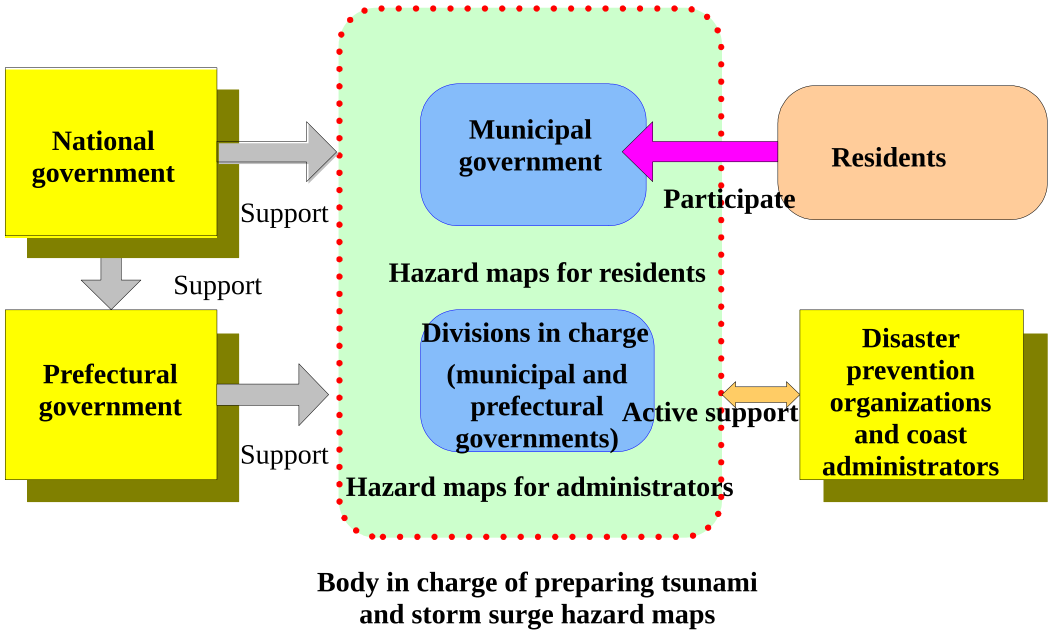


Figure 2.3.1　Bodies in charge of preparing tsunami and storm surge hazard maps

4) Supporting the preparation of tsunami and storm surge hazard maps by constructing a coast database

In order to minimize damage, an appropreate combination of structural and non-structural measures is necessary. In particular, to mitigate damage from tsunamis and storm surges, a coast database needs to be constructed for storing various kinds of information necessary for assessing the risk of indivisual coastal areas. Construction and utilization of the coast database will reduce the load of collecting and analyzing the data necessary for preparing tsunami and storm surge hazard maps and enable the maps to be efficiently prepared.

Table 2.3.2　Examples of data necessary for preparing tsunami and storm surge hazard maps

Class of data	Example of data
Data necessary for predicting inundation	• Crown height of facility • Type of facility • Elevation of the ground
Data to be shown on tsunami and storm surge hazard maps	• Inundation prediction data (tsunami, storm surge) • Population • Land use data • Disaster records

5) Schedule of tsunami and storm surge hazard map preparation

As described in Chapter 1, measures against tsunamis and storm surges must be urgently taken, and tsunami and storm surge hazard maps should be prepared as quickly as possible depending on the urgency in each district, with the support and cooperation of related organizations.

2.4 Forms and expressions of hazard maps

> Hazard maps for residents must be easy to understand and use. To use the hazard maps for evacuation during disasters, use of fluorescent inks and water-proof materials and other methods should be considered. Information to be used during evacuation must be expressed in a simple manner and in a way different from information that is used for education in normal times.
>
> Hazard maps for administrators must also have forms and expressions appropriate for the purpose of use.

1) Forms of tsunami and storm surge hazard maps

Tsunami and storm surge hazard maps must have forms (media, materials, size, etc.) that are easy to use and to understand. Especially, hazard maps for residents are desirably posted at homes and thus should be in forms that can be posted on places that are easy to see. For example, the proper size of the maps may be about A3, considering posting on a refrigerator together with a schedule of garbage collection, list of phone numbers, and notices from governments. Also considering the carrying of the maps during disasters, they should be readable at night and water-proof.

The foregoing is draft ideas of hazard maps to be distributed to homes for residents. Hazard maps for outdoor display (evacuation signs, sign boards) and for educational display should take different forms and expressions to serve their specific purposes.

2) Expressions of tsunami and storm surge hazard maps

Expressions used in tsunami and storm surge hazard maps should be carefully chosen so as to be correctly understood by residents. Especially, hazard maps for residents are to be used for evacuation during disasters, and residents may face danger and even be killed when they fail to correctly understand information on hazard maps. Thus, hazard maps for residents must be simple and easy to understand.

However, showing inundation risk areas and evacuation zones in an easy-to-understand manner may give residents a false idea that only the areas shown in the maps will always inundate during tsunamis and storm surges. Thus, measures should be devised to avoid giving false ideas. (See *4.4 Methods for displaying predicted inundation risk areas and evacuation areas* for details of displaying inundation-prone areas and areas that need to be evacuated.)

2.5 Procedure for preparing tsunami and storm surge hazard maps

Tsunami and storm surge hazard maps should be prepared by 1) identifying inundation risk areas, and 2) displaying disaster prevention information about tsunamis and storm surges.
Inundation risk areas should be identified by setting conditions, such as external forces and facilities, and conducting simulation analyses for predicting inundation, assessing the risks of facilities, etc.
Disaster prevention information about tsunamis and storm surges should be displayed by identifying items and contents of information to be displayed and deciding display methods, such as symbolization, of the information. Information characteristic to each region, which is identified in workshops, should also be displayed.

1) Procedure for preparing tsunami and storm surge hazard maps

A flow of preparing and utilizing tsunami and storm surge hazard maps is shown in Figure 2.5.1. A procedure for preparing tsunami and storm surge hazard maps is shown in Figure 2.5.2.

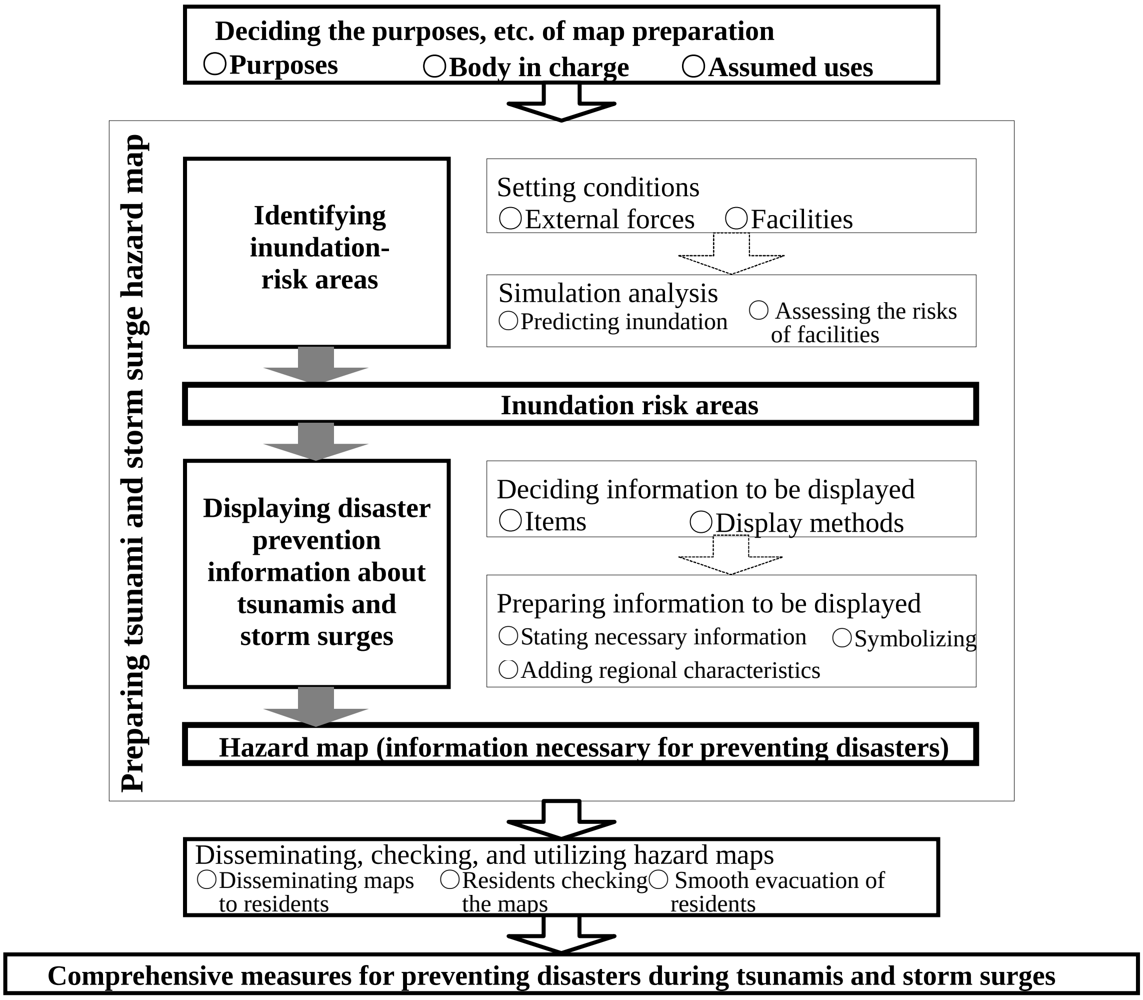


Figure 2.5.1 Flow of preparing and utilizing tsunami and storm surge hazard maps

As shown in Figure 2.5.2, hazard maps for residents are prepared by adding basic information for evacuation (minimum information indispensable for evacuation) and additional information for evacuation (such as maximum water depths predicted and estimated arrival time) to maps showing inundation risk areas. Hazard maps for administrators are prepared using basic information (information that can be shared, such as inundation risk areas and coast protection facilities) and information related to purposes specific to each administrative group (disaster prevention centers, police stations, fire departments, etc.). (See Chapter 4 for the information to be displayed in tsunami and storm surge hazard maps.)

Table 2.5.1 Information to be stated in tsunami and storm surge hazard maps

<table>
<tr><th>Map</th><th colspan="2">Information</th><th>Notes</th></tr>
<tr><td rowspan="3">Hazard maps for residents</td><td rowspan="2">Information for evacuation (See p. 55)
Information necessary for evacuation, such as evacuation sites and routes</td><td>Basic information for evacuation (See p. 57)
Basic information indispensable for evacuation</td><td></td></tr>
<tr><td>Additional information for evacuation (See p. 57)
Minimum additional information needed in the region</td><td>Added to the hazard maps depending on region</td></tr>
<tr><td colspan="2">Educational information on disasters (See p. 55)
Information for enhancing the knowledge of residents about tsunamis and storm surges</td><td>Distributed separately, etc.</td></tr>
<tr><td rowspan="2">Hazard maps for administrators</td><td>Information for preventive measures (See p. 59)
Information useful for taking preventive measures</td><td rowspan="2">Basic information (See p. 59)
Shared information

Information based on different purposes (See p. 59)
Information necessary for each specific purpose</td><td rowspan="2"></td></tr>
<tr><td>Information for emergency measures (See p. 59)
Information useful for taking emergency measures</td></tr>
</table>

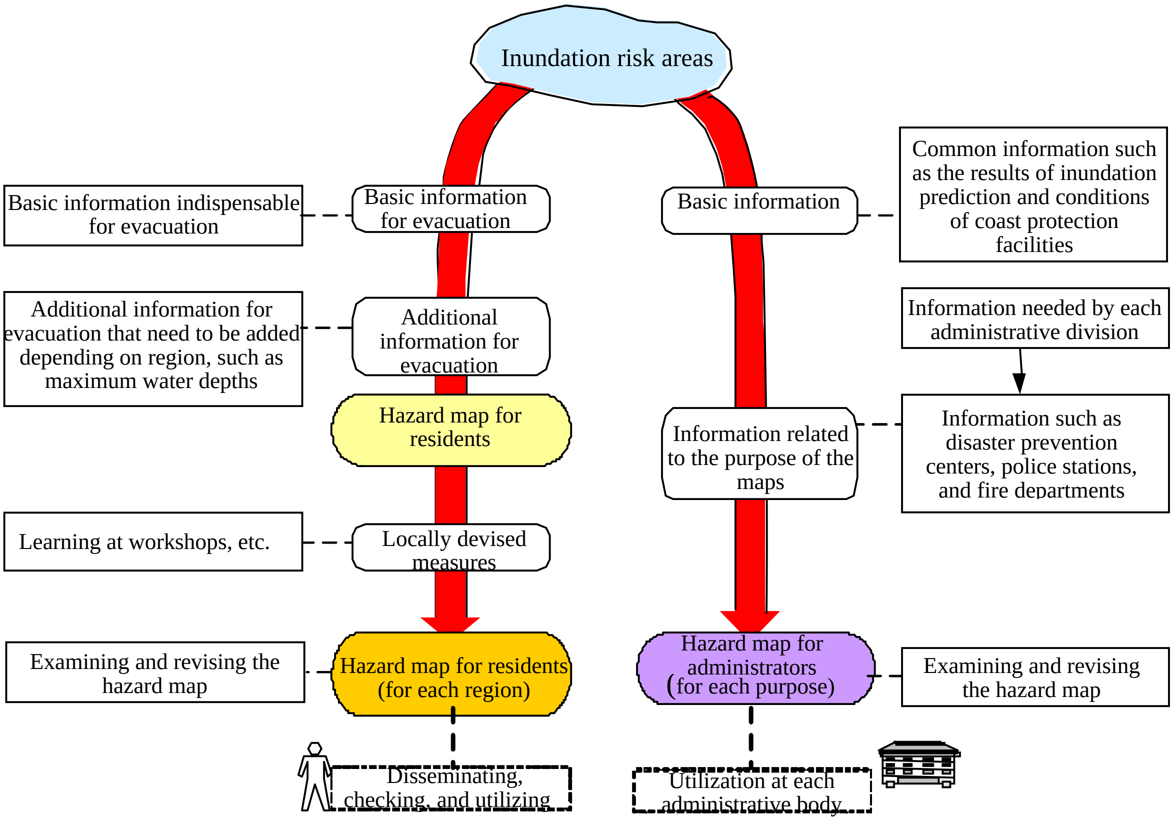


Figure 2.5.2　Flow of preparing hazard maps for residents and administrators

2) Identifying inundation risk areas by considering the characteristics of tsunamis and storm surges

Highly precise inundation prediction should be conducted by considering the characteristics of tsunamis and storm surges, including time sequential information such as inundation depth, velocity, and inundation initiation time. This information is used to execute non-structural disaster prevention measures, such as evacuation, and structural measures, such as construction and improvement of coast protection facilities.

Those in charge of preparing tsunami and storm surge hazard maps should conduct thorough investigations to determine the kinds and precision of inundation information that are needed for the maps to identify inundation risk areas. Prediction of inundation is the core of tsunami and storm surge hazard maps, and should be improved in accuracy by conducting numerical simulations, which can reflect precise settings of external forces and facilities and calculate time sequential data, such as inundation depth, velocity and inundation initiation time. (See Chapter 3 for methods for identifying inundation risk areas.)

When numerical simulations are difficult to perform, tsunami and storm surge hazard maps can be prepared just by using available data. For example, past inundation records can be used instead of inundation prediction calculations, and hazard maps can be prepared using the results of inundation prediction conducted using simple methods, records of disasters in the past, and records of evacuation sites and routes that could not be used due to inundation and collapse of buildings. In such a case, the possibility of inundation damage that exceeds the recorded damage in the past should be stated, and the estimated inundation risk areas and the information on the maps should be revised afterward in stages.

It should also be noted that prediction of inundation using numerical simulation contains uncertainty. (See *4.4 Methods for displaying predicted inundation risk areas and evacuation areas* for methods for dealing with uncertainty.)

2.6 Utilization of hazard maps during evacuation

Residents collect information such as evacuation sites and routes from hazard maps for residents and take evacuation action. Evacuation sign boards which conform with the hazard maps should be installed, and real-time information should be provided for people who do not look at the hazard maps and for preparatio for situations that can not be assumed from the maps.

Hazard maps for residents are used to take appropriate evacuation action during emergencies. Relationships between tsunami and storm surge hazard maps, evacuation measures, and evacuation action, are shown in Table 2.6.1. Past records showed that the time of obtaining information affected the evacuation behavior of residents, and delays in transmitting disaster information will lead to delays in evacuation action. Thus, information must be quickly transmitted at appropriate timing. Evacuating as soon as an earthquake is felt is the basic of evacuation from tsunami risk areas.

Table 2.6.1 Relationships between tsunami and storm surge hazard maps, evacuation measures, and evacuation action

Hazard map	Evacuation measures and evacuation action
• Hazard map for residents (printed on paper)	Local residents collect information that helps them decide evacuation, such as the risk of tsunamis and storm surges, evacuation sites, and evacuation routes
• Hazard map for administrators	Administrators utilize the map to construct evacuation sites and routes, select appropriate sites for establishing countermeasures centers, construct and improve disaster prevention facilities along rivers and coasts and at ports, educate people on disaster prevention, and draw up land use and regional development plans

Information shown in hazard maps for residents is preliminary information, and residents are expected to evacuate during an emergency based on the actual situation and the information on the maps. However, residents can collect little information about the situation during an emergency and may fail to make a sound judgment. Measures are also needed for people who do not look at the maps and for preparation for situations that can not be assumed from the maps. Thus, appropriate evacuation action should be assisted by installing evacuation sign boards which conform with hazard maps and by providing real-time information.

For example, real-time information provision through radio communication systems of municipal governments should also be in conformity with information shown on hazard maps. IT-based two-way systems for reading hazard maps are a possible method for providing real-time information during emergencies.

Chapter 3 Methods for identifying inundation risk areas

3.1 Characteristics of tsunamis and storm surges

Tsunamis and storm surges differ from each other in cause and phenomena. Inundation risk areas should be identified based on the understanding of individual characteristics.

(1) Characteristics of tsunamis

A tsunami is caused by an earthquake, and it strikes and inundates districts near the epicenter very soon after the earthquake, leaving little time to evacuate, inform residents, and close water gates and land locks. A tsunami travels fast and damages structures, especially when it recedes. Inundation is also possibly caused by damage to coast protection facilities due to earthquake motion or to collision by ships during a tsunami.

(2) Characteristics of storm surges

Most storm surges occur during large-scale typhoons and can be predicted to a certain extent. However, once a levee breaches during a storm surge, the damage spreads over a large area since water levels are high over all waterside land.

1) Characteristics of tsunamis

The time and scale of earthquakes, landslides, and volcanic eruptions, which are causes of tsunamis, are difficult to predict. Thus, although tsunami warning systems are set to work right after an earthquake, there will be very little time left for tsunami warning when the earthquake occurs near the coast, since tsunamis propagate very fast. Tsunamis can also arrive from unexpected directions when the topography is complicated. Essentially, urgent and quick evacuation based on local information is necessary. As a reference, arrival times of tsunamis are shown in Figure 3.1.1.

Tsunamis can exceed the heights of ordinary revetments and levees, and can affect even districts where such revetments and levees are completed. Tsunamis can also cause serious damage when they recede.

The area of inundation depends mainly on the height of a tsunami and the elevation of the land. The height of a tsunami depends on the scale of the causal earthquake, its hypocenter location, and submarine topography.

A tsunami arrives several times, and in some cases, the second or later wave can be the highest. The hydrodynamics of tsunamis should be considered as forces affecting facilities. Inundation from rivers should also be assessed when necessary.

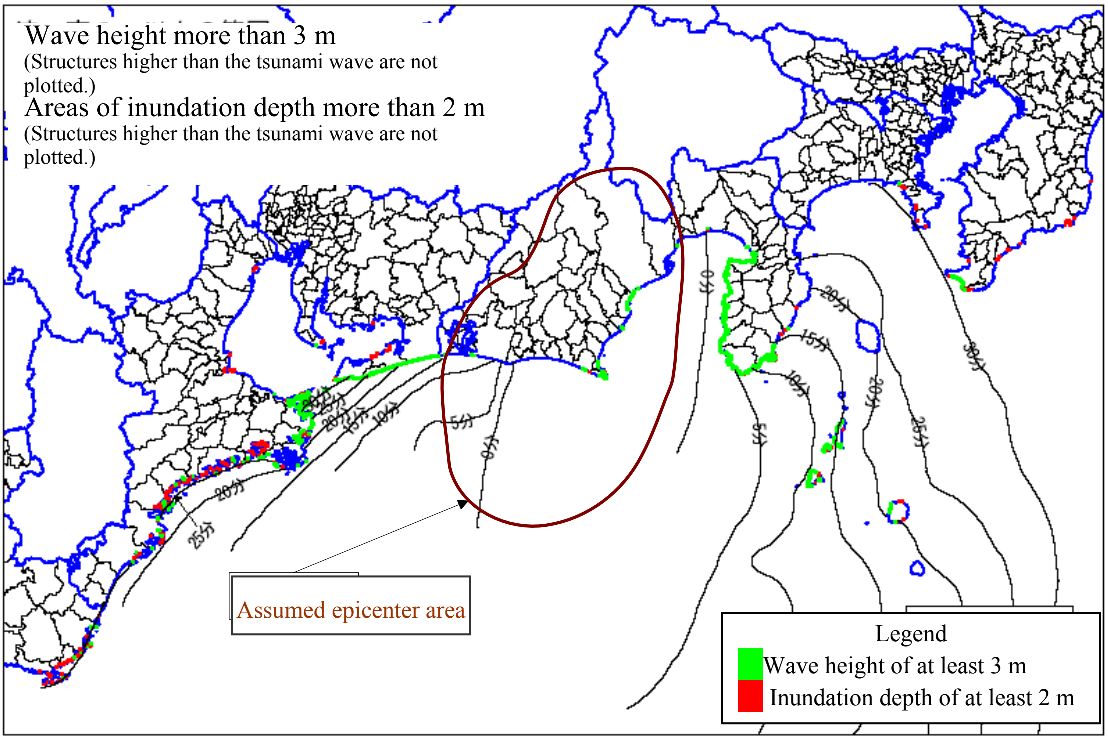


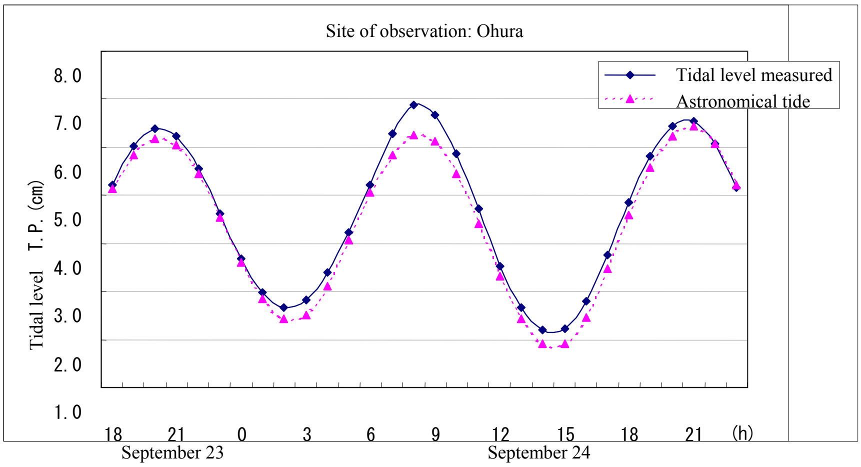
Figure 3.1.1 Arrival times of tsunami waves

Reference: "Reference of the 7th Meeting of the Investigatory Committee on Countermeasures against Tokai Earthquakes" (March 3, 2003, the Central Disaster Prevention Council)

2) Characteristics of storm surges

Most storm surges occur during large-scale typhoons and can be predicted to a certain extent. In most cases, inundation occurs when the tidal deviation reached the maximum during a high astronomical tide, but strong typhoons can cause inundation even when not coincident with high tides.

Once a levee breaches during a storm surge, the damage spreads over a large area since the water level is high over the entire waterside land and water is supplied from the sea. Thus, damage during storm surges varies greatly depending on the levee breach. Evacuation is usually difficult, since typhoon winds can blow away window glass and signboards.



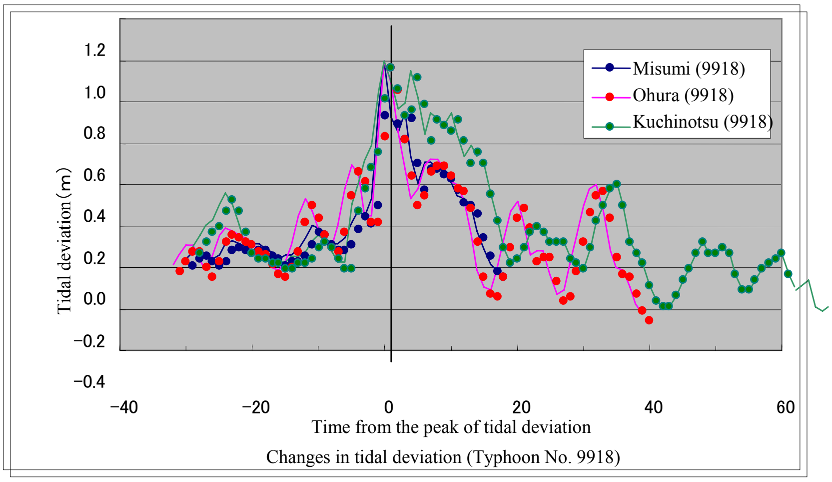


Figure 3.1.2 Changes in tidal level and tidal deviation during storm surges in the past (Typhoon no. 9918, along the Ariake Sea)

3.2 Conditions for identifying inundation risk areas

(1) Conditions

To identify inundation risk areas, both the external force conditions and the facility conditions should be appropriately set so that disaster prevention measures are studied properly. The external force condisions refer to relevant external forces; the facility conditions concern about how a facility typically would be destroyed and how operational it would be at a disastrous event.

When disasters may affect two or more municipalities, extra attention should be given to be consistent between those municipalities when they set the conditions.

1) Conditions

Generally, the conditions shown in Table 3.2.1 need to be taken into account to identify inundation risk areas for tsunami and storm surge hazard maps. Besides those conditions, the traveling speed of a typhoon may also affect inundation and may need to be considered for storm surge hazard maps, and volcanic eruptions and large-scale landslides, as well as earthquakes, are possible causes of tsunamis and may need to be considered for tsunami hazard maps.

Although other conditions besides those are difficult to display on paper-printed hazard maps, possible risk areas and the risk of disasters exceeding assumptions may need to be stated on the maps to cope with the worst case (See *4.4 Methods for displaying predicted inundation risk areas and evacuation areas* for methods for identifying possible risk areas).

Table 3.2.1 General conditions for identifying inundation risk areas

Class	Tsunami hazard map	Storm surge hazard map
External force conditions	1. Scale of earthquake 2. Hypocenter location 3. Displacement of the ground 4. Astronomical tide 5. River conditions	1. Scale of typhoon 2. Course of typhoon 3. Astronomical tide 4. River conditions
Facility conditions	1. Types of destruction 2. Operational state of facility	

2) Precautions to determine the level of each condition

a) Consistency among adjacent municipalities

When considering disasters that may affect two or more municipalities or in the case of studying preventive measures for a large area, extra attention should be given to keep consistency among adjacent municipalities in terms of the level of each condition.

b) Inundation in underground spaces

Inundation in underground spaces such as subways and underground malls should be separately investigated.

(2) Setting external force conditions

> In identification of inundation risk areas, the level of each external force should be rationally set in consideration of purposes and regional characteristics with the worst case in mind.

1) <u>External force level</u>

In Tables 3.2.2 and 3.2.3, the external forces related to inundation prediction during tsunamis and storm surges are divided into three different levels.

