Analysis of Spillover Process and Development of Estimation Methods of Tsunami Damage in Ports and Surrounding Areas

by

Katsuya Oda[1], Osamu Okamoto[2] and Kentaro Kumagai[2]

ABSTRACT

Based on the actual damage in past tsunamis that caused damage in Japan, this paper systematizes the types of tsunami damage which can be assumed to occur in coastal areas, where ports locate their centers, by classification into "direct damage" due to inundation and drifting objects and "indirect damage," in which the depression of port functions and related effects of the tsunami spill over into the surrounding region and society. Based on the results, estimation methods for tsunami damage and tsunami countermeasures in ports are proposed. The scope of research on coastal hazards of a scale exceeding the design external force (mega-risk coastal hazards) is also discussed.

KEYWORDS: Estimation method, Excess external force, Spillover process, Tsunami damage

1. INTRODUCTION

In recent years, large-scale ocean trench-type earthquakes accompanied by tsunamis have been a serious concern. Likewise, Japan is located in a seismically-active region and has experienced a number of tsunamis in the past. Based on this experience, countermeasures have been implemented, but these measures mainly involve the construction improvement of coastal protection facilities such as dikes revetments and similar works. At present, adequate study has not been given to countermeasures for wharfs and basins which lie outside of these works.

On the other hand, population and property are concentrated in coastal areas, and diverse facilities exist in these areas, including ports which serve as bases for logistics and passenger transport and coastal facilities which are important for not only disaster prevention but also conservation of environment and proper use of shore, and. In the event of a tsunami accompanying a large-scale earthquake, which is considered imminent in many parts of Japan, the damage will not be limited to "direct damage" due to inundation and other direct effects, but will also include a wide range of "indirect damage" due to reduction of port functions and the like. This means that tsunami hazards in coastal regions will have serious and wide-ranging socioeconomic effects. Therefore, as a new research topic, in addition to direct damage due to inundation, etc., it is also necessary to analyze the spillover process of tsunami damage, which includes indirect damage, and to study estimation methods for tsunami damage in ports and surrounding areas.

Considering the fact that ports play a crucial role in the social infrastructure, in this paper, damage to ports by tsunamis was systemized based on past examples, and tsunami damage was analyzed using a model port. Tsunami countermeasures in the model port were studied, and the basic concepts of tsunami countermeasures in ports were summarized.

2. ANALYSIS OF TSUNAMI DAMAGE

2.1 Systemization of Examples of Tsunami Damage

A total of 11 major earthquakes accompanied by tsunami damage have occurred in Japan since 1945, including the Showa Nankai Earthquake, Niigata Earthquake, Tokachi-oki Earthquakes, Hokkaido- Nansei-Oki Earthquake, and others. Table 1 summarizes the main tsunami damage in ports and their hinterland areas since 1964.

[1] Head, Coastal Disaster Prevention Division, National Institute for Land and Infrastructure Management (NILIM), Ministry of Land, Infrastructure and Transport(MLIT), Yokosuka-shi, Kanagawa-ken 239-0826 Japan

[2] Senior Researcher, ditto

Table 1 Damage Caused By Major Tsunami Ports and Surrounding Areas (Hinterland) Since 1964

Name, date, and magnitude (M)	Direct damage in port/hinterland				Indirect damage such as reduction of port functions, etc.
	Damage to protective facilities, mooring facilities, etc.	Inundation damage	Drift damage	Human injury (no. of persons; including injury due to earthquake)	
Niigata Earthquake Tsunami, June 6, 1964, M7.5		Inundation of products stored in warehouses, loss of value of products	Spill/fire of hazardous materials from oil tanks, drift of timber	26	Economic damage to commerce and industry due long-term inundation of hinterland
Tokachi-Oki Earthquake Tsunami, May 16, 1968, M7.9		Inundation of buildings	Drift of ships	52	
Nihonkai-Chubu Earthquake Tsunami, May 26, 1983, M7.7	Sliding/overturning of training dike, bulkhead of reclaimed land, etc.	Inundation/damage of fishery facilities, inundation of factories and houses in hinterland	Drift of timber, drift of fishing boats	104: Large number of port construction workers and port visitors were killed by tsunami.	Port activity suspended due to closure of port for collection and removal of timber
Hokkaido-Nansei-Oki Earthquake Tsunami, July 12, 1993, M7.8	Sliding/overturning of breakwater, seawall, etc.	Inundation/damage of ferry terminal, inundation/damage of fishery facilities, fire in houses in hinterland	Drift of automobiles, drift of fishing boats, drift of housing wreckage	230	Suspension of ferry service for collection and removal of drifting objects
Hokkaido-Toho-Oki Earthquake Tsunami, Oct. 4, 1994, M8.2				10 *Injury on Iturup Island	
Tokachi-Oki Earthquake Tsunami, Sept. 26, 2003, M8.0		Inundation of ferry terminal, inundation/damage of cargo handling equipment	Drift of containers, drift of fishing boats	2	Long-term stoppage of cement supply/substitution by nearby port

According to this table, damage to protective facilities/mooring facilities such as breakwaters, seawalls, which were affected by external forces due to tsunamis took the form of sliding or overturning. In the ports, inundation damage affected various port facilities such as transit sheds including stored products, ferry terminals, fishery facilities, cargo handling equipment. In the hinterland, factories, residence and others suffered inundation damage and sometimes fires occurred. Drift damage involving timber, fishing boats, automobiles, wreckage from houses, cargo containers, hazardous materials and other debris also occurred. Human injury, including injury due to the earthquake, was not limited to injury in the port, and in many cases, scores of persons were affected. In particular, there are cases in which a large number of port construction workers and visitors were injured or killed. Indirect damage also occurred due to long-term inundation of the hinterland area and reduction of port functions, such as port closure, etc. Other hazards that can be predicted to occur as a result of a tsunami, such as drifting of pleasure boats were also identified separately by referring to examples of storm surge due to typhoons.