Tsunami and storm surge hazard maps should be prepared by rationally setting a external force level with the worst case in mind – namely, the highest external force level (Level 3 in Tables 3.2.2, 3.2.3 and 3.2.4) – and by considering the purposes of the maps and the characteristics of the region. For example, to simulate situations under Level 2 (design external force) should be useful for districts where protection facilities are insufficient.

When considering disasters that may affect two or more municipalities, extra attention should be given to keep consistency between adjacent municipalities in terms of the level of external forces.

Table 3.2.2 Objectives of analysis and external force levels

Level of external force	Definition	Objective of analysis	Notes
Level 1	External force that is realistically assumed to occur	To investigate measures against disasters that occur during construction To investigate measures against disasters that occur on the seaward side of the protection line, such as on beaches	
Level 2	Design external force that meets the protection goal	Design construction goal of the facility	Using non-structural measures for those that cannot be prevented by structural measures alone Changes by time (towards Level 3)
Level 3	External force that causes the worst inundation	Estimation of the worst possible situation	Cannot be prevented by structural measures Non-structural measures need to be used to the maximum extent

Table 3.2.3 Levels of external force and scales of tsunamis and storm surges

Level of external force	Tsunami	Storm surge
Level 1	Possible damage to marine culture facilities and such, but not to the land	Frequently observable
Level 2	Devastating as design external force (the largest tsunami in the past)	Devastating as design external force (the maximum force in the past and assumed maximum force (maximum scale and worst route of typhoon in the region in the past))
Level 3	Devastating as assumed maximum tsunamis (assumed earthquake scale, worst hypocenter location)	Devastating as assumed maximum storm surges (maximum scale and worst route of typhoon in the past)

Table 3.2.4 Comparison of external force levels used (example)

	Conventional standards, etc		Tsunami and Storm Surge Hazard Map Study Meeting External force conditions for estimating inundation	
	Earthquake motion level Technical Standards and Explanations for Port and Harbour Facilities in Japan (May 1999, The Japan Port and Harbour Association, p. 258)	Design high tide level in performance-based designing (Port and Airport Research Institute)*	Tsunami level	Storm surge level
Level 1	Expected earthquake motion of a return period of 75 years (all facilities)	30 to 100 years (Tidal deviation during typhoon of relatively frequent scale and mean high tide level)	External force that is realistically assumed to occur	
			None	Frequent storm surge
Level 2	Expected earthquake motion of a return period of several hundreds of years, intraplate earthquake motion, plate boundary earthquake motion (earthquake resistant facilities)	100 to 1,000 years (Tidal deviation during typhoon of the largest known scale and ordinary mean high water spring tide)	Design external force that meets the protection goal	
			Design external force (largest in the past)	Design external force (largest in the past and assumed maximum in the region)
Level 3		5,000 to 10,000 years (Tidal deviation during typhoon of the largest possible scale and mean high water spring tide during typhoon)	External force that causes the worst inundation	
			Assumed maximum	Assumed maximum (maximum scale, worst route)

Reference: Takahashi, Kawai and Takayama “Future measures against storm surge during Typhoon No. 18 in 2000” (October 2002, Journal of the Japan Society of Civil Engineers)

2) Considerations for setting external force conditions

External force conditions used to identify inundation risk areas should be set by considering the purposes of preparing the maps, which disasters to analyze, and the characteristics of the region. Conditions that cannot be analyzed by the present technologies should be considered in the future when the necessary technologies are developed. It should also be noted that disasters can occur under conditions other than those presented in this section.

(3) Setting facility conditions

> Facility conditions for identifying inundation risk areas should be set by considering the purposes of preparing the maps, the characteristics of disasters, and the characteristics of the region.

Facility conditions that are commonly used to prepare tsunami and storm surge hazard maps are types of destruction and operational states of facilities.

Tsunami hazard maps should show types of destruction by earthquake motion, such as overturning of buildings, sliding, and liquefaction. Thus, the earthquake resistance of facilities must be inspected. Collision of vessels and ships with facilities may also need to be considered. For storm surge hazard maps, destruction of facilities by overflowing and overtopping during storms must be considered. When there is a risk of levee breaches and thus causing inundation, the possible breach points must be marked. On the other hand, actual data should be used as much as possible for the operational states of facilities, including the operational states of water gates and land locks (closing and opening).

The conditions and the methods for setting facility conditions should be adjusted according to the characteristics of disasters, the objectives of map preparation, and the characteristics of the region. Conditions that cannot be identified by today's technologies should also be considered in the future when more advanced technologies are available. It should also be noted that disasters can possibly occur under conditions other than those presented in this section. In order to choose necessary information for the maps, such as the types of destruction, an appropriate method should be selected by referring to "2000 Coastal Facility Design Handbook" (November 2000, Japan Society of Civil Engineers) and "Technical Standards and Explanations for Port and Harbour Facilities in Japan" (May 1999, Japan Port and Harbour Association).

3.3 Choosing a method for predicting inundation

Inundation prediction should be carried out by a method with accuracy suited to the purposes of map preparation and the characteristics of the region. The method should also be the one that has taken an appropriate external force and facility condition. Ideally, numerical simulation should be used, in which timesequence is considered.

Data used for prediction as well as the results should be processed into the form that is compatible with the Geographical Information System (GIS), so that they can be easily applicable to hazard maps, readily available for future reviews, and shared with others. It should be noted that the results of inundation prediction always carry uncertainty, and that the validity of the results should be appropriately evaluated.

1) Methods for predicting inundation

Inundation prediction should be carried out by a method with accuracy suited to the purposes of map preparation and the characteristics of the region. The method should also be the one that has taken an appropriate external force and facility condition. Ideally, numerical simulation should be used, in which timesequence is considered. When a simulation is difficult to perform, simpler alternatives are available for inundation prediction. Principal methods for predicting inundation, including simple ones, are shown in Table 3.3.1.

Table 3.3.1(1) Principal methods for predicting inundation

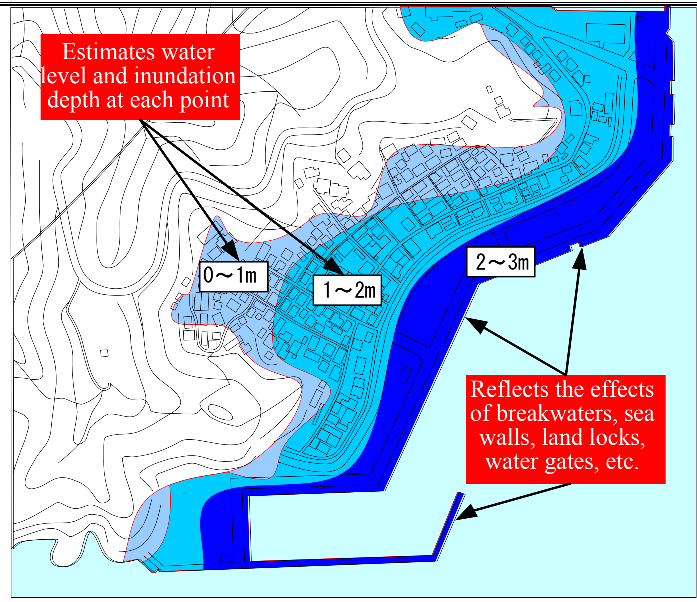
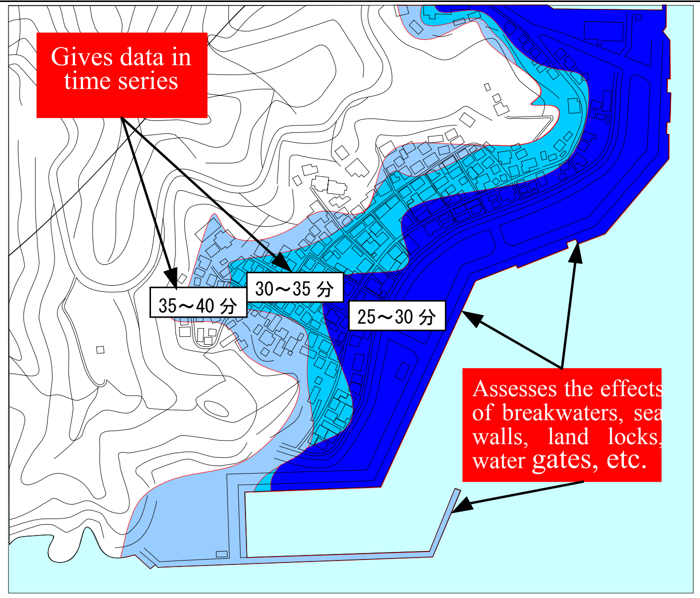
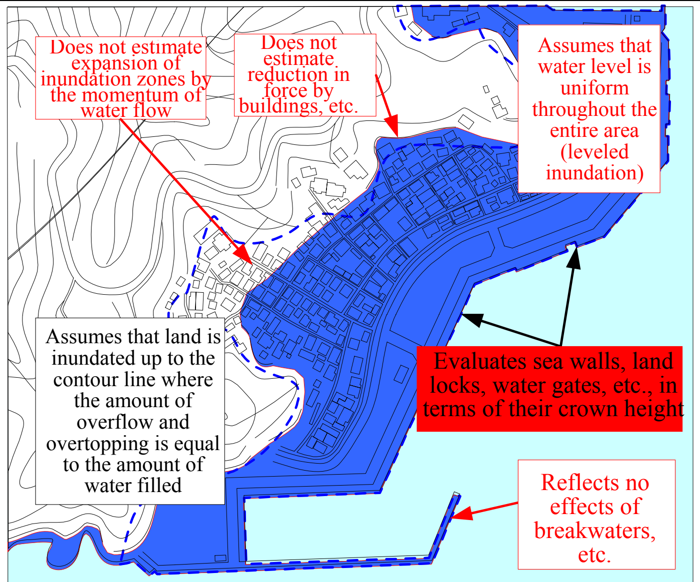
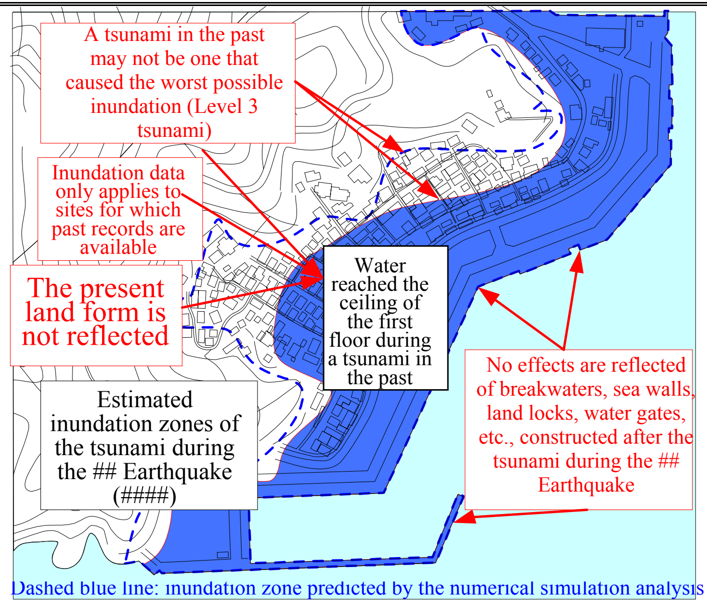
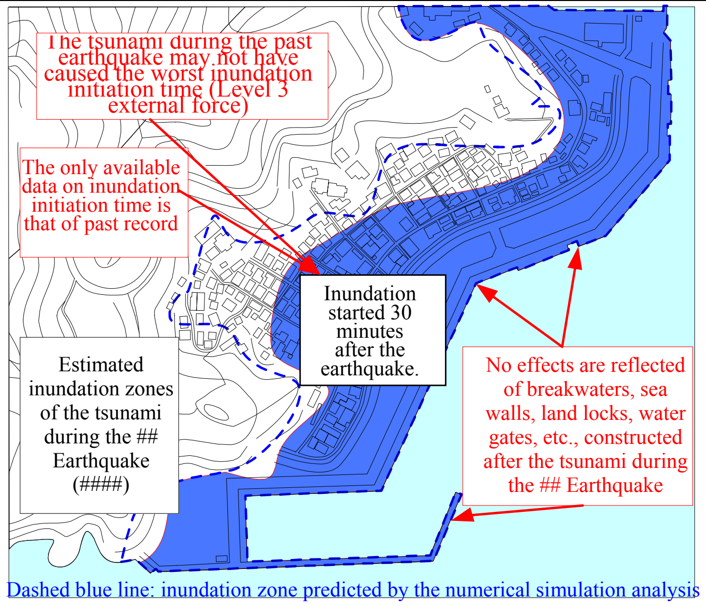
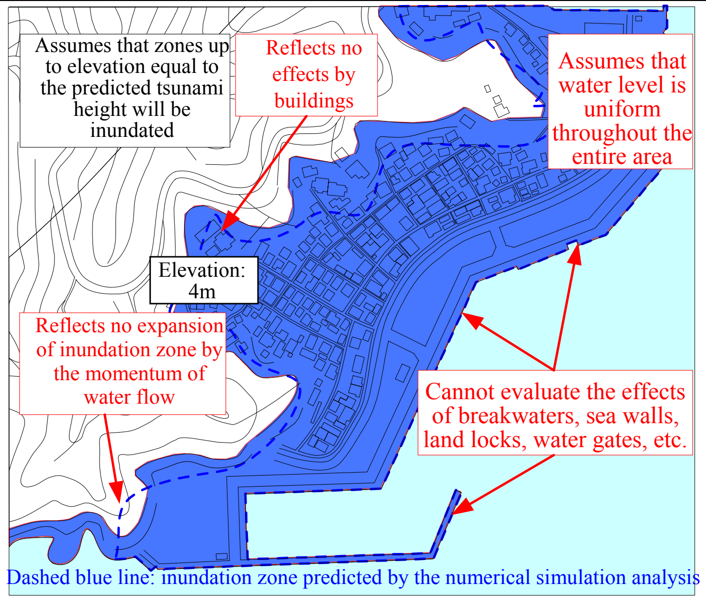
Method	Method for simulating inundation	Advangages (○) Disadvantages (●)	Prediction image (for tsunami) ＜Inundation zones and inundation depths＞	Prediction image (for tsunami) ＜Changes over time＞
Numerical simulation in time sequence	・Prediction by simulating tsunamis and storm surges (See 2))	○ Can precisely estimate the data necessary for preparing hazard maps (inundation zones in time series and inundation depth at each point) ● Requires skills and costs		
Level filling method	・The amount of flood water is determined by multiplying the width of breach, duration, and the amount of flood water per unit length and unit time, which are estimated from waves and tides that are predicted from the assumed external force level. ・Inundation risk areas and inundation depths are estimated by assuming that inundation starts from low elevation zones.	○ Requires no special skills ○ Has a certain calculation basis for determining the amount of flood water and inundation zones from the level of external force ● Ignores reduction in force by buildings (overestimates inundation area) and the momentum of water flow (underestimates inundation area) ● May result in unrealistic estimations depending on the area topography, such as showing an enclave in the inundation area, since the flow of water is ignored ● Can predict only the final inundation zones and cannot predict the speed or a time series of inundation.	 Dashed blue line: inundation zone predicted by the numerical simulation analysis	Estimates only the ultimate inundation zones (no time sequential data) Cannot evaluate the effects of breakwaters, sea walls, land locks, water gates, etc.

Table 3.3.1(2) Principal methods for predicting inundation

<table>
<tr><th rowspan="2">Method</th><th rowspan="2">Method for simulating inundation</th><th rowspan="2">Advantages (○)
Disadvantages (●)</th><th colspan="2">Prediction image (for tsunami)</th></tr>
<tr><th>＜Inundation zones and inundation depths＞</th><th>＜Changes over time＞</th></tr>
<tr><td>Prediction based on past inundation</td><td>・A time series, zones, and depths of inundation are predicted based on the past inundation events.</td><td>○ Is simple and inexpensive
● Cannot be used for areas that have not suffered inundation
● May underestimate inundation risk zones, inundation depths and inundation initiation time since the external force level of the past inundation may not the be the worst
● Cannot reflect the effects of protection facilities constructed after the past inundation
● Cannot provide data that were not monitored during the past inundation</td><td>
</td><td>
</td></tr>
<tr><td>Estimation based on ground elevation</td><td>・Estimates to be inundation risk areas those zones where the elevation is lower than the height of tsunamis and storm surges predicted from the assumed level of external force
・Predicts inundation depths by subtracting ground elevation from the height of the tsunami and the storm surge level
・The possible tsunami height is available from the Central Disaster Prevention Council, and the possible tide level can be predicted by using the probability tide levels</td><td>○ Is simple and inexpensive
● Ignores reduction in force by buildings (overestimates inundation area) and the momentum of water flow (underestimates inundation area)
● Cannot reflect the effects of protection facilities since inundation risk zones are predicted only from the tsunami height, the tidal level, and the ground elevation.
● Can predict only the final inundation zones and cannot predict the speed or a time series of inundation.</td><td>
</td><td>Estimates only the ultimate inundation zones (no time sequential data)

Cannot evaluate the effects of breakwaters, sea walls, land locks, water gates, etc.</td></tr>
</table>

2) Prediction by numerical simulation in time sequence

An overview of numerical simulation in time sequence is shown in Table 3.3.2. Numerical simulation by considering time series enables the collection of precise time-sequential data, such as inundation depth, flow speed, and inundation initiation time. Such data is necessary for devising non-structural measures like accurate tsunami and storm surge hazard maps, which helps people to evacuate safely. It is also useful to design structural measures suited to the characteristics of the inundation in the region.

Table 3.3.2 Numerical simulation in time sequence

Class	Contents
Tsunami simulation	• Numerical calculations for tsunamis should be in principle based on the non-linear long-wave theory. However, tsunami movements in the deep sea can be approximated to linear long waves. • Tsunami movements in shallow sea areas, including run-up on the land, should in principle be simulated using the theoretical equation of non-linear long waves (the shallow water theory), in which friction at the ocean bottom and advection are considered. • Cross oceanic propagation of a tsunami should in principle be calculated using the theory of linear dispersive waves. • Uncertain factors of calculation, such as the reflection rate, the conditions of wave tips, the coarseness of the ground, and the precision of calculation, should be decided based on the purpose of preparation, subjects of assessment, and technical levels at the time of preparation. • Tsunamis may not always exhibit the maximum rise and drop in water level during the first wave, and thus a sufficiently long period of time should be secured for estimating the maximum values.
Storm surge simulation	• Storm surges should in principle be simulated by using the non-linear long-wave theory, and storm surge movements in the deep sea can be approximated to linear long waves. • Storm surge movements in shallow sea areas and inundation of the land should in principle be simulated using the theoretical equation of non-linear long waves (shallow water theory), in which friction at the ocean bottom and advection are considered. • Uncertain factors of external force, such as the traveling speed of a typhoon, and uncertain factors of calculation, such as wave set-ups by breaking waves, the overtopping rate of irregular waves, the coarseness of the ground, and the precision of calculation, should be decided based on the purpose of preparation, subjects of assessment, and technical levels at the time of preparation. • Calculations must be conducted over a period until tidal deviations are not shown.

a) Earthquake fault model and initial water level (tsunami)

The largest possible tsunami that may strike a region must be considered for studying regional disaster prevention measures. An earthquake may cause vertical displacements of the ground (upheaval and sedimentation); an earthquake that causes the largest tsunami height is not necessarily an earthquake that causes the maximum inundation depth. Thus, earthquake fault models for tsunami hazard maps should be evaluated not only in terms of tsunami height but also in terms of inundation depth (difference between tsunami level and the ground elevation after a displacement). Inundation depth should be calculated by using the ground elevation described below in order to construct an earthquake fault model that can simulate the deepest inundation that has ever occurred or may possibly occur:

1) the ground elevation after sedimentation when the ground is predicted to subside,

2) the ground elevation before upheaval when the ground is predicted to upheaval.

The initial water level to be used in tsunami calculation for preparing tsunami hazard maps should in principle be determined by an earthquake fault model that is proven valid by tsunami reproducing calculations.

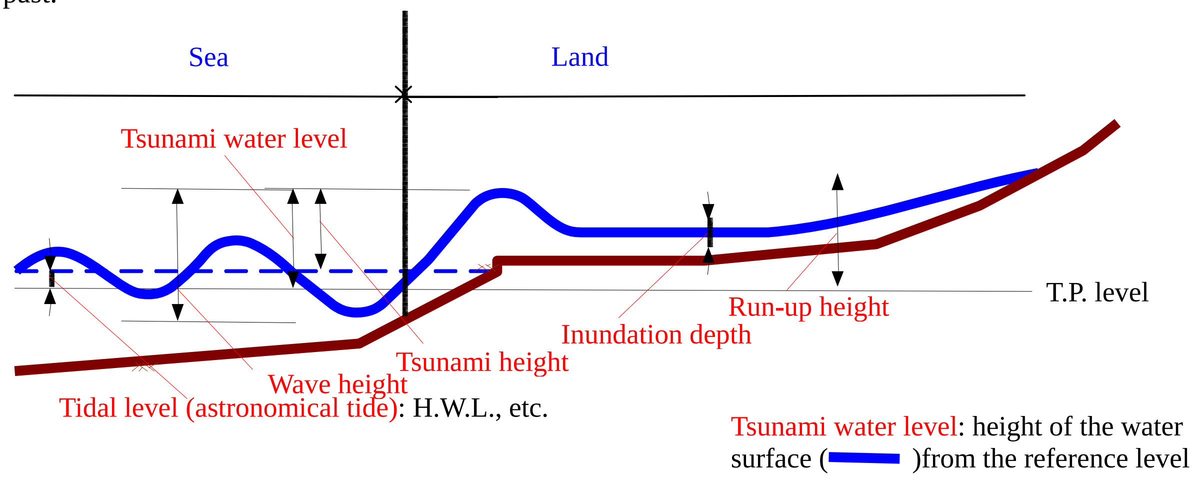
b) Scale and route of a typhoon (storm surge)

External forces to be considered in preparing storm surge hazard maps should be decided by the body in charge of preparing the map, based on the tidal deviation that can occur during a typhoon of the largest possible scale.

The scale of the largest possible typhoon should be assumed to be equivalent to that of the strongest typhoon which struck the region in the past or the Isewan Typhoon. As for the route of the typhoon to be considered for estimating inundation, the route that could cause the most serious damage in the region should be chosen by studying the routes of past typhoons.

c) Tidal level (astronomical tide) and wave height (tsunami and storm surge)

Tidal level (astronomical tide) for calculating tsunamis and storm surges should in principle be the syndic mean high water level (H.W.L.). Also, storm surge calculation should use the tidal deviation and wave height calculated based on the largest possible typhoon. When the maximum tidal deviation ever recorded is to be used for an assumed external force, the wave height should be decided by referring to measurements of the past.



Note: Tsunami height denotes the height of a tsunami.

Figure 3.3.1 Relationships among tidal level, wave height, tsunami height, inundation depth, and run-up height during a tsunami

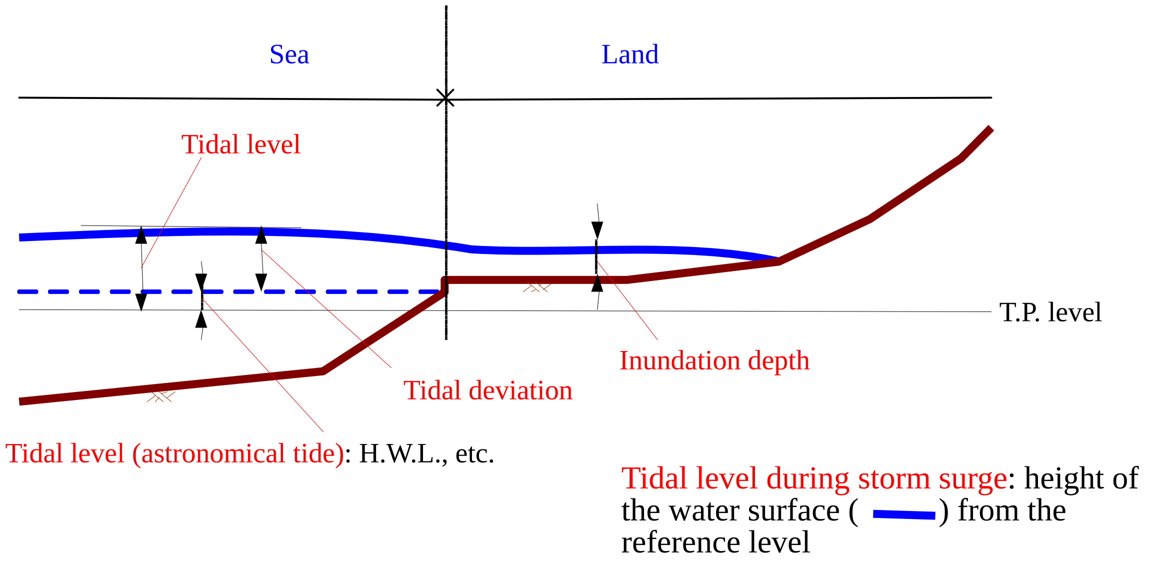


Figure 3.3.2　Relationship among tidal level, tidal deviation and inundation depth during storm surge

d) Grid intervals (tsunami and storm surge)

Grid intervals for calculating tsunamis and storm surges in the sea and land areas to be assessed should be appropriately determined so that:

The accuracy of inundation prediction is ensured, and modeled land forms, such as streams, are appropriately reflected in inundation prediction, and

Buildings and other structures are appropriately expressed as topographic models.

e) Elevation data (tsunami and storm surge)

Elevation data must have an accuracy of at least 1 m to properly estimate inundation depth. In areas where such precise data are not available, the necessary accuracy should be ensured by correcting topographic maps by using survey stations, conducting field surveys, having coast specialists check data or using other means.

f) Rivers (tsunami and storm surge)

Run-up of water along rivers should be calculated when necessary. The topographic conditions of rivers (shape and river bed elevation) should be expressed in calculation grids and elevation (water depth), and the conditions of structures, such as the crown height of river banks, should be set as well.

When inundation is predicted to occur from a river during storm surges, the discharge of the river should be appropriately determined based on the properties of the river and data from the past.

g) Structures (tsunami and storm surge)

To predict inundation by tsunami, damage to strucures should be first calculated by using the earthquake motion based on the selected earthquake fault model as an assumed external force. Then, inundation prediction should be performed, considering the calculated damage to structures.

When predicting inundation by tsunami for preparing hazard maps for residents, attention should be paid to structures that are higher than the water level during the propagation process of the tsunami (for example, banks, revetments, breakwaters, walls, and highway banks). Protection facilities, such as water gates and land locks, should be assumed to be open since it will possibly be difficult to close them before the tsunami arrives, considering that tsunamis travel fast and earthquake motion may possibly cause damage to the facilities. On the other hand, the following facilities should be assumed to be closed:

1) automated earthquake resistant facilities,
2) facilities that are always closed, and
3) earthquake resistant facilities that can be closed very quickly before a tsunami arrives.

To predict inundation during storm surges for preparing hazard maps for residents, damage to coast protection facilities by overflowing of storm surges and overtopping by high waves should be estimated, based on the present state of the facilities.

Water gates and land locks should be assumed to be closed except those that are evidently out of order. When the gates and locks are likely to be difficult to close, calculations should be performed, assuming that they are open.

For preparing hazard maps for administrators, the condition of coast protection facilities should be appropriately decided based on the purpose of investigation.

Table 3.3.3 Examples of facility conditions used for predicting inundation

	Inundation prediction during tsunami	Inundation prediction during storm surges
Banks, revetments, breakwaters, etc.	Damage to facilities by earthquake should be considered.	Facilities are assumed to function properly.
Water gates, land locks, etc.	Water gates and land locks are assumed to be open (tsunamis arrive fast and facilities are possibly damaged). They are assumed to be closed when they are: 1) automated, earthquake resistant facilities, 2) always closed, and 3) earthquake resistant facilities that can be closed very quickly before a tsunami arrives.	Water gates and land locks are assumed to be closed. Those that are known to not function (due to deterioration, etc.) are assumed to be open.
Notes	Conditions are decided based on the purpose of investigation for hazard maps for administrators. Example: The worst case – gates and locks are all open or there are no gates or locks. The maximum protection case – gates and locks are all closed.	

h) Data used for prediction and output data (tsunami and storm surge)

Care must be taken that the results of inundation prediction contain uncertainties. Tsunami and storm surge hazard maps are prepared by superimposing necessary information on maps of inundation risk areas and evacuation zones, which are identified based on the inundation areas identified by inundation prediction. Thus, the results of prediction should be prepared in forms that can be processed with the geological information system (GIS). The same is true for data used for prediction, since they will possibly be processed into hazard maps and revised in the future. The data format should be a general format to facilitate efficient construction and revision of hazard maps and sharing of data among related parties and experts.

3) Possibility of disaster beyond prediction

It must also be noted that disasters can possibly occur with external forces that are beyond prediction. Extra care should be taken to keep consistency among adjacent municipalities in terms of condition settings when the disaster to investigate is likely to cause damage over two or more municipalities. Conditions that cannot be analyzed with today’s technologies should be considered in the future. Conditions that are not yet established today are shown in Table 3.3.4.

Table 3.3.4 Non-established conditions

Class	Non-established conditions
Tsunami	• Standardized method for analyzing ground displacement • Optimum values of fault parameters and coefficient of coast friction • Method for considering buildings, houses, and other structures in grid systems • Simulation of formation of undular bore in rivers • Simulation of soliton fission and undular bore
Storm surge	• Behavior of water when storm surge water runs up a river and floodwater flows down the river at the same time • Conditions for levee breaches • Predicting the width of levee breaches • Predicting the time of levee breaches

4) Evaluating prediction

Underestimation is likely to result in predicting the inundation depth in the worst case scenario as being too low, which may lead to insufficient evacuation measures and loss of human life. On the other hand, overestimation causes disaster prevention facilities to be constructed in excess. To prevent both under- and overestimation, prediction results should be appropriately validated by regional development bureaus, and/or the coast division of each prefectural government, before the results are open to residents.

Chapter 4 Methods for preparing tsunami and storm surge hazard maps from the results of inundation prediction

4.1 Considerations for preparing hazard maps for specific purposes

4.1.1 Purposes of hazard maps

> Tsunami and storm surge hazard maps should be prepared to serve specific purposes. This manual describes methods for preparing two types of hazard maps as typical examples: those for residents and those for administrators. Hazard maps can also be prepared to serve region-specific purposes.

The contents and expressions of tsunami and storm surge hazard maps must correspond to the purpose of preparation. In Chapter 4, the contents and expressions of two typical types of hazard maps, namely those for residents and administrators, are described. Main users of the maps, and the utilization methods of such maps at each stage of a disaster, are shown in Table 4.1.1, and considerations for each hazard maps are shown in Table 4.1.2.

Hazard maps should also be prepared if necessary for other parties other than residents and administrators, such as for companies that have factories in inundation risk areas, fishermen, and people working at ports and harbours, by including information and expressions appropriate to the purposes of the maps.

Hazard maps can be used as a tool for risk communication between residents and governments, and can help them share information about risks, costs, and ways disaster prevention measures should be carried out.

Table 4.1.1 Users of tsunami and storm surge maps and utilization methods at each stage of disaster

Stage of disaster	Users	Utilization method
Before disaster	Residents	Collect information for evacuation activities, and learn about disasters and the region (land use, etc.)
	Administrators	Draw up and execute preventive measures (by constructing evacuation sites and disaster prevention facilities)
Immediately before disaster (storm surge)	Residents	Collect information about tsunami or storm surge (such as the height of high tides) and evacuation sites
	Administrators	Draw up and execute emergency measures (evacuation plans, rescue plans, etc.)
After disaster	Residents	Collect information after evacuation (orders from municipal governments, etc.)
	Administrators	Draw up and execute emergency measures (evacuation and rescue plans)

Table 4.1.2 Considerations for each hazard map

Who	When and where	What	Why and how to use
Residents	Before disaster, at home	Hazard maps for residents	To understand the risks of tsunamis and storm surges at residences, and to be aware of evacuation sites and routes
Residents	Immediately before disaster, at a place to decide evacuation	Hazard maps for residents	To appropriately decide on evacuation based on meteorological information and peripheral conditions
Residents	After disaster, at evacuation site	Hazard maps for residents	To collect basic information from municipal governments after evacuation
Administrators	Before, immediately before, and after disaster at working places	Hazard maps for administrators	To draw up plans for evacuation, construction, operation, and rescue, according to disaster situations (for example, for coast administrators to gain a correct understanding of the performances of protection facilities against tsunamis and storm surges)

4.1.2 External forces for different purposes

It is important to set external forces appropriate for individual purposes of hazard maps, so that inundation risk areas for tsunami and storm surge hazard maps can be appropriately identified based on the purpose of preparation and the characteristics of the region.

It is important to set external forces appropriate for individual purposes of hazard maps, so that inundation risk areas can be appropriately identified based on the purpose of preparation and the characteristics of the region. As described in Chapter 3, external forces for predicting inundation should be decided by comparatively investigating two or more patterns, depending on different conditions. The three external force levels shown in Tables 3.2.2 and 3.2.3 should be at least taken into consideration.

Hazard maps for residents must show the worst possible inundation in order to ensure evacuation of residents. On the other hand, hazard maps for administrators need to be prepared to serve different possibilities, including situations caused by relatively small-scale disasters that are more likely to occur before the completion of structural measures than large-scale ones (Table 4.1.3).

In this manual, inundation risk areas are to be identified by individually considering either tsunamis or storm surges as the external force, and inundation information for cases where they occur simultaneously should be included by devising appropriate display methods (See *4.4 Methods for displaying predicted inundation risk areas and evacuation areas* for display methods). Maps may be prepared by considering simultaneous occurrence of tsunamis and storm surges depending on regional characteristics.

Table 4.1.3 Inundation information and external force level for each hazard map purpose

User	Purpose	Stage of utilization	Inundation information to be included	External force
Residents	Smooth evacuation	Before disaster To understand risk	Inundation to be prevented by facilities	Level 2
			Worst inundation case	Level 3
		Immediately before disaster To know a safe place (evacuation site)	Inundation to be prevented by facilities	Level 2
			Worst inundation case	Level 3
Division in charge of disaster prevention	Smooth evacuation	Before disaster To plan evacuation	Inundation during facility construction	Level 1
			Inundation to be prevented by facilities	Level 2
			Worst inundation case	Level 3
		Immediately before and during disasters To issue evacuation-related orders	Inundation during facility construction	Level 1
			Inundation to be prevented by facilities	Level 2
			Worst inundation case	Level 3
Division in charge of disaster prevention facilities	Effective facilities	Before disasters (when construction plans are drawn up) To decide the need of constructing and improving facilities	Inundation during facility construction	Level 1
			Inundation to be prevented by facilities	Level 2
			Worst inundation case	Level 3

4.1.3 Other considerations

(1) Userfriendliness

Tsunami and storm surge hazard maps for residents must be userfrendly.

Hazard maps for residents will be used for evacuation during disasters. If residents fail to correctly understand the information on the map and make an incorrect decision, they may lose their lives. Thus, hazard maps for residents must be easy-to-understand for all of them.

(2) Flexibility of ideas

Tsunami and storm surge hazard maps should be prepared so as to help flexibility of ideas.

Inundation risk areas and evacuation zones shown in a tsunami and storm surge hazard map is merely the result of prediction under a certain condition. Showing the areas on the maps may cause residents to believe that only the areas shown on the maps will inundate during disasters.

Fixed ideas about disasters may give residents false feelings of safety and inhibit smooth evacuation. Thus, measures should be taken to prevent residents from having fixed ideas, such as by printing in bold letters “Areas other than those shown may inundate,” and “The actual inundation depth may exceed this value,” although few measures are available for displaying information on paper maps. Other measures should also be taken such as distributing leaflets showing such additional information as inundation predictions under different conditions, communicating risks to residents using tsunami and storm surge hazard maps, and participation of residents in preparing the maps.

(3) Participation of residents in preparing tsunami and storm surge hazard maps for residents

> By participating in preparation of tsunami and storm surge hazard maps, residents can help incorporate regional characteristics into the maps, become aware of them, confirm them as well as find more opportunities to use the maps.

In preparing hazard maps for residents, their participation is extremely important to incorporate regional characteristics into the maps as well as for residents to become aware of and confirm those characteristics and to find more opportunities to use the maps. By adding, for example, evacuation routes to the maps by residents themselves based on their own judgment regarding the regional characteristics and possible situations, the maps can serve their purposes more usefully and effectively at evacuation than the ones completed and distributed by an administrative body.

Participation of residents in preparing tsunami and storm surge maps can promote risk communication between residents and administrative bodies, and it can also make residents feel that they are voluntarily preparing the maps, which is an indispensable feeling for promoting frequent and effective use of the maps. Workshops are one of the effective ways to promote residents' participation (See *5.2 Measures for promoting the understanding of residents* for workshops).

(4) Characteristics of tsunami and storm surge disasters

> Tsunami and storm surge hazard maps must be prepared by considering the characteristics of tsunami and storm surge disasters, and the risks and related information must be appropriately expressed.

Table 4.1.4 shows characteristics of tsunami and storm surge disasters and the corresponding precautions to be taken when prepareing tsunami and storm surge hazard maps for residents.

Table 4.1.4 Characteristics of tsunami and storm surge disasters and the corresponding precautions when preparing hazard maps for residents

Class	Characteristics to note
Tsunami	● A tsunami may arrive soon after an earthquake. → Residents need to evacuate as soon as earthquake motion is felt. ●Buildings may collapse during an earthquake. → Collapsed buildings may block evacuation routes. ●Tsunamis cause characteristic damage → Care must be taken regarding backwash and flow speed.
Storm surge	●A storm surge can be predicted by monitoring an approaching typhoon. → Residents have time to decide on evacuation. ●Typhoons bring storms when they approach → Evacuation is difficult during storms.
Both	●Residents may create fixed impressions of disasters from hazard maps. → Effors must be made to avoid creating fixed impressions. (Information such as detailed simulation results should be included not in a map but in a separate booklet for residents to learn about disasters since such information may lead them to create fixed impressions.)

4.1.4 Naming hazard maps for residents

Easy-to-understand names should be given to hazard maps when they are distributed to residents.

Maps that carries necessary information for disaster prevention in addition to inundation risk areas during tsunamis and storm surges are called “hazard maps”, but names that are easy to understand should be given to them when they are distributed to residents, such as “disaster prevention map”, “tsunami evacuation map”, and “storm surge risk map”.

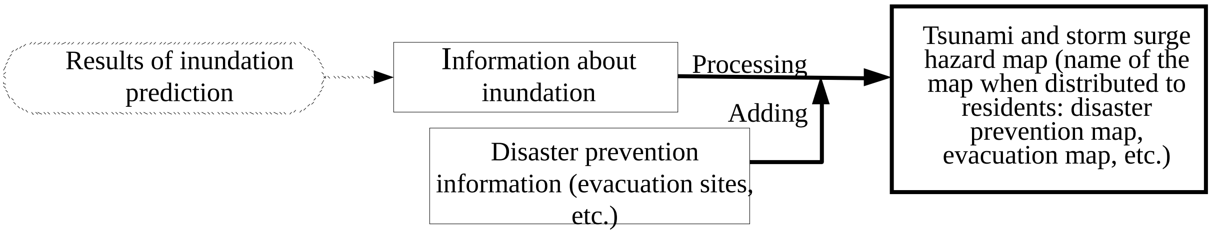


Figure 4.1.1 Concept of giving a name to tsunami and storm surge hazard maps for residents

4.2 Information to be included in hazard maps for residents

(1) “Information for evacuation” and “information for understanding disasters”

Information needed for smooth evacuation of residents is classified into “information for evacuation” and “information for understanding disasters”. “Information for evacuation” is necessary information regarding evacuation, such as evacuation sites and routes. “Information for understanding disasters” is information, such as outlines of tsunami and storm surge disasters, for increasing local residents’ awareness about disasters. Especially, critical information about the characteristics of disasters, regional characteristics, and earthquakes related to tsunamis are important as “information for understanding disasters”.

1) <u>“Information for evacuation” and “information for understanding disasters”</u>

Information needed for smooth evacuation of residents includes an illustrated or written form of “information for evacuation” and “information for understanding disasters”.

Information for evacuation must include inundation risk areas, evacuation sites, evacuation routes, and other indispensable information for evacuation. Notes about external forces that exceed assumptions should be stated, and to ensure safe evacuation, possible risk areas may be added outside inundation risk areas, both of which form evacuation zones. (possible risk areas and evacuation zones are described in *4.4 Methods for displaying predicted inundation risk areas and evacuation areas*). Tsunami hazard maps must include the estimated inundation initiation time, the direction of inundation, inundation depth; buildings that will not inundate, evacuation sites, and evacuation routes must be marked in the way they are easily recognized. Storm surge hazard maps must include precise inundation depths, inundation risk areas; evacuation sites, evacuation routes, and individual buildings must be presented in a simple and easy-to-recognize manner.

Information for understanding disasters is information helping residents to understand what tsunami/storm surge disasters are like. Records of disasters in the past (inundated areas, etc.), the current status of coast protection facilities and their effects may also be useful information for increasing residents’ awareness about disaster prevention and about self-help and mutual assistnace as well as enhancing residents’ understanding of the development of disaster prevention facilities.

2) <u>Other information</u>

Information specific to each region should also be included. For example, statements in languages other than Japanese should be included in maps for areas where many residents are non-Japanese speakers. Information on disaster characteristics should be included, such as the strong backwash and high flow speeds of tsunamis. For tsunami hazard maps, information related to earthquakes (such as densely-packed areas of wooden buildings that are prone to collapse and block streets during an earthquake, and steep slopes that are prone to cause landslides) is also important, since such information influence people’s decisions about where to evacuate and/or which routes to take.

Which site to evacuate should be determined by considering its capacity and the extent of the damage it has suffered.

Adding photographs of past disasters can be an effective way for people to realize how devastating they can be.

Displaying all these on a single map may result in a map which is complicated and difficult to understand. Thus, information to be included must be selected by considering the purpose of the map as shown in Table 4.2.1.

Table 4.2.1 Information needed for smooth evacuation of residents at each stage

	Class	Information	Notes
To evacuate	Information needed during evacuation	・Inundation prediction (inundation risk areas, inundation depth, arrival time, etc.) ・Evacuation sites (including public facilities, schools, hospitals, buildings specified for evacuation, etc.) ・Evacuation routes and dangerous spots (including spots prone to sediment-related disasters) ・Information on earthquake-related disasters (including landslide risk areas and the locations of chemical factories, etc.)	・Must be displayed in a simple and easy-to-understand manner. ・Should be included in principal maps.
	Information for investigating evacuation during normal times	・Risk information based on the characteristics of disasters (including the fast approaching speed/strong receding force of tsunamis, etc.) ・Inundation in the past (largest inundation area, maximum inundation depth) ・State of coast protection facilities (crown height of banks, revetments, design crown height, deterioration, etc.) ・Evacuation zones (risk rank, facilities needing assistance in evacuate, locations of subways and underground malls, etc.) ・Evacuation standards (standards for issuing evacuation orders, determination of external force values, importance of voluntary evacuation, etc.) ・Tips for evacuation, family rules about evacuation, etc. ・Methods for transmitting information (routes and means of transmitting information to residents, and methods for collecting information) ・Distribution of earthquake motion when strong tremors are anticipated	・Should be displayed separately from information that is needed during evacuation. ・Should be separately printed on the other side of the map or in leaflets, etc. ・Should be stated in an easy-to-understand manner.
To learn or educate	Information to educate on disasters during normal times	・Generation mechanisms of tsunamis and storm surges (meteorological factors, earthquakes, and topographic characteristics) ・Risk of tsunamis and storm surges (flood configuration, damage, and flooding and damage by multiple causes) ・Basic knowledge about meteorology and earthquakes (terms, rain patterns, earthquake intensity, etc.) ・Information about tsunamis and storm surges in the past (meteorological and hydrological data, hypocenters, earthquake intensity, inundation, damage, and evacuation) ・History of protection facility construction and the effects of the facilities ・History of the region (history of landform formation, city formation, disasters)	

	Explanations of hazard maps, etc.	・Methods for reading and using hazard maps ・Routes of transmitting disaster prevention information ・Tips for normal times, tsunamis, and storm surges ・Contact numbers during emergencies (lifelines, police, and fire department) ・Ways to deal with the situations after evacuation ・Body in charge of preparing maps, leaflets, etc. (name and date)	

(2) Basic information to be included in hazard maps for residents

> Hazard maps for residents should include the minimum amount of information that is indispensable for evacuation. The information should be expressed in a simple and easy-to-understand manner so as to be helpful for everyone.

Hazard maps for residents should include the minimum amount of information that is indispensable for evacuation since the map size is limited. Also, the information should be expressed in a simple and easy-to-understand manner so as to be helpful for everyone.

Information for evacuation is more relevant to hazard maps for residents than information for understanding disasters. Information for evacuation includes basic information for evacuation, which is essential and fundamental, and additional information for evacuation, which is specific to the region; both kinds should be included in hazard maps for residents. Table 4.2.2 shows a list of information to be included in hazard maps for residents.

When displaying information in a map, precautions should be taken to avoid giving fixed impressions of disasters to residents by stating the uncertainty of inundation prediction. Since the predicted arrival time and inundation initiation time are uncertain, the effects of such uncertainty on residents' decisions about evacuation should be considered.

Information for understanding disasters and investigating evacuation during normal times should be distributed in different forms such as leaflets, separately from hazard maps. Measures may also need to be taken such as displaying the inundation risk areas in the entire municipality on the front and displaying regional evacuation information for each district on the back.

Table 4.2.2 Information to be included in hazard maps for residents (basic design)

Item	Basic design (draft) (B: Basic information, N: points to note)			
Concept	Minimum amount of information indispensable for evacuation should be displayed in a simple and easy-to-understand manner.			
Scale	Scale enabling residents to investigate evacuation (each house should be able to be identified if necessary)			
Information to be included in hazard maps for residents	Basic information for evacuation (the information which basically	External force	One of the assumed external forces	B: External force that may cause the most serious inundation (Level 3) (Level 2 (design force) may be used) N: It should be consistent with assumed damage already announced.
		Inundation	Inundation risk area	B: Care must be taken to avoid giving fixed ideas.

	should be included)		Possible risk area	B: Possible risk areas should be set by either elevation, district numbers, or principal highways, depending on regional characteristics.
		Disaster prevention	Evacuation site	B: Designated evacuation sites/buildings N: Hills and tall buildings should also be examined.
			Evacuation route	B: Designated evacuation routes and important points on the routes (such as bridges and cliffs) N: They should be examined at workshops, etc.
	Additional information for evacuation (the region-specific information which is necessary to display for the minimum amount)	External force	External forces other than the one assumed in the basic information for evacuation	B: Tsunami level predicted by the Meteorological Agency and typhoon information when residents can judge the differences in external force.
		Inundation	Predicted deepest water depth, arrival time, and dangerous sites	B: Predicted deepest water depth and arrival time should also be stated when they should be published. N: The information may be stated in text.
		Disaster prevention	Inundation records, state of protection facilities, ground elevation, facilities that need assistance to evacuate, underground spaces to evacuate, evacuation standards, tips, rules, etc.	N: The minimum amount may be included depending on regional needs.
Size and shape	-Size and shape should be adjusted for home use (about A3, for posting on a refrigerator, coordination with garbage collection schedules, municipal information booklets, etc.) -Form should be adjusted for portable use upon evacuation (use of fluorescent ink, water-proof paper, etc.)			

Note: The table assumes hazard maps for residents, and the size and shape presented here may not apply to hazard maps for workshops and educational activities.

4.3 Information to be included in hazard maps for administrators

> Hazard maps for administrators should include “information for preventive measures” and “information for emergency measures” depending on preparation purposes of each governmental division. Information for each purpose should be superimposed on a map showing basic information, which is common information such as precise inundation risk areas.

Hazard maps for administrators should include “information for preventive measures” and “information for emergency measures” depending on preparation purposes of each governmental division. Information needed for each purpose should be superimposed on a map showing precise inundation risk areas.

Information for preventive measures includes information needed for constructing evacuation sites and routes, selecting appropriate sites for establishing disaster prevention headquarters, educating governmental personnel in disaster prevention, and drawing up land use and regional development plans (Table 4.3.1). On the other hand, information for emergency measures includes information that can be used for drawing up plans for evacuation, rescue and facility operation.

Table 4.3.1 Example of using hazard maps for administration

Purpose	Utilization
Preventive measures	(1) Constructing evacuation sites and routes (2) Selecting appropriate sites for establishing disaster prevention headquarters (3) Educating personnel about disaster prevention (4) Drawing up land use and regional development plans (5) Reviewing facility construction and improvement
Emergency measures	(1) Drawing up evacuation and rescue plans (2) Drawing up plan for operating facilities

Hazard maps for disaster prevention should include the predicted number of affected people, its distribution, and the locations/capacities of evacuation sites and routes, which are considered useful for both preventive and emergency measures.

Hazard maps for coast management administrators should include facility information, such as the locations/structures of facilities, facilities that are prone to damage, and the results of stability calculations/liquefaction reviews, which are considered useful for taking preventive and emergency measures. Table 4.3.2 shows information that is considered necessary for inclusion, based on the Manual for Predicting Tsunami Disasters. Information must be selected so as to cope with objectives of each map (Table 4.3.3).

For reference, methods for utilizing information during disasters and when taking disaster prevention measures are shown in Reference 2.

Table 4.3.2 Basic information to be included in hazard maps for administrators

	Basic information	Information for each purpose
External force	・One of the assumed external forces	・Other external forces depending on purpose
Inundation	・Inundation risk areas ・Predicted deepest inundation depth ・Predicted inundation initiation time and place ・Evacuation zones	・Disasters in the past
Disaster prevention	・Protection line ・Population distribution ・Land use ・Transportation routes during emergency ・Earthquake-resistant berths ・Evacuation facilities ・Evacuation sites ・Evacuation routes	・Disaster prevention centers ・Police, fire department ・Public facilities ・Facilities needing assistance to evacuate ・Power facilities ・Coast protection facilities

Table 4.3.3 Examples of information to be included in hazard maps for administrators

Class	Examples of information to be included (information to be layered)	Notes
Basic information	Precise inundation prediction (inundation risk area, predicted deepest inundation depth, initiation time, initiation site, and evacuation zone)	Basic information for all kinds of investigation into tsunami and storm surge disasters
	Topography	
	Protection facility	
	Overview of the region (population distribution and land use)	
	Emergency transportation routes, earthquake-proof berths, and evacuation facilities	
Information depending on purpose	Tsunami and storm surge disasters in the past (inundation areas and damaged areas)	Necessary information should be layered over the basic information considering the following: -Planning stage (preventive measures, emergency measures) -Disaster stage (immediately before and after disaster, emergency response, and restoration) -Kinds of service
	Disaster prevention centers (national, prefectural and municipal governments) [Police stations/boxes, fire headquarters/stations, meteorological observatories/stations, disaster prevention centers, communication facilities, governmental radio communication network for disaster prevention, seawalls, water gates, flood prevention warehouse, water supply centers, emergency vehicle bases]	
	Evacuation facilities (emergency meeting places, evacuation sites (emergency shelters), evacuation routes, heliports, evacuation ports, etc.), capacities and earthquake resistance of evacuation sites	
	Public facilities (transportation facilities (roads, railways, ports, airports, etc.), specifications of subways and underground malls (locations, elevations of entrances, etc.) [Power facilities (power stations, substations, and transmission lines), gas supply facilities, water supply facilities, sewerage facilities, telephone/telecommunication facilities (stations and principal lines), schools, community halls, hospitals, health centers, elderly care facilities, kindergartens, nursery schools, welfare facilities]	
	Controlled areas under the laws concerning disaster prevention (coastal protection areas, harbour areas, fishery port areas, national parks, quasi-national parks, control traffic zones, etc.)	
	Coastal protection facilities (locations and structures, facilities that are prone to damage, results of stability calculation/liquefaction review, elevation of pumping stations)	

4.4 Methods for displaying predicted inundation risk areas and evacuation zones

(1) Inundation risk areas and evacuation zones

> Inundation risk areas and evacuation zones should be displayed on a hazard map so as to serve the purpose of the map. It should be noted that the prediction of inundation risk areas contains uncertainty.

The results of inundation prediction conducted in Chapter 3 should be processed according to the purpose of the hazard map, and should be displayed as inundation risk areas and evacuation zones. It should be noted that the prediction is made based on a certain assumption and contains uncertainty. The flow of processing inundation prediction results into inundation risk areas and evacuation zones is shown in Figure 4.4.1.

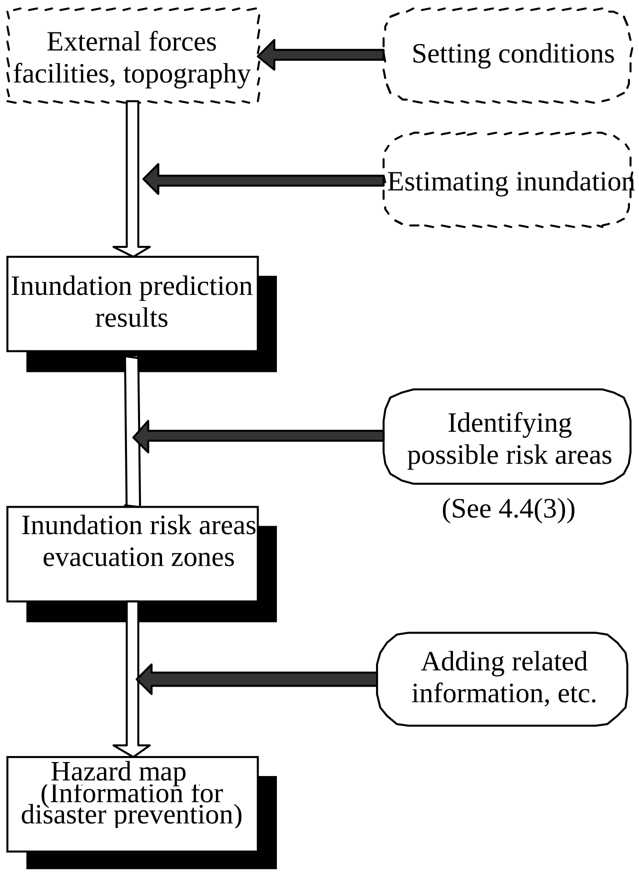


Figure 4.4.1 Flow of processing inundation prediction results into inundation risk areas and evacuation zones

(2) Accuracy of displaying inundation risk areas

> Inundation risk areas should be displayed in as small a grid size as possible and by using as detailed topography as possible so as to correctly reflect actual landforms.

Inundation risk areas are the basis of all kinds of investigation and must be correctly displayed. Tsunami and storm surge hazard maps should show topographic data as precisely as possible in the smallest grid size possible so that users can identify inundation areas, inundation depth, each building, evacuation sites and inundation conditions along evacuation routes in order to make sound judgment for evacuation and to select a safe evacuation route. The maps should be prepared with representational accuracy that is good enough to allow users to identify side ditches along evacuation routes, houses and bridges that may collapse, the structural characteristics of water gates and land locks, topographic characteristics, and the characteristics of rivers. Here, grid size denotes the side of the grid to be displayed on maps, not the grid intervals for predicting inundation.

Precise inundation depth can be displayed by the method in Figure 4.4.2 using precise topographic data, such as elevation. However, it should be noted that the precision of displayed inundation depth depends on the precision of the prediction.

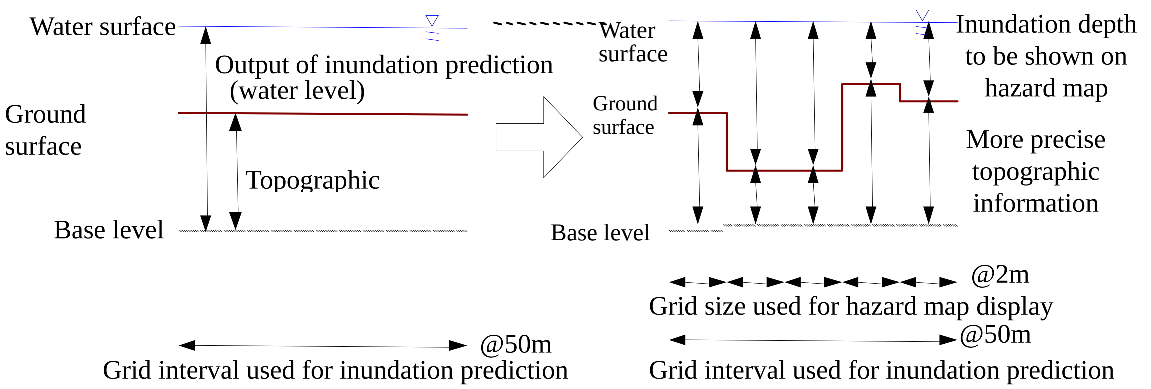


Figure 4.4.2 Method for precise display of inundation depth

(3) Methods for displaying inundation risk areas and evacuation zones

> Inundation-related information that is used to investigate evacuation includes inundation area, inundation depth, inundation initiation time, and innundation speed. To ensure evacuation, possible risk areas, in addition to inundation risk areas, should be included in evacuation zones. Possible risk areas are areas that are not predicted to be inundated but are possible to be inundated considering the uncertainty of prediction. Such zones should be designated outside inundation risk areas by considering the characteristics of disasters, topography and occupancy of the areas.

1) <u>Information on inundation for investigating evacuation</u>

Information on inundation for investigating evacuation includes inundation area, inundation depth, inundation initiation time, and flow speed.

2) <u>Method for displaying inundation areas to investigate evacuation</u>

Inundation depth should be shown on tsunami and storm surge hazard maps on the basis of elevation (T.P.). Maps should also show a statement describing the need to consider external forces larger than those assumed, since the prediction of inundation areas contains uncertainty. Measures should also be devised for drawing users' attention to the uncertainty of prediction.

One of such measures is to show two or more prediction results by using different external forces. For example, the prediction results based on the largest storm surge in the area and the largest external force experienced by the country (for example, Isewan Typhoon for Japan) can be stated on hazard maps. Since using two different external forces may often complicate the prediction procedure, however, a simple method for estimating inundation risk areas based on one external force is shown in Figure 4.4.3. The figure illustrates how possible risk areas can be displayed outside inundation risk areas. Here, "possible risk area" denotes an area that is predicted to escape inundation but which cannot rule out the possibility of innundation if the uncertainty of prediction is taken into account. In most cases, there being almost no difference in risk between either side of the boundary, the areas should be shown in color gradation to prevent misunderstanding, as illustrated in Figure 4.4.3. Prediction may give completely different results depending on conditions used, and conditions appropriate for each region must be considered.

Possible risk aras can be identified using the method shown in Table 4.4.1. However, other methods should also be considered so as to use a method which is appropriate for the region and other conditions. For example, areas below certain elevation can be designated as possible risk areas, but evacuation orders can be issued to residents according to administrative district boundaries. When this method results in an excessively large possible risk area which is unrealistic, multiple inundation predictions by using different external forces and facility conditions are a possible way to accommodate the uncertainty of prediction.

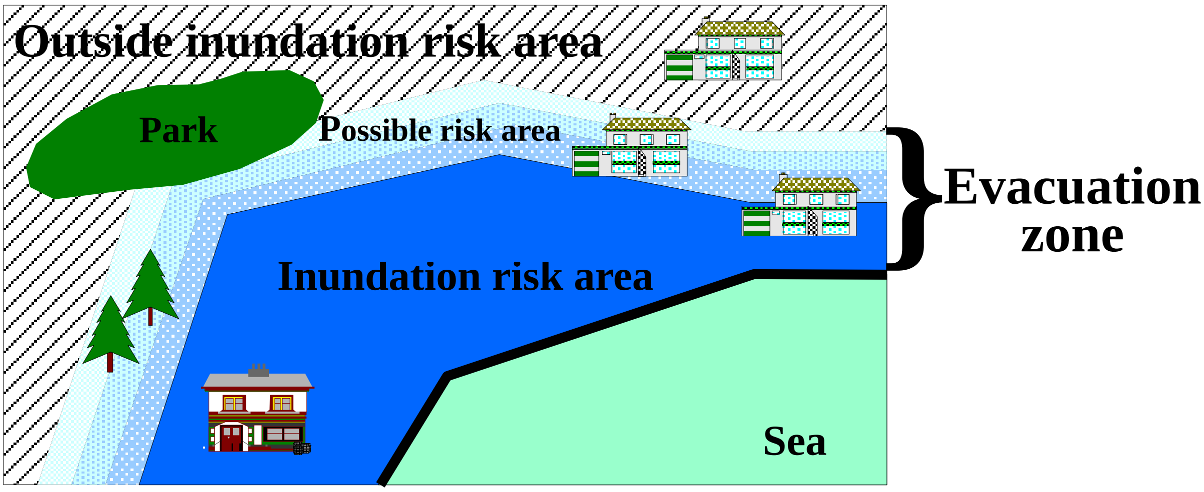


Figure 4.4.3 Schematic diagram of possible risk area

Table 4.4.1 Methods for setting areas to evacuate

Class		Method
Based on landform	Elevation	Areas lower than X m in elevation (predicted maximum inundation depth plus Y percent) are set as evacuation zones.
Based on administrative perspectives	Streets and highways	Areas that are outside an inundation risk area and surrounded by large streets and highways are set as evacuation zones.
	Districts	Districts adjacent to inundation risk areas are set as evacuation zones.

(4) Methods for displaying information about inundation

> Hazard maps must transmit appropriate information about inundation. Display methods should be devised so that residents can easily imagine inundation damage.
> Tsunami hazard maps should display information so that users understand the direction to evacuate and locate buildings and sites that will not inundate.
> Storm surge maps should display information so that users understand the time and direction to evacuate, locate buildings and sites that will not be inundated, and avoid inundation risk spots along evacuation routes.

1) Displaying information about inundation on tsunami hazard maps

Inundation depths should be displayed, such as inundation up to the first floor, to the second floor, etc. Hazard maps should also be devised to carry information characteristic of tsunamis, such as backwash and fast flow speed, and buildings that will not be inundated and can be used for emergency shelter.

Inundation initiation time should be displayed in units of 5 minutes after an earthquake when it is effective for deciding the time and direction to evacuate. In some cases, it is better not to show inundation initiation time. When inundation initiation time is displayed together with inundation depth, use of arrows to show directions of inundation, use of contours and hatching to show inundation initiation time, and use of other methods, should be considered to prevent misinterpretation.

2) Displaying information about inundation on storm surge hazard maps

Inundation depths should be shown in relation to human body parts (heel (15 cm), knee (50 cm), waist (80 cm), chest (1.2 m), and over).

Inundation initiation time should be displayed in units of 30 minutes after the start of inundation. When inundation initiation time is displayed together with inundation depth, use of contours and hatching to show inundation initiation time, and other methods, should be considered to prevent misinterpretation.

3) Considerations for displaying information about inundation

Information about inundation can be displayed by using the methods described above and by flexibly meeting the requests of residents which are collected during workshops.

(5) Superimposing necessary information

> In preparing tsunami and storm surge hazard maps, inundation information and other relevant information should be based on data from the geological information system (GIS), so that such information can be provided upon request for various investigations using those maps.

1) Necessary data for displaying inundation and background information

To display inundation and background information, the following data are needed:

Inundation depth data: used for two-dimensional expression of information related inundation risk areas such as inundation initiation time and deepest inundation depth;

Ground elevation data: used to express inundation states;

Data on buildings and evacuation sites: used to express individual houses, and facilities/buildings that will serve as evacuation sites, and

Other background data: used to express information along evacuation routes.

2) Overview of basic data

a) Inundation depth data

Inundation depth data should be collected from the results of inundation prediction. The data includes location, inundation initiation time, and deepest inundation depth. The data should be converted into GIS data to be superimposed with other background data for investigations. To express precise inundation depth estimated from inundation prediction, the precise ground elevation data in b) should be used.

b) Ground elevation data

Ground elevation data throughout Japan is available from "numerical maps 50m mesh (elevation)" of the Geographical Survey Institute. The maps are inexpensive, but care must be taken since they have relatively coarse grid intervals and contain errors. City plan maps, etc. can be used to correct elevation.

Recently introduced aerial laser survey technology can provide precise ground elevation data, which can express inundation areas in 2 m grids, but surveys are quite expensive.

c) Data on buildings and evacuation sites

When a municipal government has electronic city plan maps of 1:2,500, such maps can be used. However, most of the maps show no names of buildings, and names should be added for evacuation sites.

Other available data on buildings is electronic residential map data sold by map makers. Names and floor numbers of buildings are already included in the data. When hazard maps using this data are to be distributed, it should be noted that contracts may need to be made with the makers.

d) Other background data

Data on roads is available from electronic 1:2,500 city plan maps prepared by municipal governments and from the numerical map 2500 (national land space data infrastructure) of the Geographical Survey Institute. Electronic residential map data described in c) also contains precise background data.

Precise ground elevation data collected by aerial laser survey and images from satellites can be superimposed by using GIS.

3) Coordination with various investigations

Data should be prepared by using the geological information system (GIS), so that the data can be provided on request for various investigations using hazard maps.

Chapter 5 Use of tsunami and storm surge hazard maps

5.1 Disseminating tsunami and storm surge hazard maps

(1) Importance of disseminating tsunami and storm surge hazard maps

> To effectively utilize hazard maps for residents in the prevention of disasters during tsunamis and storm surges, it is important to thoroughly inform residents of the maps, and measures should be taken to do so.
>
> Measures should also be employed to prevent users from having fixed ideas on disasters, since the inundation information shown on the maps contains uncertainty.

Mere distribution of tsunami and storm surge hazard 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 hazard maps is essential. Also, users may not take proper evacuation actions, mistakenly assuming that only the inundation risk areas on the maps will be dangerous. Thus, measures should be devised to avoid giving users fixed ideas in distributing or posting hazard maps. (See *4.1.3 Basic considerations for preparing tsunami and storm surge hazard maps* for methods of avoiding fixed ideas.)

(2) Ways to disseminating hazard maps

> Tsunami and storm surge hazard maps should be distributed to each household and posted on community bulletin boards to promote residents' awareness of disasters.
>
> Information related to disaster prevention can be provided to residents by distributing printed materials, setting up bulletin boards, using the Internet, etc.
>
> Methods should also be devised for disaster-vulnerable people, such as the handicapped, elderly, and children as well as for foreigners, tourists, drivers, etc.

1) Tools for disseminating hazard maps

a) Printed hazard maps

Distributing a hazard map to each household is the most basic way to inform residents. However, careful attention should be paid t to the size and a distribution method of the map.

Hazard maps are often seen placed between pages of community information bulletins. In this way, maps may have little chance to be noticed because people often thrown away those bulletins without reading. Hazard maps are better delivered alone, or handed out at fire/flood drills. Also, asking residents to bring their hazard maps to fire/flood drills will be effective in raising their awareness of the maps.

The best size may be just large enough to post on a refrigerator.

b) Bulletin boards and signs

Bulletin boards are useful in posting hazard 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 hazard maps at bus stops, railway stations, and other public spaces, is also effective in informing tourists and visitors.

Universal design, such as pictograms, should be used for signs on hazard maps, because it ensures easy understanding for all sorts of people.

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. Thus, distributing hazard maps to residents though those media should be 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. Hazard 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 hazard maps

Hazard 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 are not fluent in Japanese should also be considered.

Since tsunamis may affect not only the land but also ships, etc., at sea, methods should be investigated to inform people engaged in ship operation (cargo vessels, working ships, fishing boats, pleasure boats, etc.) and fish farming about the possible disasters and measures to deal with them. Measures should also be investigated for people working at ports, since their work sites are prone to damage during tsunamis and storm surges.

5.2 Ways to promote the understanding of residents about hazard maps

(1) Need of residents' participation

Tsunami and storm surge hazard maps should not be unilaterally prepared by governments and distributed to residents, but should be prepared together with residents to promote their understanding of inundation risk areas, evacuation zones, and use of the maps.

Residents' participation should be encouraged in order to reflect local information in tsunami and storm surge hazard maps and to promote their understanding of the maps.

Local evacuation plans during tsunamis and storm surges 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 hazard map preparation through workshops and through risk communication between residents and administrative bodies is essential for promoting the use of tsunami and storm surge hazard maps.

Participants should represent various groups, such as communities, chambers of commerce and industry, and youth associations.

Other ways to promote the understanding of residents include:

- Holding local study meetings,
- Preparing interactive electronic hazard 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 and storm surge hazard 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 hazard maps prepared only based on manual instructions may miss such important information. To prepare truly effective hazard 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 5.2.1. Experts and public representatives express their opinions regarding what should be included and how they should be displayed on hazard maps form different points of view.

Experts on tsunamis and storm surges must be present at workshops. Also officials of the national and prefectural governments in charge of disaster prevention and coastal areas, should be requested when necessary.

In a workshop, the administrative side should explain the purpose of the workshop, details about hazard 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 hazard maps.

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

Table 5.2.1 Examples of core members of workshop

Class	Member	Veiwpint /Roles
Chair	Learned person, member of municipal government, or consultant	Expediting the proceedings, collecting and summarizing opinions
Core members	Expert on tsunami, storm surge, coast engineering	Technological advice
	Town planning committee member	Town planning
	School teacher	Evacuating from schools and ensuring the safety of students
	Elderly	Presenting an elderly point of view
	Resident	Daily living, assisting the elderly, etc.
	Employee working for a local factory/corporation	Commuting, workplace activities, cooperation with local communities, etc.
	Fire fighter	Local disaster prevention
	Flood fighting volunteer	Local disaster prevention
	Welfare facility member	Assisting the handicapped and elderly
Office	Municipal government officials (in charge of disaster prevention)	Arranging venues and preparing and explaining references

2) Example of workshop

For a workshop, participation of residents is requested directly or through existing community and disaster prevention groups, aiming to gather about 30 persons from the region. At the workshop, evacuation plans for 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 decided so as to conform to regional conditions.

The venue should be large enough to accommodate all participants, and an overhead or liquid-crystal projector, 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 5.2.2.

Table 5.2.2 References and tools to prepare for workshop

	References and tools to prepare (examples)
Hazard map	(Hazard maps) showing inundation risk areas (results of simulation analyses and areas inundated in the past)
References for disaster prevention	References of evacuation areas, evacuation sites, and evacuation routes designated by the municipal government
Other tools	Pencils, pens, oil-based markers, transparent plastic sheets, solvent, packing tapes

During the workshop, the chair should speak clearly and explain in an easy-to-understand manner for the participants. The chair should invite as many residents as possible to ask questions, so as to make them feel that it is their own issue. Since residents tend to be inexperienced and to view serious disasters as unrealistic, information to be shown on maps and the expression methods used should be carefully selected to correctly inform the participants of inundation risk areas and evacuation zones.

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

(3) Educational opportunities for residents to promote understanding of tsunami and storm surge hazard maps

> Providing learning opportunities about disasters to residents is one of the effective ways to promote their understanding of tsunami and storm surge hazard maps.
>
> Such opportunities can be provided in volunteer flood fighting groups and at schools. Information technology should be utilized to enhance residents' understanding. Training residents to become tsunami and storm surge advisors is also effective.

1) Volunteer flood fighting groups

One of the effective ways to promote understanding of the maps is to encourage volunteer flood fighting groups to use tsunami and storm surge hazard maps as tools for studying disaster prevention.

Especially, it will be very effective when the risk in each district and on each evacuation route is reviewed at meetings of local flood fighting groups, which know the districts very well. The members can prepare more precise hazard maps for the district by investigating fine details that could not be discussed at workshops. Flood fighting groups that may cooperate against a common disaster should exchange information, communicate with each other, and coordinate their disaster fighting measures.

2) Schools

Tsunami and storm surge hazard maps can be used in learning disaster-related issues at schools. By teaching about tsunami and storm surge disasters from elementary schools, a system can be developed to continuously educate people about hazard maps and related issues from childhood to adulthood. Educational opportunities at schools like this may provide a chance for family members to talk about disaster prevention and further promote understanding of disaster prevention in the districts.

Considering teaching materials for elementary schools, the content should be described and displayed in a way for children to easily understand.

3) Educational resources

Internet web pages that show related information are listed in Reference 3, and can be used as sources for studying disaster prevention. The pages also have links, which provide a wide variety of related information and more educational resources.

4) Use of information technology

To encourage residents to study and use hazard maps, measures should be taken to make people feel that tsunamis and storm surges are their personal concern. However, hazard maps showing an entire city on one or several sheets of paper may not look realistic.

Information technology can be helpful in accommodating information to personal needs. For example, an interactive hazard 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.

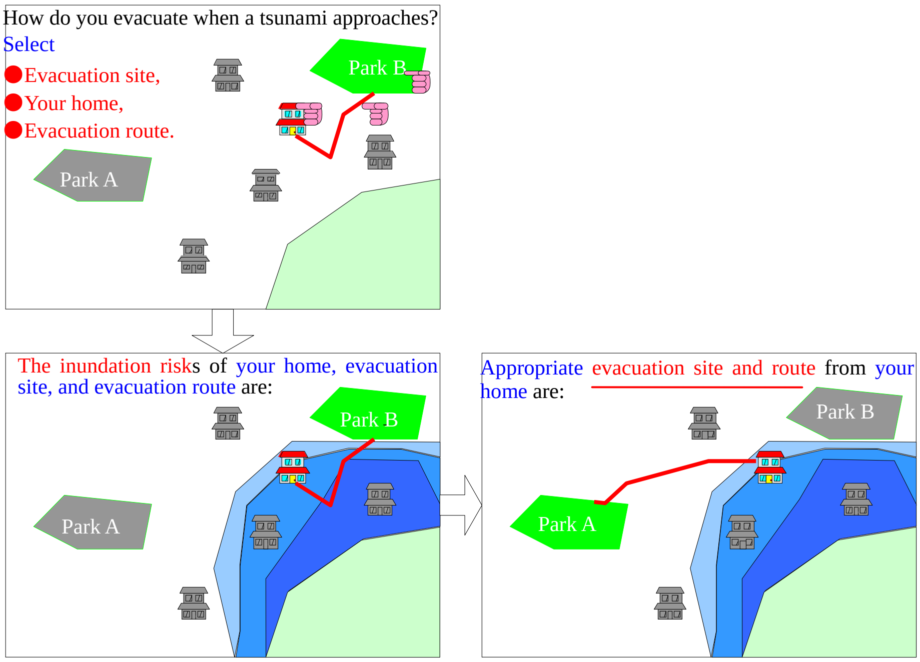


Figure 5.2.1 Example of an interactive hazard map system

An IT-based comprehensive scenario simulation system for a tsunami disaster is shown in Figure 5.2.2. A simulation model for each factor (disaster information transmission, evacuation decision, evacuation action, and tsunami (external force)) is individually developed for this system, which calculates and visually outputs the possibility of safe evacuation when a user inputs a scenario (time of starting evacuation, for example). IT-based systems for simulating tsunami strikes and evacuation should be effective in assisting public understanding.

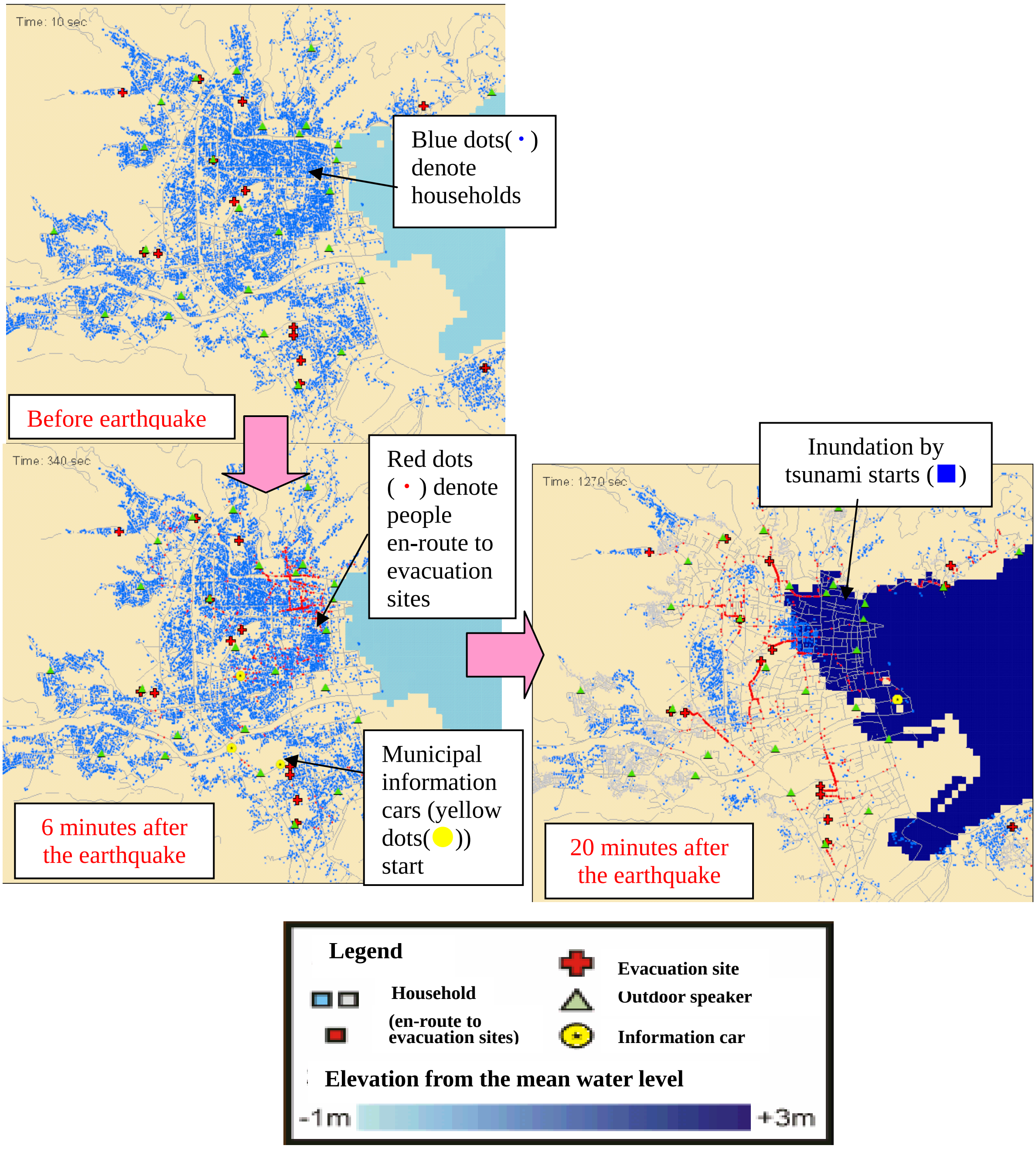


Figure 5.2.2 Comprehensive scenario simulation system for tsunami disasters
Reference: Laboratory of Prof. Katada, Department of Civil Engineering, School of Engineering, Gunma University

5) Training programs

There are people called “river counselors” who have comprehensive knowledge about rivers in their local areas. Since damage by tsunamis and storm surges varies depending on region, experts called “tsunamis and storm surge advisors for the region” can be trained as long-term advisors on disaster prevention. Tsunami and storm surge hazard maps will be useful tools for the advisors to teach children about tsunamis and storm surges, to supervise school teachers in giving disaster prevention classes, and to give advice on disaster prevention during tsunamis and storm surges. Such activities will be effective in increasing public understanding of hazard maps.

5.3 Utilization of tsunami and storm surge hazard maps for developing measures against tsunamis and storm surges

> Tsunami and storm surge hazard maps for residents can enhance the self defensive ability of residents and their smooth evacuation. Hazard maps for administrators can be used to prepare evacuation plans for residents and investigate facility construction, depending on the purpose of preparation.
> The hazard maps can also be used for risk communication between governments and residents on future disaster prevention measures.

Tsunami and storm surge hazard maps can be used for comprehensive disaster prevention measures, including both structural and non-structural measures. Utilization examples during normal times and during disasters (immediately before and after disasters) are shown in Figure 5.3.1 and Table 5.3.1 for each process.

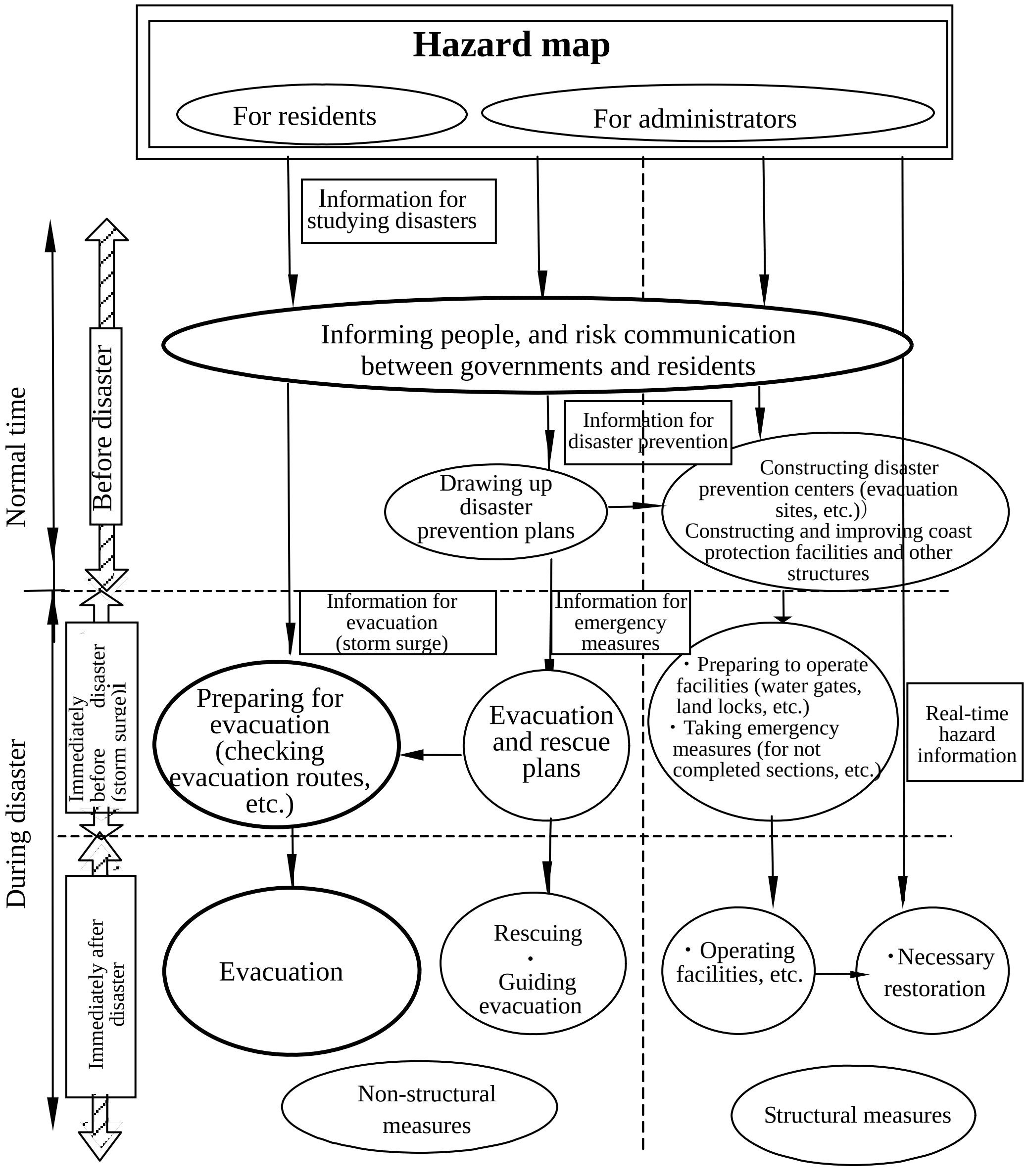


Figure 5.3.1 Utilization of tsunami and storm surge hazard maps at each stage of a disaster

Table 5.3.1 Utilization of tsunami and storm surge hazard maps by residents and administrators

User		Residents	Administrators
Utilization methods	Non-structural	Enhance their self-defensive ability (by helping themselves and each other)	Assisting residents in helping themselves Drawing up evacuation plans by establishing evacuation sites and routes to mitigate damage by tsunamis and storm surges (supporting residents to help themselves)
	Structural		<Normal time> Maintaining and repairing old facilities (public support) <During disaster> Urgently repairing and restoring damaged facilities (public support) Reinforcing and repairing sections prone to secondary damage (public support)

1) <u>Utilization of hazard maps for residents</u>

Hazard maps for residents can be used during tsunami and storm surges for the purposes shown in Table 5.3.2.

Table 5.3.2 Methods of use by administrators of hazard maps for residents

Purpose	
Smooth evacuation	To inform residents about the risk of tsunami and storm surge
	For residents to check the risk of tsunami and storm surge
	Information provision after evacuation
Risk communication	To communicate with residents on future disaster prevention

2) <u>Utilization of hazard maps for administrators</u>

Utilization of hazard maps for administrators depends on the purpose of preparation. Examples are shown in Table 5.3.3.

Table 5.3.3 Utilization and effects of hazard maps for administrators

Purpose of preparation and measures		Effects of hazard map
Purpose	Measure	
Preventive measures	Constructing evacuation site	Locations of inundation risk areas, candidates for evacuation sites, roads, etc., are easy to understand, enabling evacuation sites and sign boards to be appropriately located.
	Constructing disaster prevention facilities (installing sign boards, etc.)	
Emergency measures	Evacuation plan	The number of people that can be accommodated in evacuation facilities and the estimated number of people are easy to understand, enabling an appropriate evacuation plan and efficient plan for delivery of emergency supplies to be drawn up.
	Rescue plan	

3) <u>Utilization at each stage of disaster</u>

Tsunami and storm surge hazard maps are used at each stage of a disaster: before, immediately before, and after the disaster. Users and utilization methods are shown in Table 5.3.4.

Table 5.3.4 Users and utilization methods of tsunami and storm surge hazard maps at each stage of disaster

Stage of disaster	User	Utilization method
Before disaster	Residents	Collecting information for evacuation, learning about disasters and the region (population distribution and land use), and making risk communication
	Administrators	Planning and executing disaster prevention measures (constructing evacuation sites and disaster prevention facilities) and making risk communication
Immediately before disaster	Residents	Collecting information to decide on evacuation (for storm surge, inundation depth and evacuation sites)
	Administrators	Planning and executing emergency measures (evacuation and rescue plans)
After disaster	Residents	Collecting information after evacuation (instruction by governments, etc.)
	Administrators	Planning and executing emergency measures (evacuation and rescue plans)

4) Coordination with sign boards

Evacuation must be made very quickly, especially during a tsunami. People's lives may be at risk if they don't know exactly where to go. Thus, sign boards for evacuation that are coordinated with hazard maps must be installed (See Reference 2 for details).

5.4 Review and revision of tsunami and storm surge hazard maps

Hazard maps should be reviewed and revised along with the progress of coast protection facility construction, changes in socioeconomic conditions, and development of prediction technologies.

1) Reviewing tsunami and storm surge hazard maps

Hazard maps should be reviewed for evacuation sites, time needed for evacuation and evacuation routes by executing evacuation drills on a regular basis.

Governments should not only provide information unilaterally but should also lead and support local disaster prevention organizations to voluntarily review the maps.

2) Revising tsunami and storm surge hazard maps

Residents should always be provided updated information; thus hazard maps must be revised so as to reflect the progress of coast protection facility construction, changes in socioeconomic conditions, and development of prediction technologies.

The maps should be revised by considering changes in land use, the state of coastal construction, records of tsunamis and storm surges, the progress of calculation technologies, and also by obtaining the advice of coast engineers when necessary.

It is also important to keep track of the revision record. Whenever a revision is made, what is revised when and how must be clearly documented. Different version numbers may be assigned depending on the content of revision, as shown in Table 5.4.1.

Table 5.4.1 Example of version control of tsunami and storm surge maps

Original version: ver 1.0 ↓ First revision: ver 1.1 (when misspelled words and other minor errors were corrected) Second version: ver 2.0 (when inundation prediction was revised)

5.5 Measures for encouraging preparation

> Since the utilization of hazard maps enables comprehensive disaster prevention measures against tsunamis and storm surges to be effectively deployed, including both structural and non-structural measures, the importance and methods of preparing, publicizing and utilizing hazard maps should be stated in the various disaster prevention plans of municipal governments.

[Including statements about hazard map preparation in the plans of municipal governments]

Few municipal governments have statements about hazard maps in their plans for disaster prevention. Since utilization of hazard maps will enable comprehensive disaster prevention measures against tsunamis and storm surges to be effectively deployed, including both structural and non-structural measures, statements about the importance and methods for preparing, publicizing and utilizing hazard maps should be included in the disaster prevention plans of municipal governments.

The present relationship between hazard maps and disaster prevention plans concerning tsunamis and storm surges is shown in Table 5.5.1.

Statements about the preparation of hazard maps should be included in, for example, regional disaster prevention plans, basic plans for coast protection, and flood defense plans. Table 5.5.2 shows how hazard maps are incorporated into those plans.

The Outline of Measures against the Tokai Earthquake (May 29, 2003, the Central Disaster Prevention Council) mentions preparation of hazard maps as a preventive measure.

Table 5.5.1 Positions of hazard maps in plans for disaster prevention during tsunamis and storm surges

Plan	Present position of hazard maps
<u>Regional disaster prevention plans</u> (The Disaster Countermeasures Basic Law)	・The plans are the very basis of disaster prevention measures. ・The Disaster Countermeasures Basic Law states that the heads of municipal governments are responsible for the evacuation of residents. ・Some municipal governments mention preparation of hazard maps as a non-structural measure in their regional disaster prevention plans. For example, the Kochi City regional disaster prevention plan (fiscal year 2002) states, in the section headed "Disaster prevention information" of the chapter on "Education and training in disaster prevention," that "leaflets on disaster prevention and disaster prevention maps should be distributed to residents, including those involved in disaster prevention activities."
<u>Basic plans for coast protection</u> (The Coast Law)	・The plans are set by local municipalities and state the basics for protection, utilization, and environment of coastal areas. ・Matters to be included in the plans are to be decided by the bodies in charge of preparing the plans. ・Some municipal governments, such as the prefectural governments of Shizuoka and Wakayama, include the preparation of hazard maps as a non-structural measure against disaster in their basic plans for coast protection. In Shizuoka Prefecture, 16 municipal governments have prepared hazard maps.
<u>Flood fighting plans</u> (The Flood Fighting Act)	・The plans are the basis of measures against water-related disasters during tsunamis and storm surges. ・The Flood Fighting Act, revised in 2001, states that the Minister of Land, Infrastructure and Transport or the prefectural governors are responsible for publicly announcing inundation risk areas around the rivers subject to flood forecast. ・Based on those inundation risk areas, municipal governments prepare flood hazard maps.

Table 5.5.2 Sample statements for plans of municipal governments

Plan	Examples of statements
Regional disaster prevention plans (The Disaster Countermeasures Basic Law)	[Disaster prevention] ・Need of preparing hazard maps in conjunction with facility construction ・Examples of utilizing hazard maps (preventive plans by utilizing hazard maps) [Emergency measures] ・Examples of utilizing hazard maps (evacuation guidance plan, emergency measures at facilities) [Restoration] ・Examples of utilizing hazard maps (restoration plans using real-time hazard maps)
Basic plans for coast protection (The Coast Law)	Basic items concerning coast protection [Items concerning protection of coast] ○ Objectives of protection ・Areas to be protected (to be shown on hazard maps) ○ Measures for attaining the goals of protection ・The importance is to be stated of comprehensive disaster prevention measures using hazard maps. (Examples of statements) ・In areas where population and assets are concentrated, tsunamis and storm surges, when they occur, are highly likely to cause serious damage over a large area. ・Thus, in addition to the construction of protection facilities, non-structural measures must be taken such as preparing and using hazard maps for ensuring evacuation routes and sites during emergency, making people aware of what action to take during an emergency, and coordinating evacuation routes, and for collecting and disseminating information quickly and adequately. ・Hazard maps should also be used to create systems for disaster prevention activities among residents, to educate people about disaster prevention, disseminate knowledge, and improve safety. ・Hazard maps are also effective for regular inspection and maintenance of coast protection facilities. They can serve such purposes by helping study monitoring systems for old facilities while inspecting facilities' capability to properly function and ensure safety. They can also help study reporting systems capable to detect damage or malfunction at an early stage and request repair or improvement. By studying such systems through use of hazard maps, responsible bodies should make efforts to be equipped with measures that enable them to respond to disasters quickly and properly.
Flood fighting plans (The Flood Fighting Act)	Flood fighting plans are decided by governors of prefectures by consulting with the Disaster Prevention Council, and should be coordinated with regional disaster prevention plans. Thus, statements on hazard map preparation can be included in the plans as a method for coordinating structural and non-structural measures. The Flood Fighting Act makes statements regarding floods, including designation of inundation risk areas and measures for ensuring smooth and quick evacuation. Since storm surges are included as one of the disasters in this law, statements on hazard map preparation can be included in the law in line with the policies for floods.

Tsunami and Storm Surge Hazard Map Manual

References

Reference 1: Predicting inundation by time-series numerical simulation
Chapter 1　Calculations for predicting inundation during tsunamis

1.1 Flow of calculations for predicting inundation

A general flow of calculations for predicting inundation is 1) assuming the external force of a tsunami (target earthquake), 2) preparing topographical data, 3) setting and inputting initial conditions, 4) reproductive simulation, 5) predictive simulation, and 6) outputting results.

1) Flow of calculations for predicting inundation

A general flow of calculations for predicting inundation is shown in Figure .1.1.

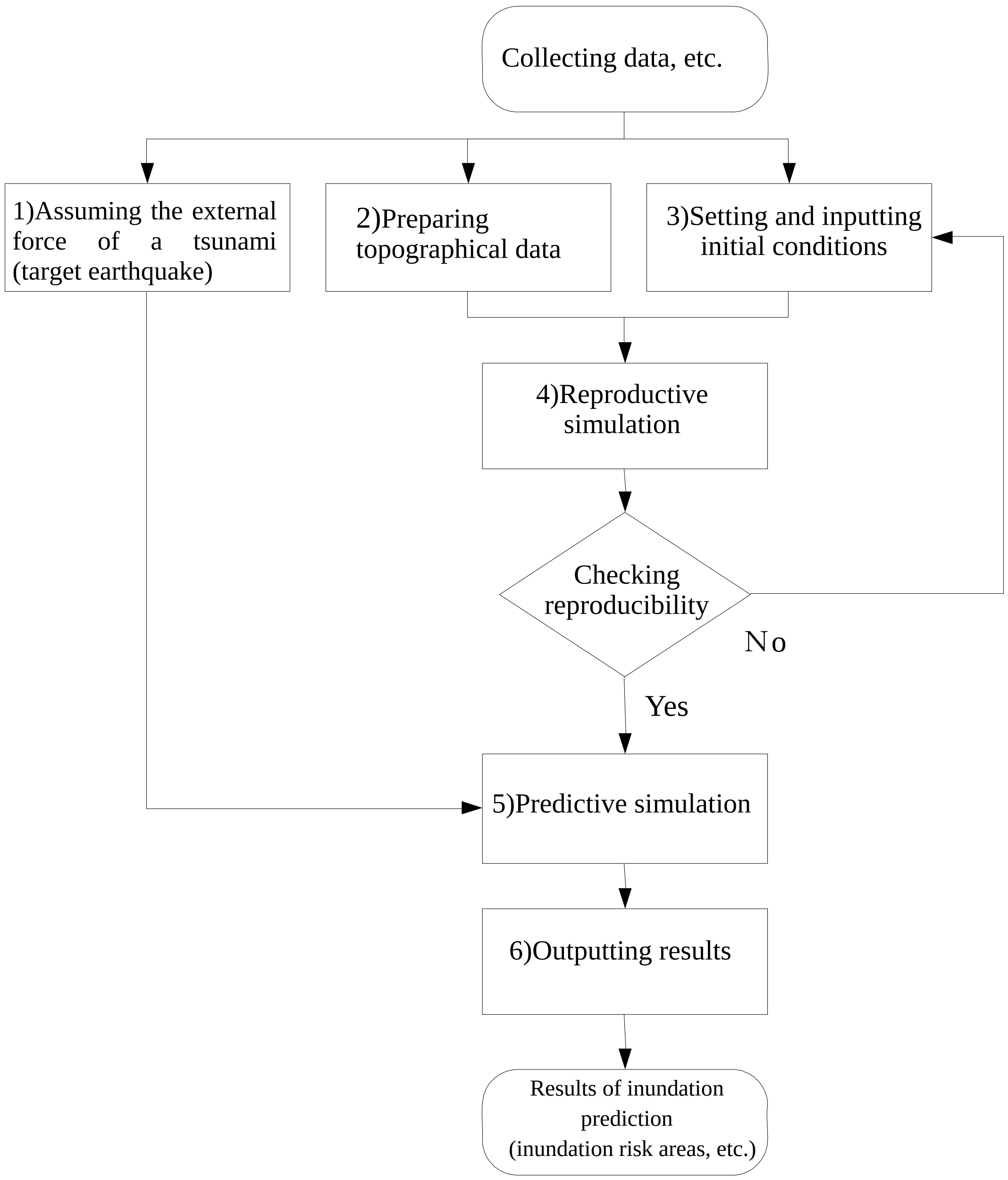


Figure 1.1.1　Flow of calculations for predicting inundation

2) Conditions used for preparing tsunami hazard maps

This manual presents an overview of how to deal with uncertain factors, or conditions used for preparing tsunami hazard maps, while considering how such factors should be set to minimize damage to residents. Conditions used for preparing tsunami hazard maps are shown in Table 1.1.1.

Table 1.1.1 Conditions used for preparing tsunami hazard maps

Item	Conditions used for preparing tsunami hazard maps
External force of tsunami	1. Earthquake fault model
	2. Initial water level expressed in the earthquake fault model
Topographical conditions	3. Grid intervals
	4. Elevation
	5. Conditions of river topography
Tidal level	6. Tidal level (astronomical tide)
Structures	7. Condition of structures
	8. Damage to structures during the earthquake
Analytical method	9. Tsunami numerical analysis

1.2 Earthquake fault model

Disaster prevention for a district should be studied, assuming that the largest possible tsunami[*1] would hit the district. Since the ground may heave up or subside during earthquakes, an earthquake that causes the highest tsunami may differ from an earthquake that causes the deepest inundation. Thus, the earthquake fault model that is to be used for preparing tsunami hazard maps should be assessed not only by tsunami height but also by inundation depth (tsunami height minus ground elevation after displacement).

An earthquake fault model that causes the deepest inundation ever recorded or possible should be chosen by calculating the inundation depth based on the estimated ground elevation after subsidence when the ground is predicted to subside, and also based on the initial elevation when the ground is predicted to heave up.

1) Effects on results of inundation prediction

Earthquake fault models (locations, depths, lengths, widths, slippage, strike angles, inclination angles, and sliding angles of faults) determine the initial condition (initial water level) and ground displacement for tsunami simulations. These specifications directly affect the scale of tsunami and inundation effects.

When the ground heaves up or subsides during earthquakes, an earthquake that causes the highest tsunami[*1] may differ from one that causes the deepest inundation. In other words, tsunami damage may not be positively correlated with earthquake damage. Thus, the earthquake fault model that is to be used for estimating the most serious inundation damage must be determined after estimating tsunami height and ground displacement.

Although the ground displacement may exceed 1 m, existing manuals describe no uniform standards about displacement, but over years decisions have been made case by case regarding how to consider ground displacement:

a) disregard ground displacement when it is negligible,
b) consider both upheaval and subsidence, or
c) consider only subsidence

To estimate the worst inundation case, Case c) should be considered.

*1 The highest tsunami should be the tsunami that causes the most serious damage in the region, and should be determined by the body charged with preparing hazard maps.

When two earthquakes of the same scale but different hypocenters are investigated (Earthquakes A and B) for a region shown in Figure 1.2.1, their effects at a site (shown with a double open circle in the figure) could be as shown in Table 1.2.1. In this case, Earthquake A causes more earthquake damage and less tsunami damage than Earthquake B.

Table 1.2.1　Effects at a site by two earthquakes

Case	Earthquake	Earthquake motion	Ground displacement	Tsunami water level	Earthquake damage	Inundation damage
Case 1	A	Stronger than B	Upheaval (+ 2 m)	Higher than B (10 m)	More serious than B (proportional to earthquake motion)	Small (inundation depth = tsunami water level - ground elevation) (10 - 2 = 8 m)
Case 2			No upheaval (+ 0 m)			(10 - 0 = 10 m)
Case 3	B	Strong	Subsidence (- 1 m)	High (8 m)	Serious	Large (8 - (-1) = 9 m)

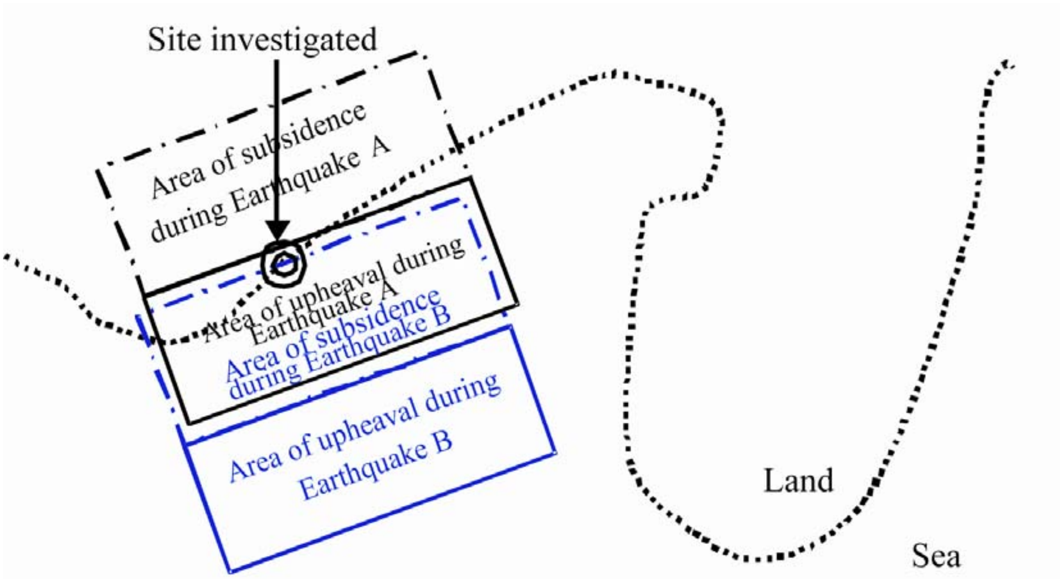


Figure 1.2.1　Conceptual diagram of fault position and site investigated

In Figure 1.2.1, Earthquake B (9 m) causes deeper inundation than Earthquake A (8 m) when inundation depth is simulated as the difference between tsunami water level and ground elevation after displacement. When the upheaval during Earthquake A is disregarded, Case 2 (10 m) causes the deepest inundation, and simulations should be conducted using Earthquake A.

2) Sellection of past earthquakes and assumed earthquakes

Only when reliable data on tsunami and inundation effects are available, past earthquakes should be used to determine the initial conditions and ground displacement. Assumed earthquakes should be ones based on already-developed earthquake fault models. Such models include the assumed Tokai Earthquake, the assumed Tonankai Earthquake, the assumed Nankai Earthquake (those three are developed by the Central Disaster Prevention Council), and the models developed by the four ministries related to the coast. (Reference: Survey on methods for earthquake and tsunami disaster prevention plans along the Pacific coast, 1996, the four ministries related to the coast)

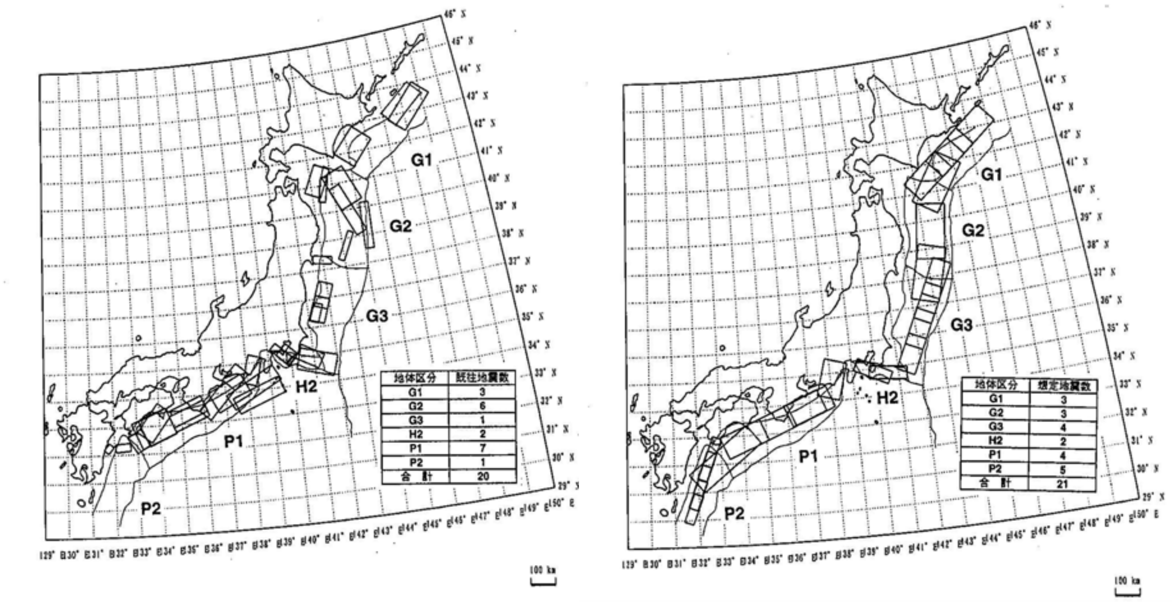


Figure 1.2.2 Example of earthquake fault model (left: earthquake in the past, right: assumed earthquake)

3) <u>Causes of tsunamis</u>

Causes of tsunamis include earthquakes, volcanic eruptions, landslides into the sea, submarine landslides, and meteoritic bombardments. Of these causes, this manual describes tsunamis triggered by earthquakes caused by fault movement, which are the most frequent and affect the largest area.

1.3 Initial water level simulated by the earthquake fault model

> Initial water level used for tsunami simulation in hazard map preparation should in principle be determined by conducting a reproductive simulation and using a fault model that has been proved valid.

1) <u>Effects on the results of inundation prediction</u>

Numerical tsunami simulation uses the equations of motion and continuity over time that use the displacement distribution of the sea surface (initial water level) as the initial condition. Thus, the water level of a tsunami, which is an output of the simulation, largely varies depending on the initial water level.

Initial water level is generally determined using the following fault models. Errors decrease and accuracy of simulation increase in the alphabetical order.

a) Fault model based on seismological and geodetic data,

b) Fault model optimized by simulated tsunamis (developed by conducting reproductive simulation of tsunamis and proved valid), and

c) Fault model based on ones that optimized by simulated tsunamis but further modified by using trace values, etc. so as to match with the tsunami simulation for a certain investigation.

2) Concepts of determining an initial water level

Two or more fault models may have been proposed for an earthquake in the past, such as a model based on seismological data and a model developed by conducting reproductive simulation and proved to be valid.

An initial water level for tsunami simulation in hazard map preparation should be determined by using a fault model optimized by simulated tsunamis. Then, the initial water level is used to conduct a reproductive simulation by using a tsunami simulation model in order to check the reproducibility. If there are any systematic errors attributable to the tsunami simulation model, they should also be corrected.

When an initial water level is determined by using an assumed earthquake, the reproducibility should be checked and any systematic errors attributable to the tsunami simulation model should be corrected.

1.4 Grid intervals

> Grid intervals for tsunami simulation in target sea and river areas should be appropriately determined by ensuring the precision of the target inundation prediction area and taking account of minute topography, such as structures.

1) Grid interval and results of inundation prediction

An example of the effects of grid intervals on inundation simulation is shown in Figure 1.4.1. When the topography of the inundation area in District A is approximated by using grids of 50 m x 50 m, water is estimated to reach up to Line B. However, the actual inundation area is up to Line C. Thus, the use of 50 m grids results in underestimation of the inundation area. Topographic approximation using 12.5 m grids can achieve a more precise estimation. When 50 m grids are used, the building in District A is estimated to escape inundation, whereas the use of 12.5 m grids correctly estimates the inundation of the building.

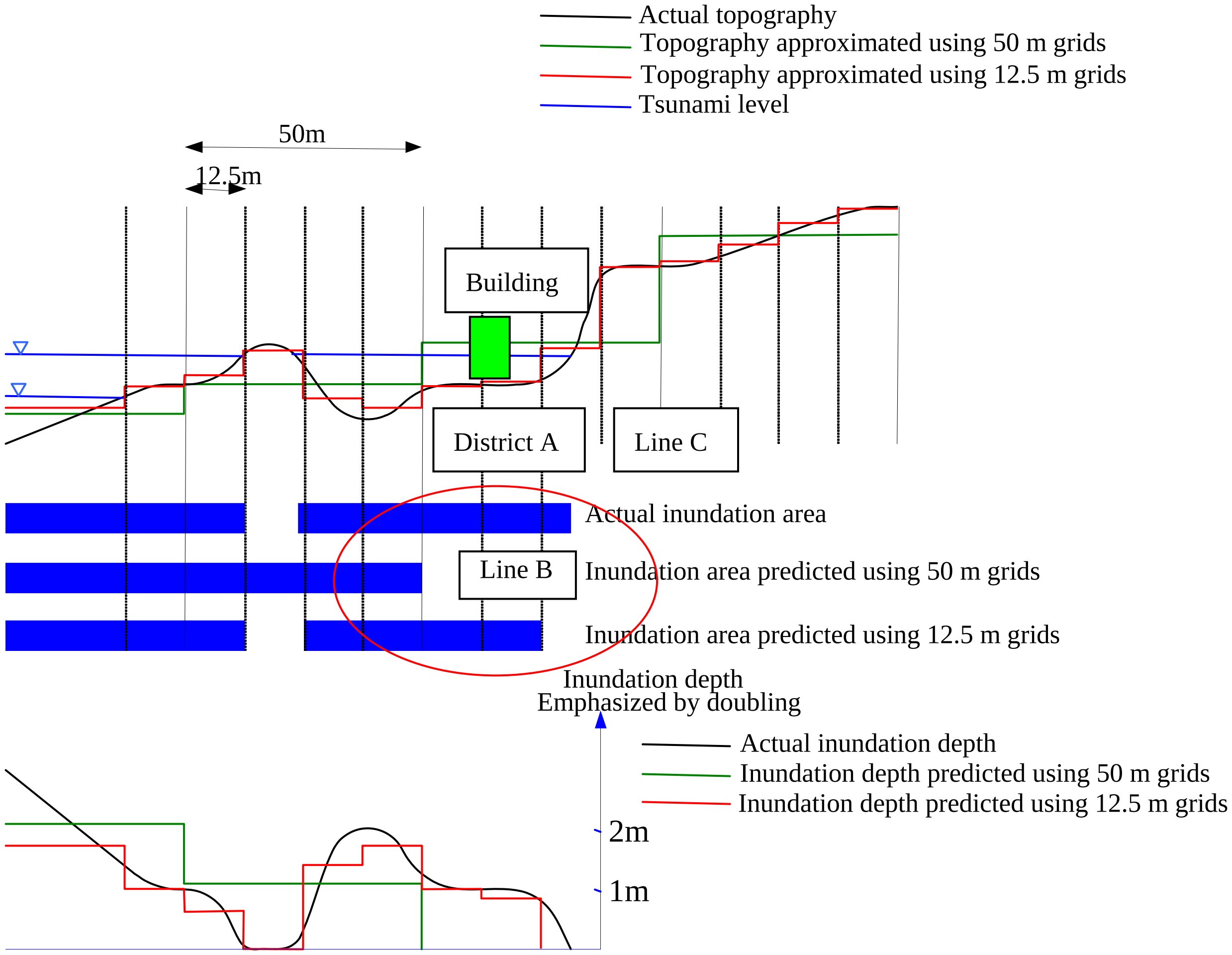


Figure 1.4.1 Example of the effects of grid dimensions on inundation simulation

2) Determining grid intervals and micro topography

In tsunami simulation, landforms are usually expressed in rectangular grids, and elevation is the mean elevation in each grid. Thus, structures (buildings and houses) in the grids cannot be directly considered. In tsunami simulation for predicting the behavior of a tsunami on land, use of smaller grids improves the precision of topographic approximation, the effects of structures and micro topography are reflected, and thus the calculation results are more precise.

To investigate the effects of structures, etc., the following methods may be employed:

1) Use of reliable data and 12.5 m grids

Reliable data, such as 1:2,500 topographical maps and aerial photogrammetry data, as well as grid intervals of about 12.5 m can be used. When the resolution of the data is larger than 12.5 m, the data itself is not reliable since it should be calculated by interpolating data of larger grid intervals, and the inundation prediction will not be precise.

2) Use of mean coarseness that shows the land use in the grid (see Table 1.4.1).

Table 1.4.1 Coefficient of coarseness

Land use	Coefficient of coarseness
Residential district	0.04～0.08
Industrial district	0.04
Farmland	0.02
Forest	0.03
Water	0.025
Others (vacant land, green space, etc.)	0.025

Reference: Kotani, Misa, Imamura, Fumihiko, and Shudo, Nobuo: Tsunami run-up calculations and damage estimation method using GIS, (Coastal Engineering Journal, Vol. 45, November 1998)

When simulation is conducted to understand the behavior of and inundation by tsunamis over large areas, such as throughout Japan or a prefecture, inundation areas may be calculated by using large grid intervals of 50-100 m depending on the objective and the size of the target area.

Note: Representation accuracy (dimensions) and grid intervals

The representation accuracy in drawing maps depends on grid intervals, but inundation depth data that appears to be precise can be prepared from calculation data obtained using large grid intervals. Strictly speaking, as shown in Figure 4.4.2 of the Manual, maps so prepared do not have the precision expressed since the grid dimensions used for calculation are large, but they should be accurate to some extent since the water surface is continuous.

Use of reduced grid dimensions improves calculation precision but requires larger calculation loads and costs for preparing data. Precision of elevation data has a greater effect on the precision of calculation than does that of grid intervals.

1.5 Elevation

Elevation data for tsunami simulation directly affects the resultant estimated inundation depth and thus should be precise. Especially, the elevation data for areas where inundation is predicted during tsunamis need a precision smaller than 1 m to estimate inundation depth. When such precise data is not available, the necessary precision should be ensured by correcting data using the survey points of topographic maps, reconnaissance surveys, and surveys by coast experts.

1) Effects on inundation prediction

An example of the effects of elevation data on inundation simulation is shown in Figure 1.5.1. When the elevation of District A is expressed in grids of 50 m, Line B is the inundation line and the inundation depth is 1 m. However, the inundation depth in the past was at least 2 m, and the use of 50 m grids leads to underestimation of the inundation depth in this case. When 12.5 m grids are used to express elevation data, the estimated inundation line will be Line C, which shows depths of 1.8 and 2.0 m and is similar to the actual inundation depth.

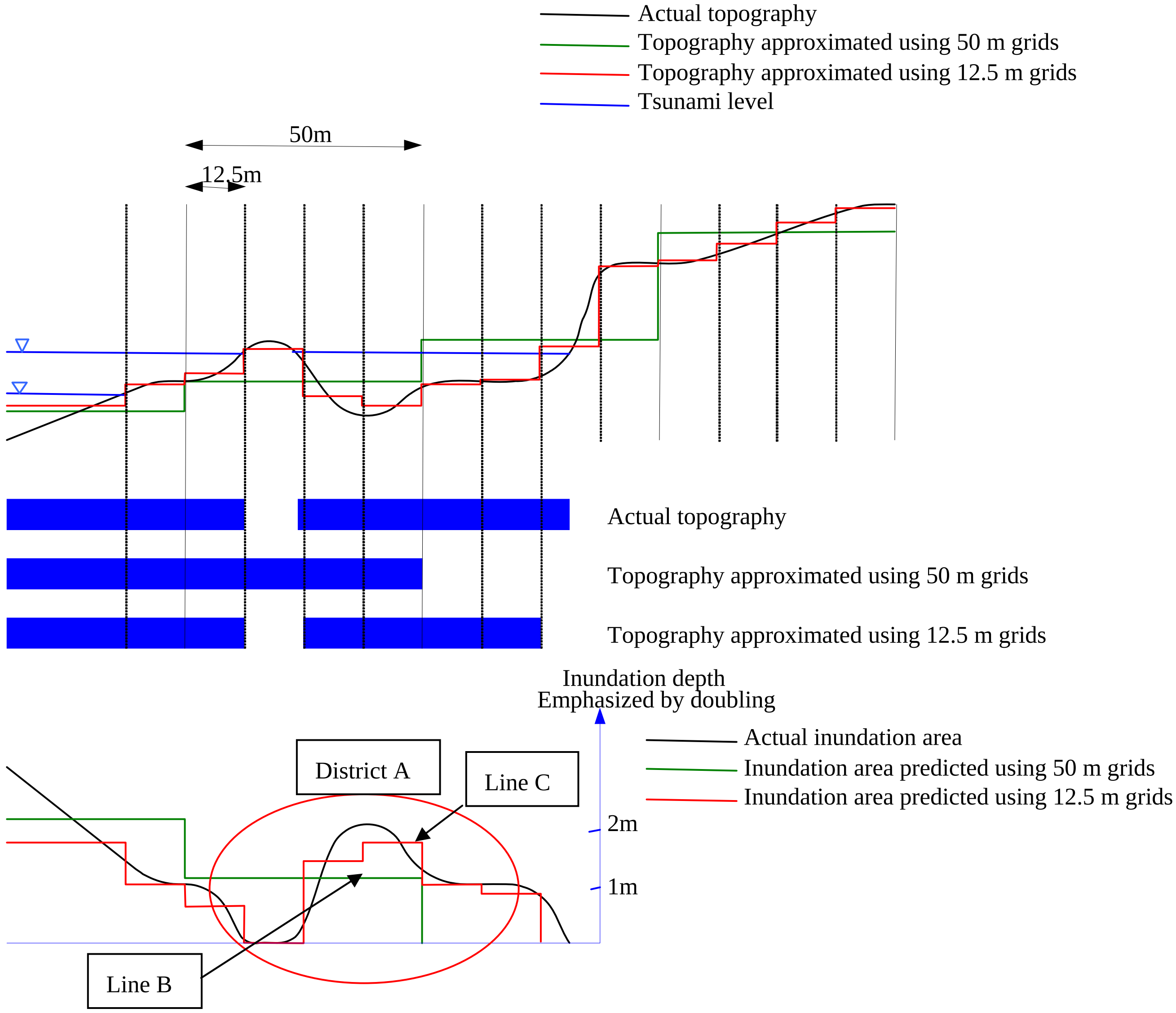


Figure 1.5.1 Example of the effects of elevation data on inundation simulation

2) Determining elevation data

Elevation data is used for simulating tsunamis and estimating inundation. In tsunami simulation, the propagation of a tsunami is calculated based on the elevation of each grid point to determine the water levels of the grid points in time sequence. On the other hand, inundation is expressed as the difference between the calculated tsunami water level and ground elevation.

Usually, one of the following elevation data is used:

- Contour lines of 1:50,000 and 1:25,000 topographical maps issued by the Geographical Survey Institute
- Elevation data of 50 m grids of numerical maps issued by the Geographical Survey Institute
- Contour lines and elevation data of 1:2,500 maps (basic national land maps) prepared by municipal governments

1:25,000 topographical maps show elevation with contour lines of 10 m intervals. Thus, the elevation of waterfront lowlands may be difficult to reproduce accurately. Elevation data of 50 m grids of numerical maps has been prepared from the contour lines of 1:25,000 maps and has the same precision. On the other hand, 1:2,500 maps show contour lines at 1 m intervals and enable highly precise elevation data to be prepared.

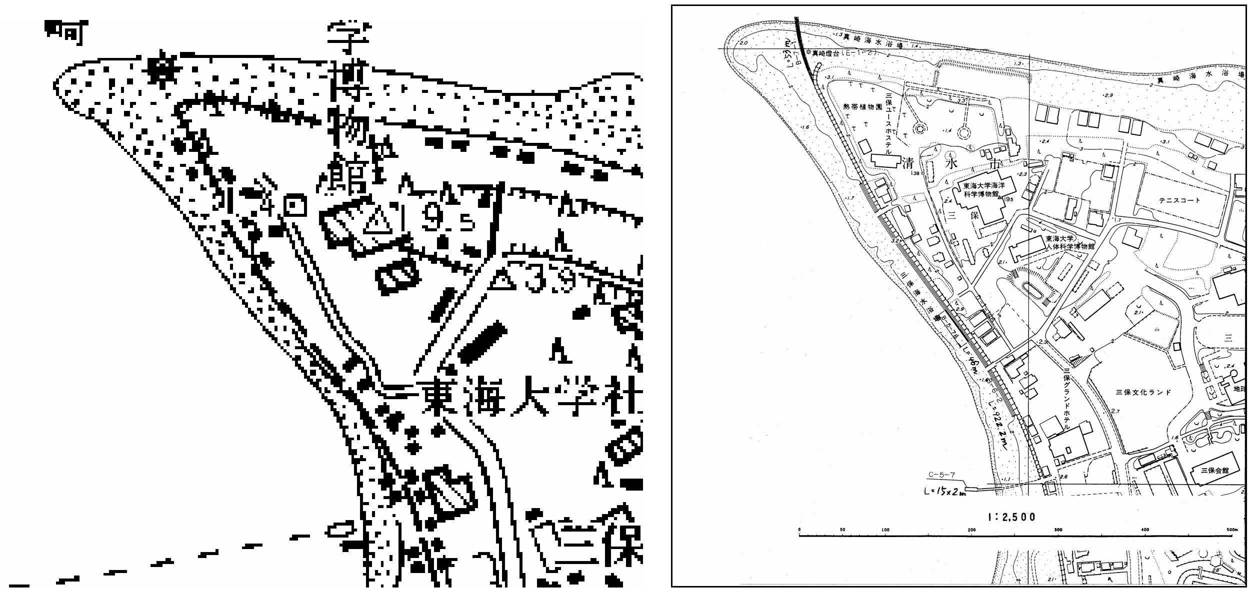


Figure 1.5.2 Example of elevation expression by topographical maps of different scales

For example, Figure 1.5.2 shows topographical maps of Masaki District, Shimizu City. The left is a topographical map of 1:25,000, and the right is a map of 1:2,500. They are shown at the same scale to compare the information contained.

No contour lines are shown in the 1:25,000 map since there are no ground sections higher than 10 m in elevation in this district, but elevation at three points is stated. On the other hand, the 1:2,500 map shows contour lines at 1 m intervals and elevation at many points.

The waterfront in this district is sand beach, the elevation of which cannot be determined from the 1:25,000 map but can be seen on the 1:2,500 map, which shows the 2-m contour line on the beach. Similarly, the elevation of sites where buildings are located cannot be judged from the 1:25,000 map but can be seen on the 1:2,500 map.

Elevation of lowlands is not available through 1:25,000 maps, which have been simplified, but needs to be collected from 1:2,500 maps.

A survey on tsunami heights and degrees of damage (Table 1.5.1) showed differences in damage between tsunami heights of 1 m and 2 m, suggesting that errors of inundation prediction (predicted tsunami water level - ground elevation) should not exceed 1 m. Thus, the latest elevation data needs to be collected from 1:2,500 maps or by aerial photogrammetry data.

Table 1.5.1 Tsunami heights and degrees of damage

Tsunami intensity	0	1	2	3	4	5
Tsunami height (m)	1	2	4	8	16	32
Tsunami type: Gentle slope	Rises at coast	Water wall off shore Second crushing wave	Breakers at wave tips	Even the first wave produces plunging breakers		
Tsunami type: Steep slope	Fast flow velocity	Fast flow velocity	Breakers at wave tips	Even the first wave produces plunging breakers		
Sound		Continuous sound by front breakers (sea rumbling, storm sound)				
Sound			Huge sound by entraining breakers at beaches (thunder, not heard at distances)			
Sound				Huge sound of waves colliding against cliffs (thunder, blasting, can be heard at distances)		
Wooden houses	Partially destroyed	Totally destroyed				
Stone-built houses	Resists		(No data)	Totally destroyed		
Reinforced concrete buildings	Resists			(No data)		Totally destroyed
Fishing boats		Damage occurs	50% affected	100% affected		
Damage to tsunami control forest	Slight damage		Partially affected	Entirely affected		
Effects of tsunami control forest	Mitigate damage	Stop driftwood	Stop driftwood	No effect		
Mariculture rafts	Affected					
Coastal villages		Damage occurs	50% affected	100% affected		
Runup height(m)	1	2	4	8	16	32

Note: The tsunami height was calculated as the height of the tsunami from the tidal line for ships and mariculture rafts at sea, and as the inundation depth from the ground surface for houses, tsunami control forests and other structures on land. Damage to coastal villages, at the bottom of the table, shows the percentage of houses affected in a village by the maximum runup height (m) recorded in the village.

Reference: Shudo, Nomuo: Tsunami intensity and damage, Tsunami Engineering Laboratory Bulletin, No. 9, pp. 101-136, 1992.

Note: Precision of elevation data

Elevation data for tsunami simulation are determined by modeling the landform of the district to be investigated and by interpolating elevation points. Errors in this process will seriously affect calculation precision.

For example, the 50 m grid data of the Geographical Survey Institute is prepared by linearly interpolating the 10-m interval contour lines of 1:25,000 topographic maps. The data is inexpensive and available for all regions in Japan, and thus is easy to use for simulation. However, the following points should be noted in using the data:

- The inundation depth along the coast is overestimated since elevation is linearly interpolated from the coastline (0 m elevation).
- Elevation differences smaller than 1 m are not shown.
- There are errors in elevation attributable to linear interpolation.

1.6 Conditions of river topography

In tsunami simulation, river topography (river alignment and riverbed elevation) should be expressed in calculation grids and elevation (water depth) data, and structural conditions, such as the crown height of a river bank, should be determined.

1) Effects on inundation prediction

Part of a tsunami that reaches the coast may run up a river, causing the river water to flood. In tsunami simulation, river topography (river alignment and riverbed elevation) and the crown heights of the river bank should be considered to appropriately evaluate the flooding of rivers.

When the river topography is not considered, the elevations of the land areas along the river are usually used for grids that actually correspond to the river, and tsunamis that overflow the river cannot be calculated. On the other hand, when the river topography is considered, the elevation of the riverbed, which is determined from river profiles, etc., is used, and tsunamis that run up the river can be estimated.

When there are bridges in sections where tsunamis may possibly run up, the heights of the girders and the effects of the bridges on the run-up of the tsunami and overflowing of river water must be taken into account.

2) Determining the river topography

In tsunami simulation, river topography (river alignment and riverbed elevation) should be expressed in calculation grids and elevation (water depth) data, and the crown height of river banks should be determined. Undular bores are sometimes observed in shallow rivers, which cannot be expressed using the shallow water theory.

A conceptual diagram of tsunami simulation in a river is shown in Figure 1.6.1. The elevation of the riverbed (solid black line) is used as the elevation of the ground (water depth). When there are banks on both sides of the river, their positions and crown heights (dotted red line) are drawn as a boundary line of the structure. The water level at the river mouth is assumed, for convenience, to be equal with that of the sea (H.W.L.: mean monthly highest water level).

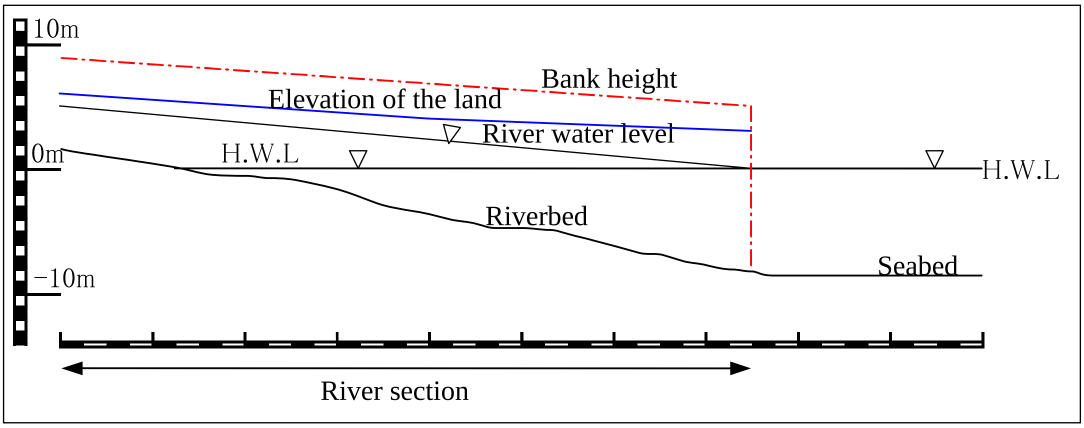


Figure 1.6.1 Schematic profile of a river

1.7 Tide (astronomical tide)

> In tsunami simulation, tide (astronomical tide) should be the H.W.L. (mean monthly highest water level).

1) Effects on inundation prediction

Generally, the higher the tide, the easier a tsunami will inundate larger areas.

2) Determining tide

In prediction of inundation during tsunamis, the most hazardous inundation damage should be assumed, and tide (astronomical tide) at the H.W.L. (mean monthly highest water level) should in principle be used. For tsunami simulation to examine reproducibility, tidal data of a past tsunami should be used if reliable data is available.

1.8 Conditions of structures

> In inundation prediction, the effects of structures higher than the ground (breakwaters, sea walls, walls, and embanked roads) on the propagation of tsunamis should be considered. Water gates, land locks, and other tsunami control facilities, should in principle be assumed to be open (not operating) since they may be difficult to close due to the traveling speed of tsunamis, or may not be functional due to damage during the earthquake. Earthquake-resistant automatic facilities, facilities that are always closed, and earthquake-resistant facilities that can be closed before tsunamis arrive, are assumed to be closed.

1) Effects on inundation prediction

Structures higher than the ground (breakwaters, sea walls, walls, and embanked roads) may affect the propagation of tsunamis and block the run-up of tsunamis. However, tsunami control structures that need to be closed, such as water gates and land locks, may possibly be left open since tsunamis arrive rapidly, and inundation may expand from this point.

2) Determining the conditions regarding structures

Conditions regarding structures should be appropriately determined to improve the precision of simulation. Tsunami control structures, such as water gates and land locks, should in principle be assumed to be in the state that can cause the worst inundation (closed or open), but also should be determined according to the objective of simulation and the characteristics of the target tsunamis and region.

Tsunami control structures, such as water gates and land locks, should be assumed to be open, since there may be no time to close them because tsunamis arrive immediately, and they may be deformed by the earthquake motion and not be closeable. However, 1) earthquake-resistant automatic facilities, 2) facilities that are always closed, and 3) earthquake-resistant facilities that can be closed before tsunamis arrive, should be assumed to be closed.

When the tsunami control structure to be assessed is smaller than the grid dimension, the size of the structure should be reflected using the following methods to ensure calculation precision.

1) When there are two or more structures, the structures (water gates and land locks) should be assumed to be a single structure by considering their planar arrangements.

2) When there is one structure, its effect should be reflected in one grid by considering the estimated height of the tsunami and the crown height of the structure.

1.9 Damage to structures during earthquakes

> Inundation during tsunamis should be predicted by considering the damage to structures by tsunamis. Such damage should be estimated by using the earthquake motion as the external force, which should be calculated based on the selected earthquake fault model.

1) Effects on inundation prediction

Structures, such as breakwaters, sea walls, and walls, mitigate inland inundation damage while they maintain their functionality. When these structures are damaged during earthquake and cannot function, the inland inundation damage expands.

2) Determining damage to structures during earthquakes

Types of damage to structures should be determined, according to the purpose of map preparation, by the body in charge of preparing hazard maps. When structures are damaged by earthquake motion, they may lose their function of controlling tsunamis. According to records of earthquake damage to harbour facilities, not many structures were affected too severely to lose their capacity to control the run-up of tsunamis. However, damage to structures should be estimated by using the earthquake motion as the external force, which should be calculated based on the selected earthquake fault model.

Earthquake resistance of structures is to be assessed using available technologies, and new technologies should be used when they are developed. (See “Handbook for Designing Coastal Facilities 2000” (November 2000, Japan Society of Civil Engineers) and “Technical Standards of Harbour Facilities and Explanations” (May 1999, The Japan Port and Harbour Association).)

1.10 Method of numerical analysis for tsunamis

> In tsunami simulation, the linear long-wave theory may be used for deep sea areas. For shallow sea areas, including land sections where tsunamis may run up, the non-linear long-wave theory (shallow water theory), in which sea bottom friction and advection are considered, should be used. Propagation of tsunamis from a distant site over the ocean should in principle be calculated using the theory of linear dispersive waves.

1) Basic equations for tsunami calculations

The movements of long waves, such as those of tsunamis, are expressed by the non-linear long-wave theory (shallow water theory), which can reproduce the basic behavior of tsunami propagation from the source to the land. For deep sea areas, the linear long wave theory that disregards friction and advection at the ocean bottom may be used. Tsunamis that reach shoaling coasts may show soliton fission (long waves dividing into waves of shorter wavelengths) due to the dispersion effect, and the resultant waves become higher than the waves before division.

2) Concepts of soliton fission

Tsunamis that were observed during the Nihonkai Chubu Earthquake showed soliton fission and undular bores and are difficult to reproduce unless the Boussinesq equation is used. Waves that underwent soliton fission during the earthquake showed amplification of wave height due to the waveform curvature effect. Since amplified waves will break, considering wave breaking models.

3) Coarseness of the land

The effects of structures on the land can be investigated by using the mean coarseness in calculation grids, which depends on the land use situation (See Table 1.4.1).

4) Tsunamis from distant sites

Propagation of tsunamis from afar may be calculated by using the linearity theory, since the wave height of such tsunamis is smaller compared to the water depth. When waves of different wavelengths are contained in the initial waveforms, the propagation speed in deep water differs depending on wavelengths, and short waves delay in the course of propagating a long distance.

To reproduce this effect, equations of motion that include dispersion terms should be used. Besides considering the Coriolis force, spherical coordinates should be used to consider the effects of the globe being a sphere.

Chapter 2 Calculations for predicting inundation during storm surges

2.1 Flow of calculations for predicting inundation

A general flow of calculations for predicting inundation during storm surges is 1) assuming the external force of a storm surge (target typhoon), 2) preparing topographical data, 3) setting and inputting initial conditions, 4) reproductive simulation, 5) predictive simulation, and 6) outputting results.

1) <u>Flow of calculations for predicting inundation during storm surges</u>
A general flow of calculations for predicting inundation is shown in Figure 2.1.1.

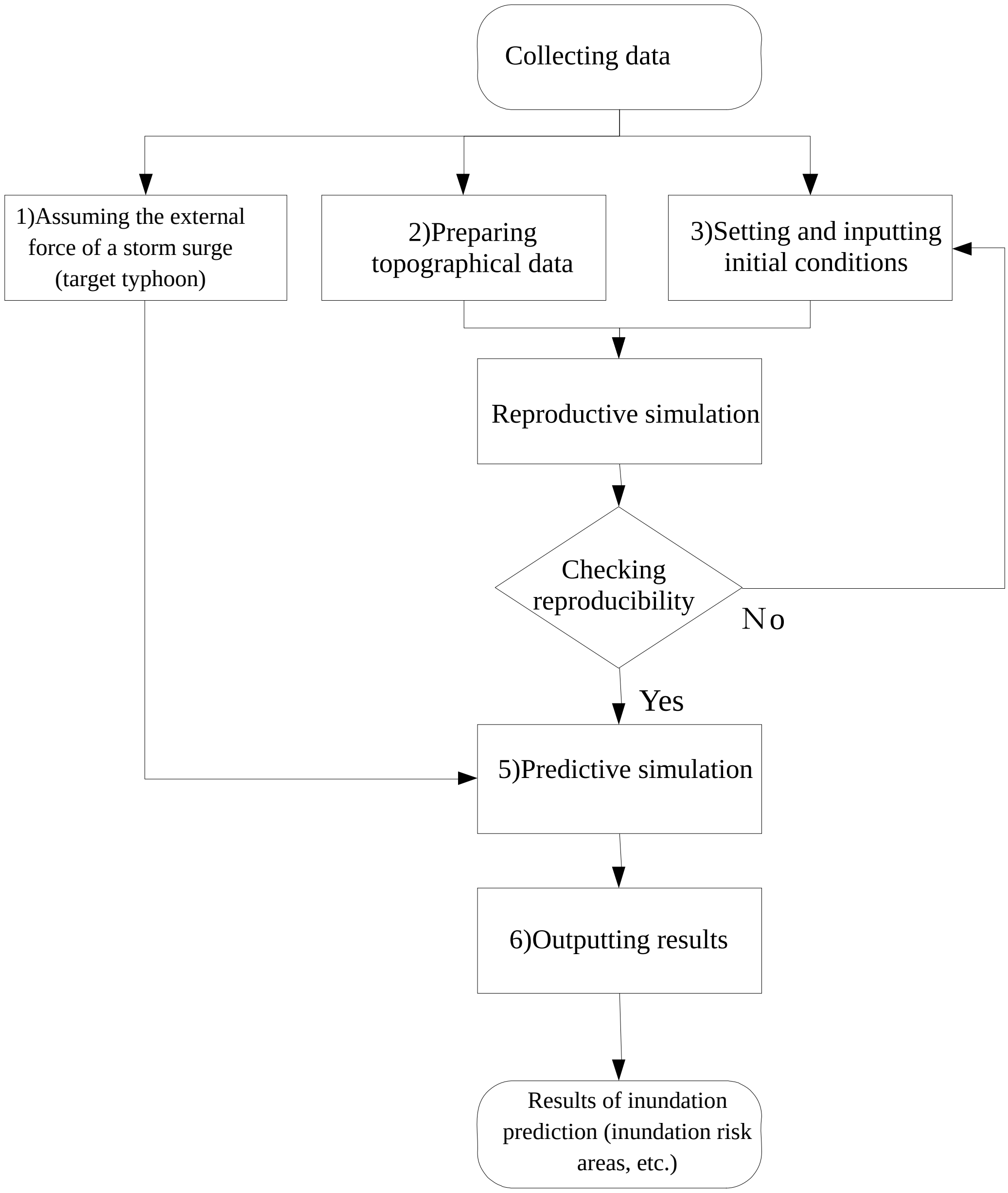


Figure 2.1.1 Flow of calculations for predicting inundation

2) Conditions used for preparing storm surge hazard maps

This manual presents an overview of how to deal with uncertain factors, or conditions used for preparing storm surge hazard maps, while keeping in mind how such factors should be set to minimize damage to residents. Conditions used for preparing tsunami hazard maps are shown in Table 2.1.1.

Table 2.1.1 Conditions used for preparing storm surge hazard maps

Item	Conditions used for preparing storm surge hazard maps
Typhoon	1. Scale of typhoon
	2. Route of typhoon
Tidal levels and waves	3. Tidal level (astronomical tide)
	4. Calculated waves
Topographical conditions and run-up along river	5. Grid intervals
	6. Elevation
	7. Run-up along river
Structures	8. Conditions of structural damage
	9. Operational state of facilities
	10. Method of numerical analysis for storm surge

2.2 Scale and route of typhoon

The external force to assume when preparing storm surge hazard maps should be investigated and determined by the body in charge of preparing the maps, according to the storm tide that may be caused by the largest possible typhoon and other conditions.

The assumed typhoon for simulations should be the largest typhoon recorded or a typhoon of the scale of the Ise-wan Typhoon. The route of the typhoon for calculating inundation should be the route that causes the most serious damage to the area by referring to the routes of typhoons in the past.

1) Assumed external force

The assumed external force should be determined in reference to the storm tide that would be caused by the largest possible typhoon*[1] assumed based on available knowledge.

2) Assumed typhoon

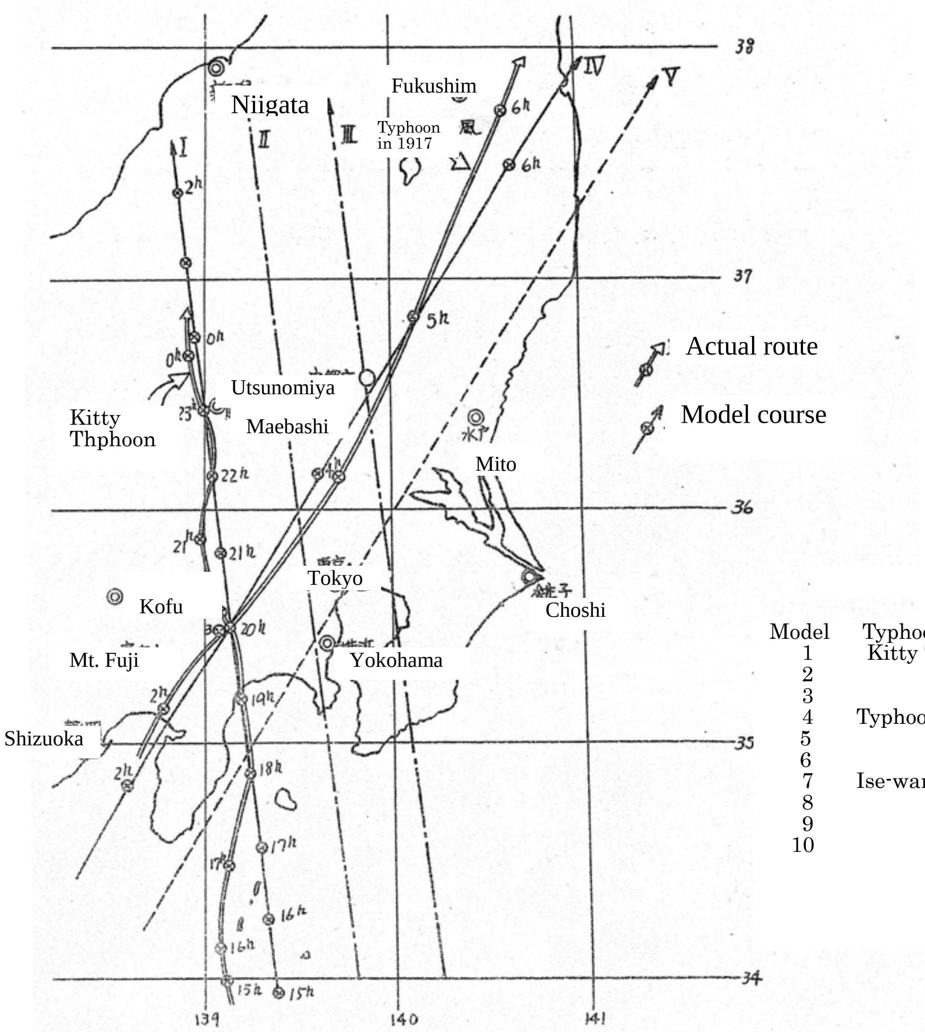
Unlike river discharge, typhoons are difficult to express in probability distribution because there is little observation data available regarding typhoons. Therefore, simulations should be performed based on the data from both the largest recorded typhoon in the area and/or the Ise-wan Typhoon, which is the largest typhoon ever recorded in Japan (in terms of atmospheric pressure after landfall). The traveling speed of the typhoon should also be appropriately determined. Concerning a typhoon of the scale of the Ise-wan Typhoon, data for simulations do not have to be that of the Ise-wan Typhoon; data that are most suited to the area should be employed in reference to typhoons in the past. The conditions of bank damage should be determined according to the scale of the typhoon.

*[1] The largest typhoon denotes a typhoon that would cause the most serious damage to the target area, and should be investigated and determined by the body in charge of preparing the hazard map.

Reference: Scales and routes of typhoons for Tokyo Bay

For the Tokyo Bay, model scales (Ise-wan and Kitty Typhoons) and routes are assumed to calculate the largest storm tide using two-dimensional models. The routes used for simulation calculations, and the results, are shown in Figure 2.2.1.

The largest deviation at the depths of the bay is shown when a typhoon of the scale of the Ise-wan Typhoon takes almost the route of the Kitty Typhoon.



Model	Typhoon	Route
1	Kitty Thphoon	I
2	〃	II
3	〃	III
4	Typhoon in 1917	IV
5	〃	V
6	〃	VI
7	Ise-wan Typhoon	VII
8	〃	VIII
9	〃	IX
10	〃	X

Figure 2.2.1　Routes of typhoons used for storm surge simulation and results

2.3 Tide (astronomical tide)

Tidal levels for storm surge simulation should in principle be the mean monthly highest water level (H.W.L.). A storm tide calculated by using the assumed typhoon or the largest recorded storm tide should be used.

<Method for determining tidal level>

Tidal levels for storm surge simulation should in principle be the mean monthly highest water level (H.W.L.). The mean monthly highest water level during the typhoon season should be investigated when necessary. The typhoon season is generally July to October, although this may depend on area.

2.4 Calculated wave height

> Wave height for storm surge simulation should in principle be the wave height calculated by the simulation conducted by using the assumed typhoon. When the largest recorded storm tide is used as the assumed external force, appropriately calculated wave height should be determined by referring to records.

<Method for determining wave height>

Wave height for storm surge simulation should in principle be the wave height calculated by the simulation conducted by using the assumed typhoon.

The relationship between storm tide and waves as well as tidal level (astronomical tide) for simulation should be investigated and determined by the bodies in charge of preparing the maps.

When the largest recorded storm tide is used as the assumed external force, appropriately calculated wave height should be determined by using the design wave height for facilities and 50 year probability wave height.

2.5 Grid intervals

> Grid intervals for storm surge simulation in the target sea and river areas should be appropriately determined by ensuring the precision of the target inundation risk area and by taking account of minute topography, such as structures.

Grid intervals for storm surge simulation should be determined in the same way as those for tsunami simulation are. (See *1.4 Grid intervals* for methods for determining grid intervals for tsunami simulation.)

2.6 Elevation

> Elevation data for storm surge simulation directly affects the resultant estimated inundation depth and thus should be precise. Especially, the elevation data for areas where inundation is predicted during tsunamis need precision smaller than 1 m to estimate inundation depth. When such precise data is not available, the necessary precision should be ensured by correcting data by using the survey points of topographical maps, reconnaissance surveys, and surveys by coast experts.

Elevation for storm surge simulation should be determined as that for tsunami simulation is determined. (See *1.5 Elevation* for methods for determining elevation for tsunami simulation.)

2.7 Run-up along rivers

> In areas where inundation from river water during storm surges may occur, the run-up of the high waves along rivers should be calculated by appropriately determining river discharge based on river characteristics and records in the past.

1) Rivers for which run-up should be considered

Bays are prone to storm surges when they face the open sea, are shallow in depth, and extend far inward. Rivers that flow into such bays are prone to run-up of sea water during storm surges. When there are bridges in river sections where sea water may run up, the heights of the girders must be examined, and the effects of the bridges on run-up and swell-head must be considered.

2) River discharge

The effects of river discharge on the run-up of sea water along the river have not been clarified. Simulations have shown a general tendency that the run-up of sea water causes smaller rises in river water as river discharge becomes larger. In other words, when the discharge of a river is large, rises in tidal level at the river mouth are not transmitted along the river, and the water level of the river is determined by the flood discharge. On the other hand, when the river discharge is small, the rises in tidal level are transmitted along the river and cause rises in the water level of the river. Thus, rises in water level of a river would be largest when the discharge of the river were to be zero. Note that the focus here is placed on "rises in water level caused by storm surges", and such rises does not mean rises in river water level itself.

Since the behavior of water when run-up of sea water and downflow of flood water are combined is little understood, river discharge should be tentatively determined in the following manner:

1) For rivers running in areas where important assets are located, river discharges should be calculated on the assumption that such areas are in a critical situation. Calculations should be conducted by drawing a flood hydrograph in which the design high water peak discharge occurs simultaneously with the highest tidal level at the river mouth, or by determining a certain design high water peak discharge at the river mouth.

2) For rivers running in areas where no important assets are located or for which no design flood hydrograph exists, the run-up along a river during storm surges should be calculated by using the normal discharge of the river as the river discharge.

2.8 Conditions of structure damage

> Damage to coast protection facilities and other structures by overflows and overtopping should be considered on the basis of their present conditions.

1) Determining facility conditions

Facility conditions should be determined by surveying the actual states of facilities, investigating the possibility of overflows and overtopping for each facility, and conducting simulations by using different conditions.

Facilities may possibly be damaged by collision with containers and driftwood, depending on region.

2) Mechanisms of levee breachs

Levee breachs during storm surges are asummed to be caused by overtopping of sea water, which is triggered by abnormal rises in sea level, but the detailed mechanisms are not yet understood as in breaches during non-storm surge periods.

3) Levee breach width

During storm surges, breach widths vary, and the widths are difficult to estimate. The breach width of river levees is estimated based on river width, but this method cannot be used for coastal levees, since the breach widths will vary even along the same coast depending on the landform at each point, the conditions of the levees, and the actual external force received.

4) Levee breach height

When a coastal levee breaches, its concrete foundation may remain. However, sea water inundates the land. Thus, levees should be assumed to be destroyed down to the foundation, the height of the levees after destruction should be considered to be as high as the elevation to the inland.

5) Progress of levee breaches

Levee breaches are determined by a combination of tidal level and wave height, which changes over time, and the start of levee breaches is difficult to estimate. Thus, calculations should be conducted by assuming that a levee starts breaching at the peak tidal level, when it is most dangerous, or immediately before the peak (for example when the amount of overtopping exceeds the allowable level). The progress of levee breaches (expansion of levee breach width) should be ignored in calculations, since coastal levees are likely to be destroyed in units of certain lengths at once due to their concrete, three surfaces armoring structure.

2.9 Operational states of facilities

For inundation prediction during storm surges, water gates and land locks should be assumed to be closed except for those that will apparently not function. Simulations should also be conducted by assuming, when necessary, that some are open.

<Determining facility conditions>

Water gates and land locks should be able to be closed before storm surges strike. For large cities, where the population is large and the damage will be serious, such as ordinance-designated cities, simulations should be conducted by assuming the water gates and land locks are both open and closed.

The effects of pumping stations should also be investigated when necessary.

2.10 Method of numerical analysis for storm surge

In storm surge simulation, the linear long-wave theory may be used for deep sea areas. For shallow sea areas, including land sections where tsunamis are likely to run up, the non-linear long-wave theory (shallow water theory), in which ocean bottom friction and advection are considered, should be used. Calculations should be continued until the highest storm tide appears, including the resurgence period.

1) Characteristics of storm surge calculation

The scale of a storm surge is similar to the causal meteorological disturbance and is much larger than water depth. Thus, storm surges are expressed by the equations of the linear long-wave theory. Storm surges are characterized by rises and drops in water level caused by changes in atmospheric pressure and forced fluctuations in water surface caused by the continuously acting external forces of winds. Thus, calculations should be conducted by considering the rotation of the earth, drops in atmospheric pressure, friction of winds acting on the water surface, and ocean bottom friction. The precision of calculation can be improved when the deflection of winds by mountains and other landforms is appropriately considered.

Calculations should be continued until the highest storm tide appears, including the resurgence period.

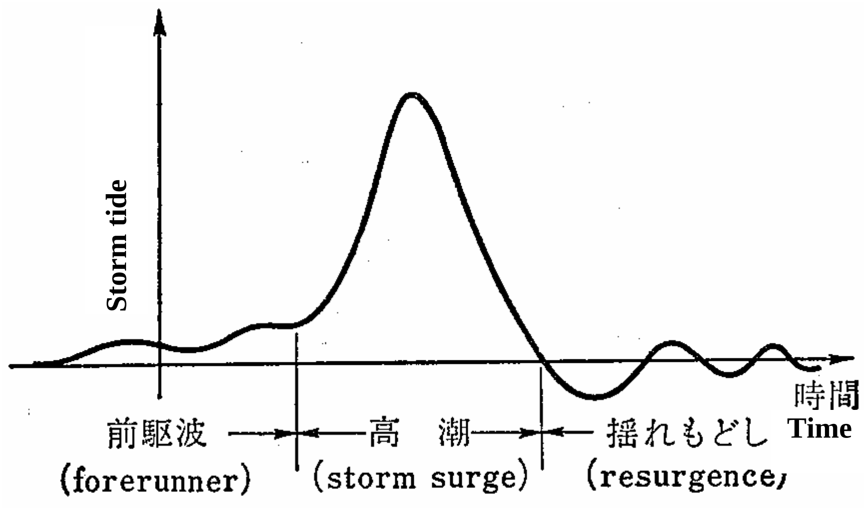


Figure 2.10.1　Time-series change in storm tide during storm surges
Reference: Iwagaki, Yuichi and Sawaragi, Toru, Coast Engineering (in Japanese), 1979, Kyoritsu Shuppan

2) Other uncertainty factors

The traveling speed of a typhoon, which is an uncertainty factor of external force, and the uncertainty factors of calculations, such as wave set-ups by wave breaking, the coefficient of friction of the sea surface, and irregularity of the amount of overtopping, should be considered based on the latest technologies.

3) Coarseness of the land

The effects of structures on the land sections can be investigated using the mean coarseness in calculation grids, which depends on the land use (see Table 1.4.1).

Reference 2: Examples of utilizing tsunami and storm surge hazard maps for developing measures for preventing disasters

Utilization of tsunami and storm surge hazard maps enables non-structural measures for avoiding disasters (such as enhancing residents' self defense capabilities and drawing up evacuation plans) and structural measures (such as the investigation of emergency and restoration plans using real-time information) to be effectively taken.

1) Utilization of hazard maps for taking non-structural measures

Tsunami and storm surge hazard maps, which show information about tsunami and storm surge disasters and inundation risk areas, are effective for taking non-structural measures for avoiding disasters during tsunamis and storm surges, such as enhancing residents' self defense capabilities and drawing up evacuation plans (evacuation sites and routes) (Figure 1). This reference describes examples* of utilizing tsunami and storm surge hazard maps to help administrators draw up non-structural measures.

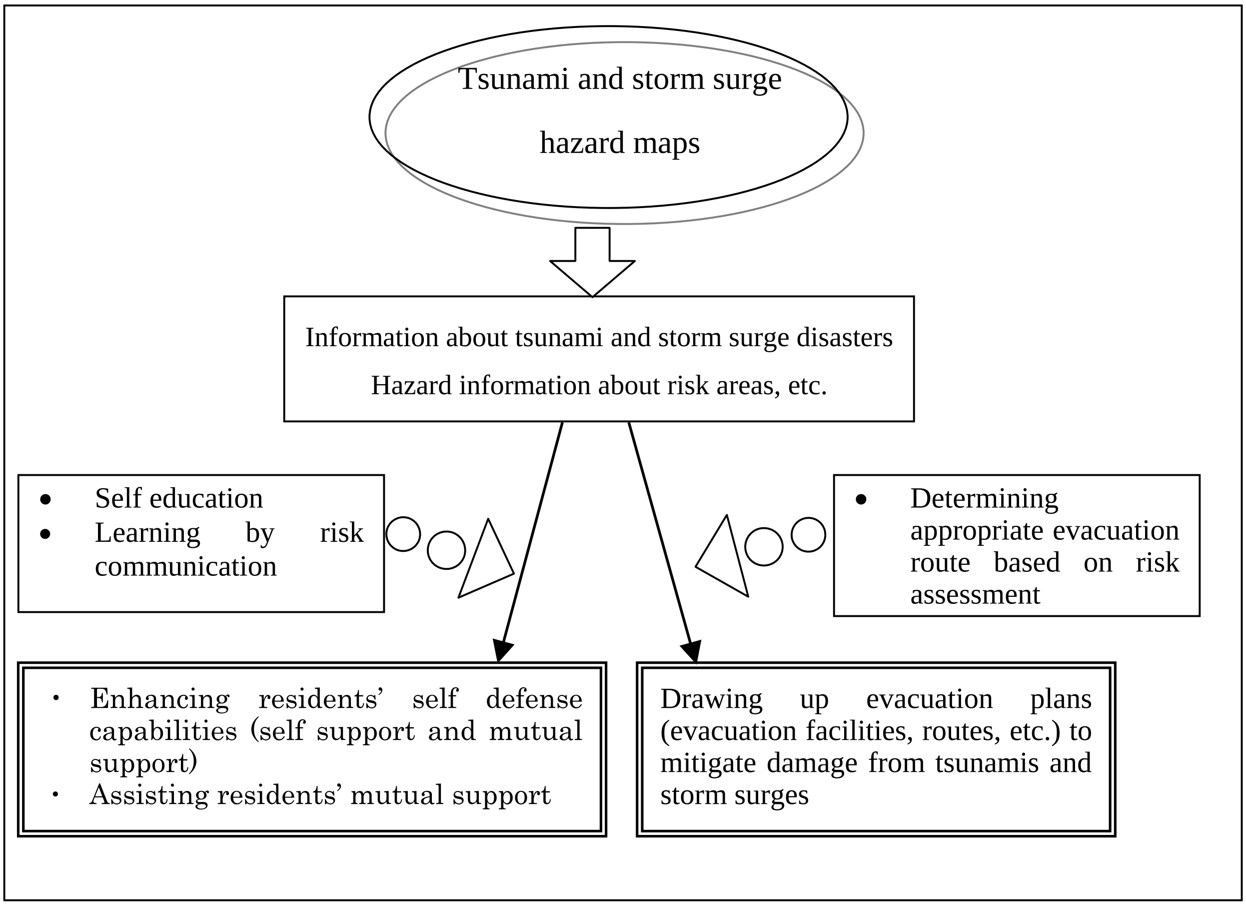


Figure 1. Flow of investigating non-structural measures against tsunamis and storm surges by utilizing tsunami and storm surge hazard maps

*Examples described in this reference are mere examples and do not limit the activities to be undertaken.

2) Utilization of hazard maps for taking structural measures

Tsunami and storm surge hazard maps for administrators, which show information on tsunami and storm surge disasters and inundation risk areas, and information for each purpose, are effective for taking structural measures for preventing disasters caused by tsunamis and storm surges by facilitating investigation of emergency and restoration measures by using real-time information. This reference describes examples of utilizing tsunami and storm surge hazard maps to help administrators draw up structural measures.

1. Methods for enhancing residents' self defense capabilities by utilizing tsunami and storm surge hazard maps

(1) Learning about tsunami and storm surge disasters (residents)

> Residents can effectively learn about tsunami and storm surge disasters and enhance their self defense capabilities by utilizing hazard maps for residents provided by administrative bodies. Residents may study printed hazard maps and sign boards, visit websites, participate in local meetings of disaster prevention groups, and exchange risk information with administrative bodies.

Tsunami and storm surge hazard maps become effective only when residents themselves use those maps and learn about tsunami and storm surge disasters and enhance their self defense capabilities. Learning activities include studying printed hazard maps and sign boards, visiting websites, and sharing awareness of disaster prevention with other residents through local meetings of disaster prevention groups and through risk communication with administrative bodies that prepared the hazard maps.

○Learning at meetings of local disaster prevention groups

Local disaster prevention groups should hold meetings to learn about disasters by utilizing hazard maps to educate residents and share information. Investigating the risks and evacuation routes for each small district will be especially effective. It is also helpful to prepare more detailed local hazard maps by investigating very local and minute details that cannot be discussed at workshops. Local disaster prevention groups that may confront the same disaster should mutually exchange information and coordinate emergency measures.

(2) Providing residents with information to help them decide evacuation (for administrative bodies)

> Information for enabling residents to appropriately evacuate can be supplied by providing accurate information on tsunamis and storm surges in conjunction with tsunami and storm surge hazard maps, and by installing signs that are coordinated with the hazard maps for guiding evacuation.

Tsunami and storm surge hazard maps can be used to take appropriate evacuation action during disasters. The relationships between hazard maps and evacuation actions are summarized in Table 1.1.1. Researches have revealed that the timing of information acquisition affects the evacuation behavior of residents, and delays in information provision lead to delays in evacuation. Thus, extra care should be taken regarding the timing of information provision.

Table 1.1.1 Relationship between tsunami/storm surge hazard maps and evacuation action/measures before disasters

Hazard map	Evacuation actions/measures
For residents (paper)	Understanding the risk of tsunamis and storm surges, evacuation sites and routes, other information for deciding evacuation (local residents)
For administrators	Constructing evacuation sites and routes, selecting appropriate sites for establishing disaster prevention headquarters, constructing river, coastal, and harbour facilities, providing education on disaster prevention, and utilizing the information for drawing up land-use and regional plans (administrators)

It should be noted that information shown on tsunami and storm surge hazard maps is based on certain assumptions and contains uncertainty. Thus, unexpected disasters may occur during actual tsunamis and storm surges.

1) Providing residents with accurate information on tsunamis and storm surges in conjunction with tsunami and storm surge hazard maps

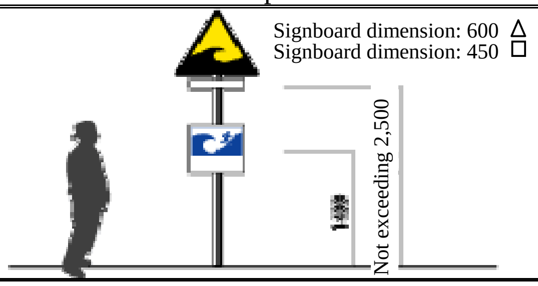
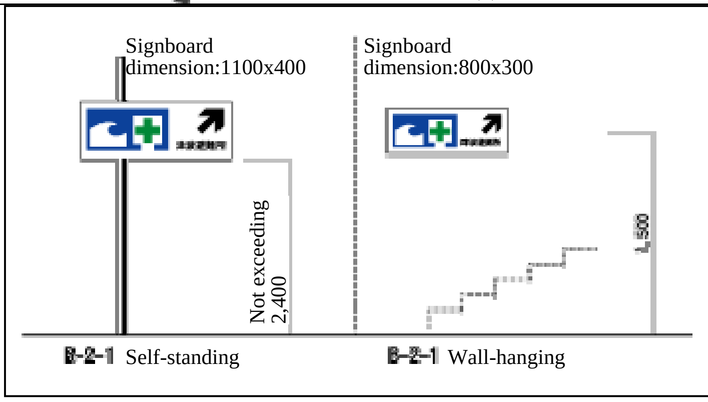
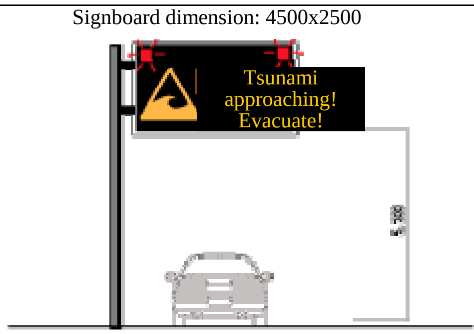
Information shown on tsunami and storm surge hazard maps is preliminarily information, and residents must decide on evacuation, and evacuate during an emergency, on the basis of the information on the maps. However, during emergencies, residents may not be able to collect sufficient information to correctly decide on evacuation. Disasters beyond the assumptions of the hazard maps may also possibly occur. Thus, for appropriate evacuation, correct information on tsunamis and storm surges must be provided to residents in a manner coordinated with the hazard maps.

For example, information on tsunamis and storm surges broadcast by municipal governments through their disaster prevention radio systems should be provided in ways that are coordinated with their hazard maps. A real-time two-way hazard map provision system using IT is also an effective method for transmitting correct information on tsunamis and storm surges in emergencies.

2) Installing signs for guiding evacuation in coordination with the hazard maps

Especially during a tsunami, people need to evacuate in a hurry. They may lose their lives if they get lost. To avoid such situations, signboards showing evacuation routes must be installed in coordination with tsunami and storm surge hazard maps. For example, the signboards shown in Table 1.1.2 should be installed. When evacuation sites differ from those to be used during fires, different signs should be used to show the evacuation sites, but uniform signs should be used for each kind of disaster.

Table 1.1.2 Signs for guiding evacuation

Kind of sign	Functions	Examples
Signs to show risk	Educate about the characteristics and risks of tsunamis	
Signs to show evacuation sites	Transmit information about evacuation routes and sites	
Signs to warn of tsunami approach	Warn residents about approaching tsunami as quickly as possible	

Reference: Kochi Prefectural Government

Diverse evacuation guiding systems, such as those that use sounds and lasers, are needed for nighttime evacuation and should be used on a trial basis.

2. Drawing up evacuation plans by using tsunami and storm surge hazard maps (for administrative bodies)

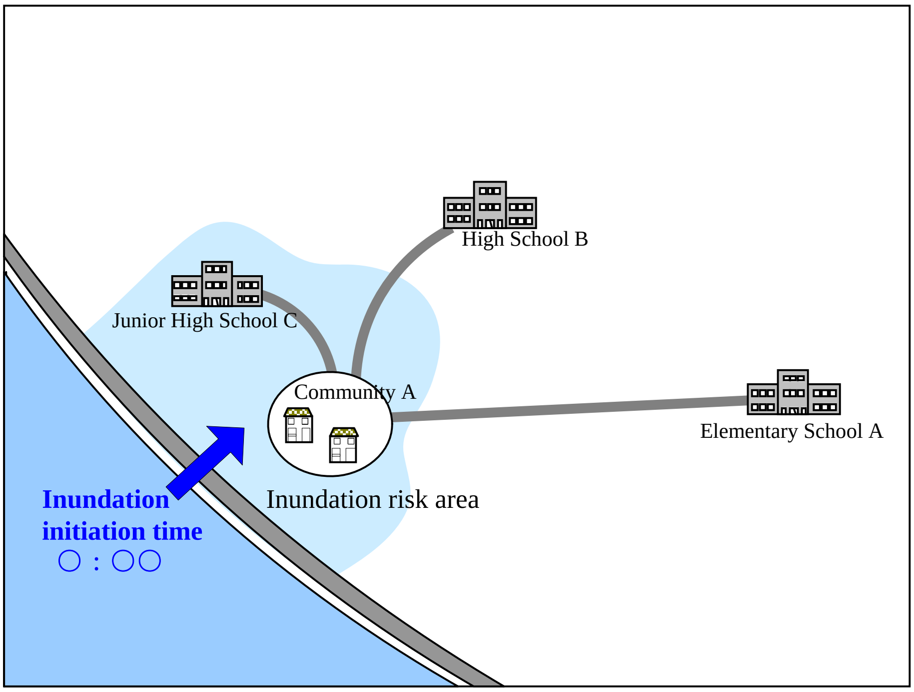
(1) Investigating plans for disaster prevention measures and constructing disaster prevention centers (normal time)

> Information shown on tsunami and storm surge hazard maps, such as inundation areas and inundation depths, can be used to investigate evacuation routes and sites that can minimize damage.
>
> Information on dangerous sites and evacuation routes can be used to investigate the scales of evacuation sites, routes of emergency vehicles, and the amount of emergency goods to transport and its transportation routes.

Information shown on tsunami and storm surge hazard maps, such as inundation areas, inundation depths, dangerous sites, and evacuation routes, can be used to investigate evacuation routes and sites, routes for emergency vehicles, and the amount of emergency goods to transport and its transportation routes. Examples are described in the rest of this section.

<Example 1-1>

Theme	Information shown	Use the information to understand
Investigating evacuation sites during storm surges	Inundation initiation time	Affected areas and expansion
	Inundation initiation site	Inundation risk areas
	Population distribution inland	Number of people who need to evacuate
	Evacuation site	Evacuation site



Candidate for evacuation site	Inundation risk area	Distance	Judgment
Elementary School A	Outside the area	Far	
High School B	Outside the area	Near	
Junior High School C	Inside the area	Near	

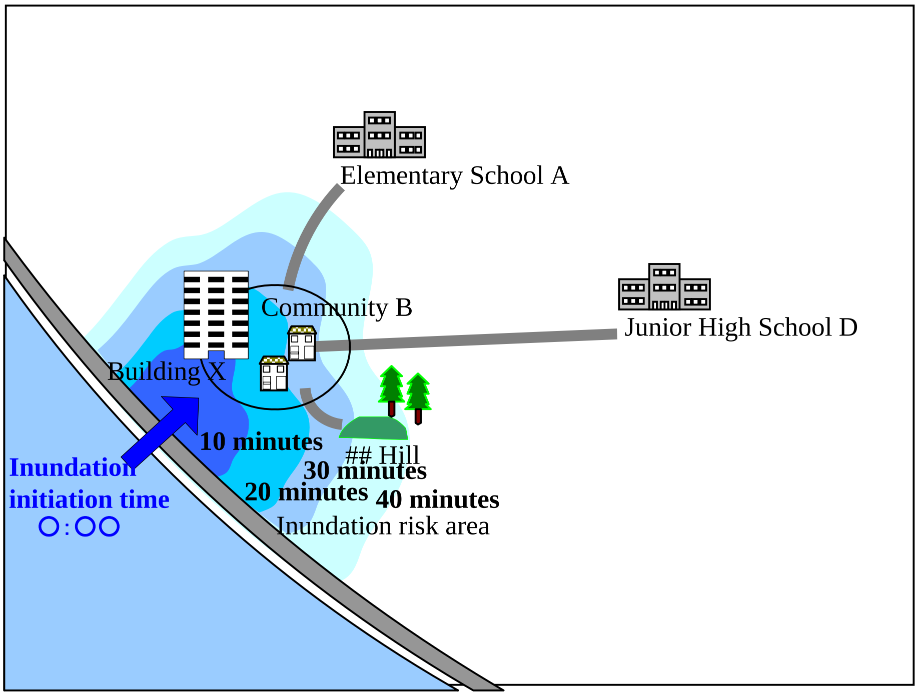
→ High School B was chosen to be the evacuation site.

Figure 1.2.1 Using tsunami and storm surge hazard maps for determining evacuation sites during storm surges

<Example 1-2>

Figure 1.2.2 Using tsunami and storm surge hazard maps for determining evacuation sites during tsunamis

Theme	Information shown	Use the information to understand
Investigating evacuation sites during tsunamis	Inundation initiation time	Affected areas and expansion
	Inundation initiation site	Inundation risk areas
	Population distribution inland	Number of people who need to evacuate
	Evacuation site	Evacuation site



⇨

Time allowance	Candidate for evacuation site	Inundation risk area	Distance
Almost no time	Building X	Inside the area	Very near
Not much time	## Hill	Inside the area	Near
Sufficient time	Elementary School A	Outside the area	Rather far
Sufficient time	Junior High School C	Outside the area	Far

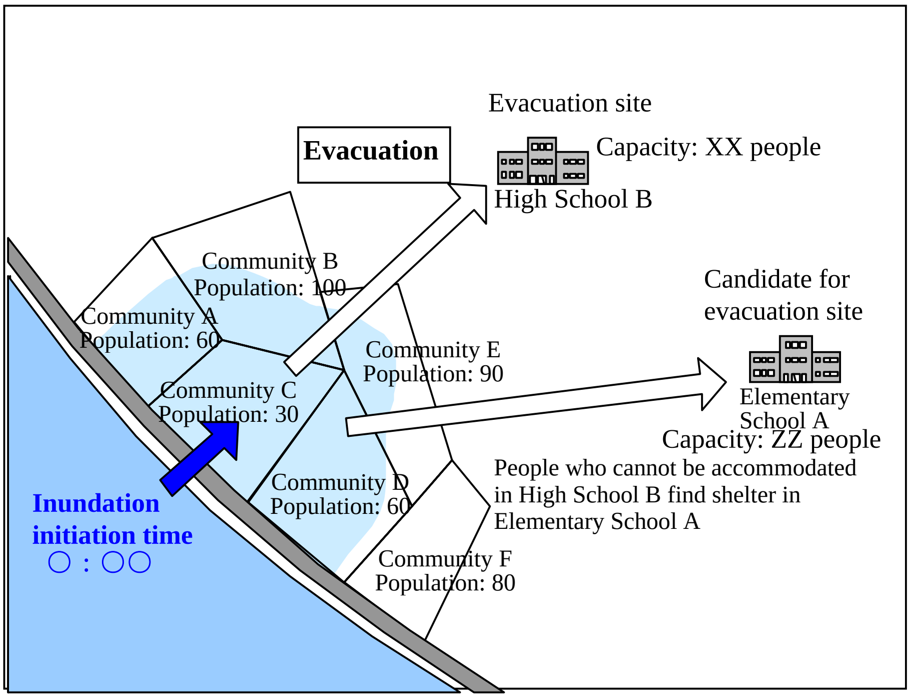
→ When there is little time to evacuate, Building X and ## Hill should be set as the evacuation sites.

Evacuation sites during tsunamis must be nearby (which is an important condition for the elderly), since there will be little time after an earthquake before the resultant tsunamis reach the coast.

<Example 2>

Figure 1.2.3 Using tsunami and storm surge hazard maps to understand the demand for evacuation sites

Theme	Information shown	Use the information to understand
Understanding the demand for evacuation sites	Inundation initiation time	Affected areas and expansion
	Inundation initiation site	Inundation risk areas
	Population distribution inland	Number of people who need to evacuate
	Evacuation site	Evacuation site
	Capacity of evacuation site	Capacities of evacuation sites



Community	Population	Area	Size of inundation risk area	Number of people evacuating Within parenthesis, the number of people evacuating over a long period of time
A	60	150m²	50m²	60(20)
B	100	200m²	100m²	100(50)
C	30	100m²	100m²	30(30)
D	60	150m²	50m²	60(20)
E	90	150m²	50m²	90(30)
F	80	100m²	0m²	0(0)
Total			350m²	340(150)

Note: The number of people evacuating over a long period of time is calculated from the population of the community and the percentage of inundated area in the total area of the community.

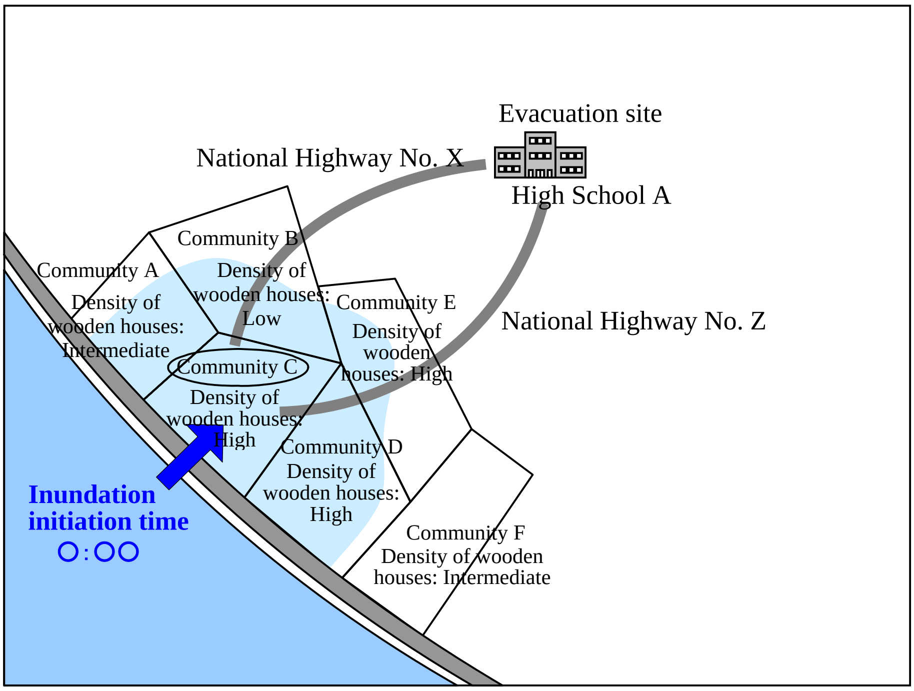
→ 340 persons are estimated to evacuate to High School B (150 persons will stay there over a long period of time)

When the number of people finding shelter in High School B exceeds its capacity, some must move to another evacuation site. The optimum allotment should be decided by combining the results of Examples 1-1 and 2, such as XX persons to High School B and ZZ persons to Elementary School A, to support the evacuation of residents.

<Example 3>

Figure 1.2.4 Using tsunami and storm surge hazard maps for investigating evacuation routes

Theme	Information shown	Use the information to understand
Investigating evacuation routes during tsunamis	Inundation initiation time	Affected areas and expansion
	Inundation initiation site	Inundation risk areas
	Density of wooden houses	Safety of the district during earthquake
	Evacuation route candidates	Safety of evacuation routes
	Evacuation site	Evacuation site



Highway	Communities to pass to reach the evacuation site	Density of wooden houses	Judgment
X	Community B	Low	○
Z	Community D	High	X
	Community E	High	

National Highway X was decided to be the evacuation route from Community C.

During a tsunami, the earthquake preceding the wave may destroy buildings and bridges, blocking evacuation routes. Hazard maps can be used to investigate such possibilities.

New evacuation routes may need to be constructed in districts where wooden houses are densely built.

(2) Checking the operation and conditions of systems (during disasters)

Coast protection facilities (water gates and land locks) can be appropriately operated by utilizing tsunami and storm surge hazard maps.

When a tsunami or storm surge is anticipated, coast protection facilities (water gates and land locks) can be appropriately operated by utilizing tsunami and storm surge hazard maps together with information on the scale of the tsunami or storm surge. Especially during typhoons, appropriate measures against storm surge can be taken by utilizing the prediction results for the corresponding typhoon route.

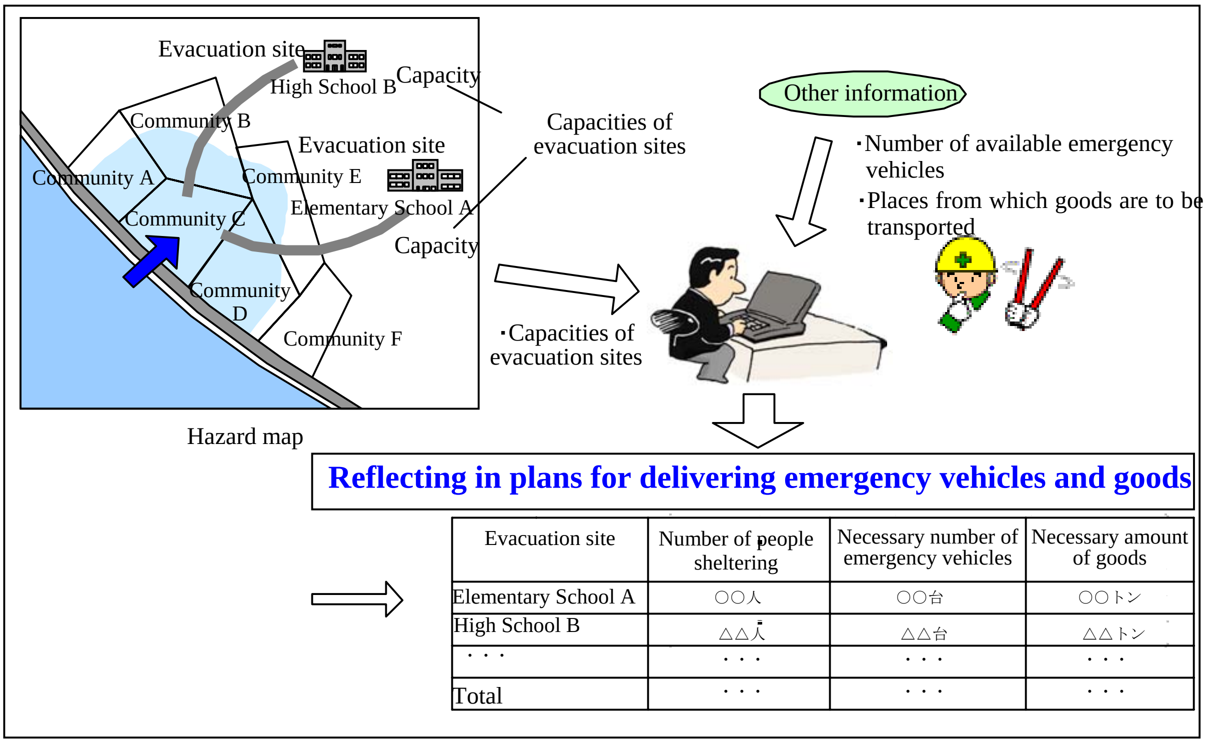
(3) Investigating evacuation and rescue plans (during disasters)

During disasters, evacuation and rescue plans can be investigated, such as methods for evacuating residents (determination of evacuation routes and sites) and delivering emergency vehicles and goods to evacuation sites, by comparing the scale of the actual disaster with those shown in tsunami and storm surge hazard maps.

During disasters, appropriate evacuation of residents (by specifying evacuation routes and sites) can be supported by judging the scale of the disaster, comparing the scale with those shown in tsunami and storm surge hazard 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.

After the disaster, tsunami and storm surge hazard maps can be used to figure out the numbers of people injured and evacuated and to undertake appropriate rescue measures.

<Example 1>



Evacuation site	Number of people sheltering	Necessary number of emergency vehicles	Necessary amount of goods
Elementary School A	○○人	○○台	○○トン
High School B	△△人	△△台	△△トン
・・・	・・・	・・・	・・・
Total	・・・	・・・	・・・

Figure 1.2.5 Utilization of tsunami and storm surge hazard maps for drawing up evacuation plans (methods of delivering emergency vehicles and goods)

<Example 2>

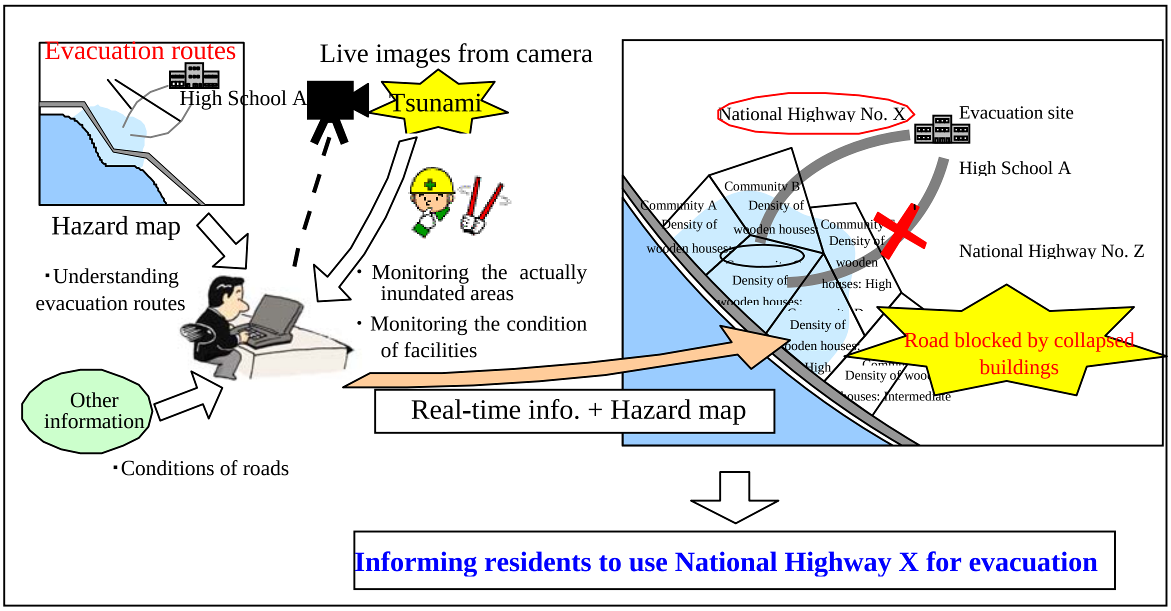


Figure 1.2.6 Utilization of tsunami and storm surge hazard maps for drawing up evacuation plans (issuing evacuation orders)

3. Investigating emergency measures and restoration plans using real-time information

Coast protection facilities to be operated during disasters (water gates, land locks, etc.) should be shown on tsunami and storm surge hazard maps to ensure their operation. When real-time information from cameras, etc., is available, the operational conditions should be monitored and the information should be used for emergency and restoration measures.

After a disaster, the actual damage should be compared with the assumed and predicted damage shown on tsunami and storm surge hazard maps to investigate practical emergency and restoration measures.

Facilities that are little prone to damage should also be monitored in real time and be reinforced and repaired when necessary.

Facilities may be monitored using cameras for transmitting live images, by inspecting facilities according to tsunami and storm surge hazard maps, and by preparing real-time hazard maps.

Coast protection facilities that are to be operated during disasters (water gates, land locks, etc.) and which are shown on tsunami and storm surge hazard maps can be monitored in their operation by utilizing the results of inundation prediction and real-time information. The information can also be used to investigate emergency and restoration measures.

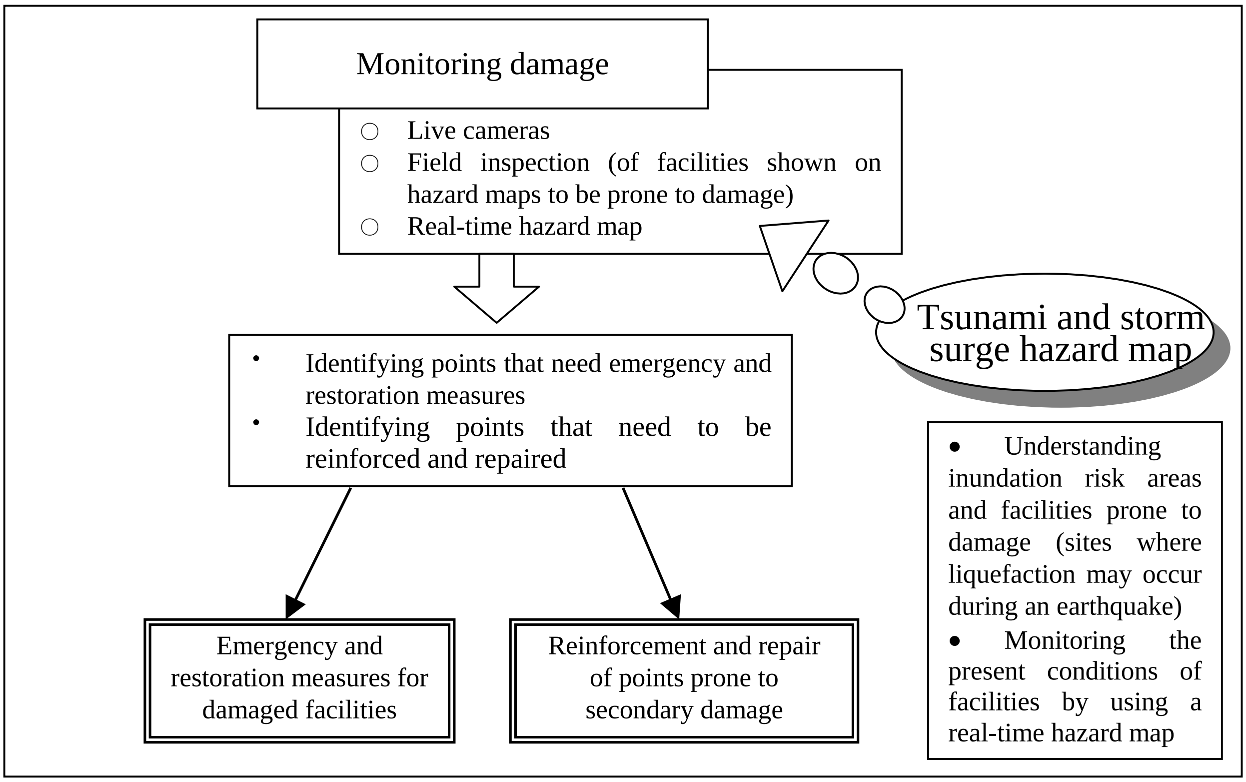


Figure 1.3.1 Flow of investigating emergency and restoration measures using real-time information

The following is a mere example and does not designate bodies in charge.

<Example>

Theme	Information shown	Use the information to understand
Investigating emergency measures for damaged facilities	Inundation initiation time	Affected site
	Protection facilities and their structures	Affected facilities
	Population distribution inland	Priority of restoration

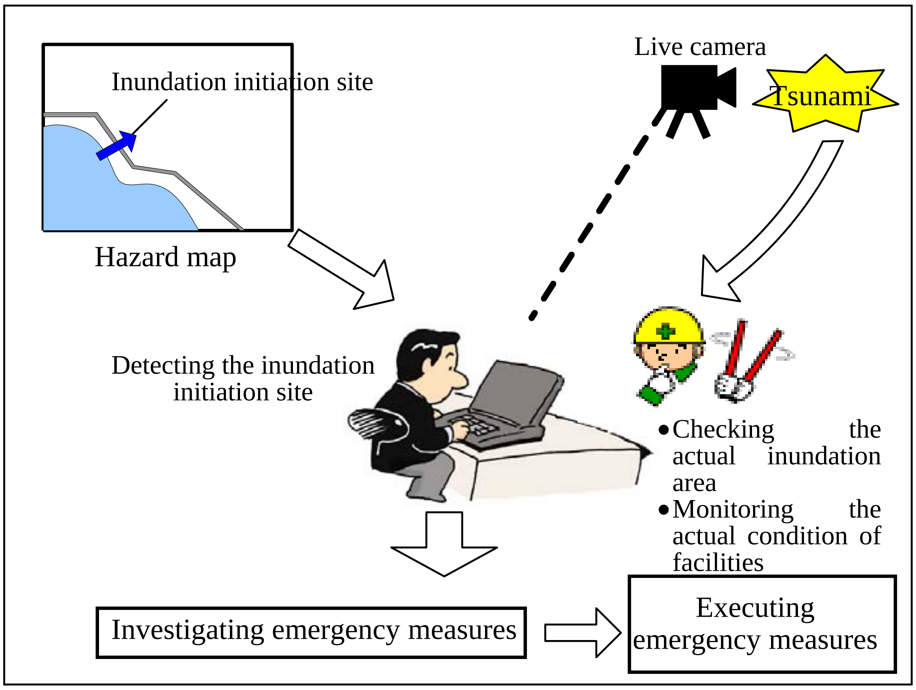


Figure 1.3.2 Utilization of tsunami and storm surge hazard maps for deciding emergency measures for damaged facilities

Reference 3: List of related web sites

Class	Site	URL
Administrative organization	Pages of the Cabinet Office in charge of disaster prevention	http://www.bousai.go.jp/
	Pages of the Central Disaster Prevention Council	http://www.bousai.go.jp/jishin/chubou/index.html
	Headquarters for Earthquake Research Promotion	http://www.jishin.go.jp/main/index.html
	Fire and Disaster Management Agency	http://www.fdma.go.jp/
	Japan Meteorological Agency	http://www.jma.go.jp/JMA_HP/jma/index.html
	Disaster Prevention Information Provision Center	http://www.bosaijoho.go.jp/link.html
	Study Committee on Tsunami and Storm Surge Hazard Maps	http://www.mlit.go.jp/kowan/hazard_map/hazard_map.html
Research institute	National Research Institute for Earth Science and Disaster Prevention	http://www.bosai.go.jp/jindex.html
	Earthquake Research Institute, the University of Tokyo	http://www.eri.u-tokyo.ac.jp/Jhome.html
	Disaster Prevention Research Institute, Kyoto University	http://www.dpri.kyoto-u.ac.jp/default.j.html
	Japan Weather Association	http://www.jwa.or.jp/
	Disaster Reduction and Human Renovation Institution	http://www.dri.ne.jp/
Other	NHK Disaster Prevention Notes	http://www.nhk.or.jp/nhkvnet/bousai/

As of February 2004

Explanation of terms

Terms	Explanation
Outcome index	an index for indicating effects and outcomes of measures and projects.
Advection	state in which fluid or substances in fluid move and change by a flow field.
Overtopping	phenomenon in which sea water passes over the upper surface (crown) of coast protection facilities, such as breakwaters, sea walls, and walls, by the force of waves.
Coriolis force	recurvature force. Apparent force acting on a substance moving on a rotating coordinate axis, such as the earth.
Wave breaking	phenomenon in which waves lose their stability, cannot maintain the waveform, and break. Waves from offshore cannot maintain their waveform and break forward when they reach shallow water.
Mean monthly highest water level (H.W.L.)	mean of the high water levels of each month, which appear between 2 days before and 4 days after the synoidal days.
Geological Information System (GIS)	comprehensive technology for controlling, processing, and visualizing data on position (spatial data), based on geological locations, to enable advanced analyses and rapid judgment.
WebGIS	GIS provided through the Internet.
Water gate	gates and other structures that open and close at rivers and water channels to regulate the flow of water.
Land lock	gates installed at banks, etc., that open and close for the passage of people and vehicles.
Spectrum method	a method for estimating waves. A general term for methods that trace and calculate the development and attenuation of the spectrum based on the equation of energy equilibrium.
Solinton fission	phenomenon in which waves of certain wavelength divide into waves of shorter wavelengths.
Bore	waves generated by discontinuous changes of water surface when water gates and other structures on a standing open channel flow are suddenly closed or opened.
Crown	the tops of banks and other protection facilities. Crown height is the height from the basic reference level.
Mean sea level of Tokyo Bay (T.P.)	reference level for land elevation in Japan.
Inland	land protected from floods by river and coast protection facilities.
Hydrograph	Diagram showing time-series changes of river discharge

Items	Explanation
Non-linear long-wave theory	one of the equations for analyzing tsunamis and storm surges. The relative water depth (the ratio between wave length and water depth) is assumed to be infinitively small, the vertical acceleration is ignored, and the finite amplitude is incorporated.
Uncertainty	term denoting that future results can be judged in advance only in terms of probability.
Boussinesq’s equation	one of the models for analyzing waves. A long-wave equation is used that considers both the non-linearity and dissipation of waves.
Undular bore	waves that have turned into waves of a shorter period by solinton fission.
Calculation grid and grid intervals	aggregate of data recorded by dividing a two- or three-dimensional coordinate into grids. Grid intervals are the dimensions of the grids (fineness of data).
Significant wave method	one of the methods for estimating waves. A general term for the SMB method, which describes a method for estimating significant waves (1/3 maximum wave), and Wilson’s method, which expands the SMB method for general water areas.

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