Damage due to a tsunami can be classified as human injury, damage to facilities and other property due to run-up of the tsunami on the land, and drift damage due to debris which were transported from water basins onto the land or vice versa. The locations where damage occurs were classified as damage in the port area, including wharfs, basins, etc., and damage in urban areas in the hinterland of the port. The results of the analysis of these kinds of tsunami damage are shown in Table 2.

Table 2 Classification of Tsunami Damage

Class of tsunami damage		Damage item
Human injury		Loss of life of port construction workers, port visitors, etc.
Damage due to inundation	Damage in port area	Inundation and damage of ferry terminal facilities
		Damage of goods in warehouses, sheds, etc.
		Damage of cargo handling equipment by inundation
	Damage in hinterland	Stop of industrial activity due to inundation by tsunami
		Long-term inundation due to damage of pump stations
Damage due to drift	Damage in port area	Drift of vehicles, pulpwood, containers, ships, etc. into port
		Capsizing, stranding of ships on quays, etc.
		Drift of pleasure boats
		Drift of tankers
	Damage in hinterland	Damage to houses by fishing boats and other drifting objects
		Fire damage due to oil spill

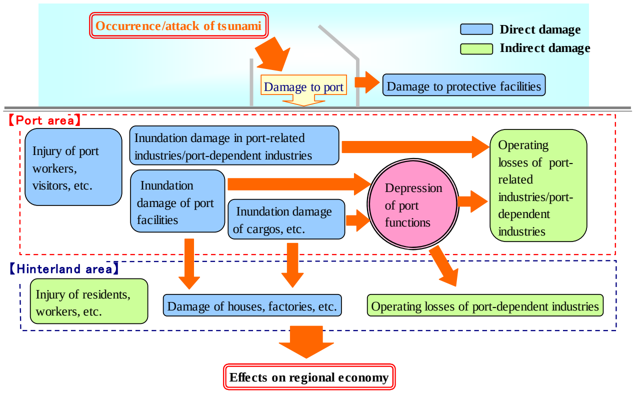

Fig.1 Schematic Diagram of Spillover Process of Tsunami Damage

2.2 Spillover Process of Tsunami Damage

Because the areas fronting onto the sea are utilized in logistics and other port functions, it is a distinctive feature of ports that the larger part of the port area is located outside the tsunami or storm surge defense line. Therefore, if a tsunami attacks, the damage is not limited to direct damage (see Table 2); indirect damage due to depression of port function also occurs over a wide area. In other words, as shown in Fig.1, when a tsunami attacks a port, it causes direct damage, and as a result, the facilities affected by the damage can no longer fulfill full essential roles. This lead to a depression of the functions of logistics and passenger transportation, and causes reduction of business activities and operating losses of business affecting not only industries with bases located in the port area, but also industries that depend on the port. In addition, because the tsunami also causes direct damage in the hinterland of the port, the activity of industries in the surrounding area is reduced, with a negative impact on the regional economy as a whole. The spillover process of tsunami damage in the port and hinterland, which was systematized considering the interrelationship of these various forms of damage, is shown in Fig.2. The temporal/spatial relationship of direct damage and indirect damage was systematized in this diagram of the spillover process, while continuing to focus on the classes of damage to port facilities such as protective facilities and mooring facilities, inundation damage, drift damage and human injury.

2.3 Simulation of Tsunami in Model Port

A numerical simulation of a tsunami in a model port was performed in order to analyze the behavior of tsunamis in ports and the damage which can be assumed to occur in the event of a tsunami. In this numerical simulation of a tsunami, the range of inundation on land and maximum inundation depth, tsunami arrival time, and rates of rise/fall of the water level and flow velocity vectors in water basins were calculated. The conditions used in the simulation are shown in Table 3. The earthquake applied to this case study was the maximum design earthquake in the model port as proposed by the Central Disaster Management Council.

Among the results of the simulation, Fig.3 shows the inundation range/inundation depth on land. In area ① in Fig.3, inundation becomes remarkable at the deepest part of the wharfs due to the increase in the water level at the extreme back of the berth, which is surrounded by the wharfs. It was also confirmed in area ② in Fig.2 that the tsunami run-up in the river flooded over the river levees.

Fig.4 shows the distribution of maximum flow velocity vectors. Increases in flow velocity can be confirmed in locations with rapidly narrowing cross sections, such as the breakwater opening, mooring basins surrounded by wharfs, openings in inner jetties surrounding reservoirs. On land, flow velocities are high in locations where overflow occurs, for example, around the deepest part of berths.

2.4 Estimation Method of Tsunami Damage

(1) Inundation damage

Inundation damage was estimated from the inundation range and the inundation depth in the simulation results.

(2) Drift damage

The objects which may be swept away and drift were assumed to be fishing boats, pleasure boats, and other boats, pontoon, floating piers, cargos stored in the open, such as timber, chips, empty containers and automobiles in wharf parking lots.

For cargos stored in the open, drifting was assumed to begin from the time of inundation, and the damage rate of such cargos in the inundation area was assumed to be 1.0.

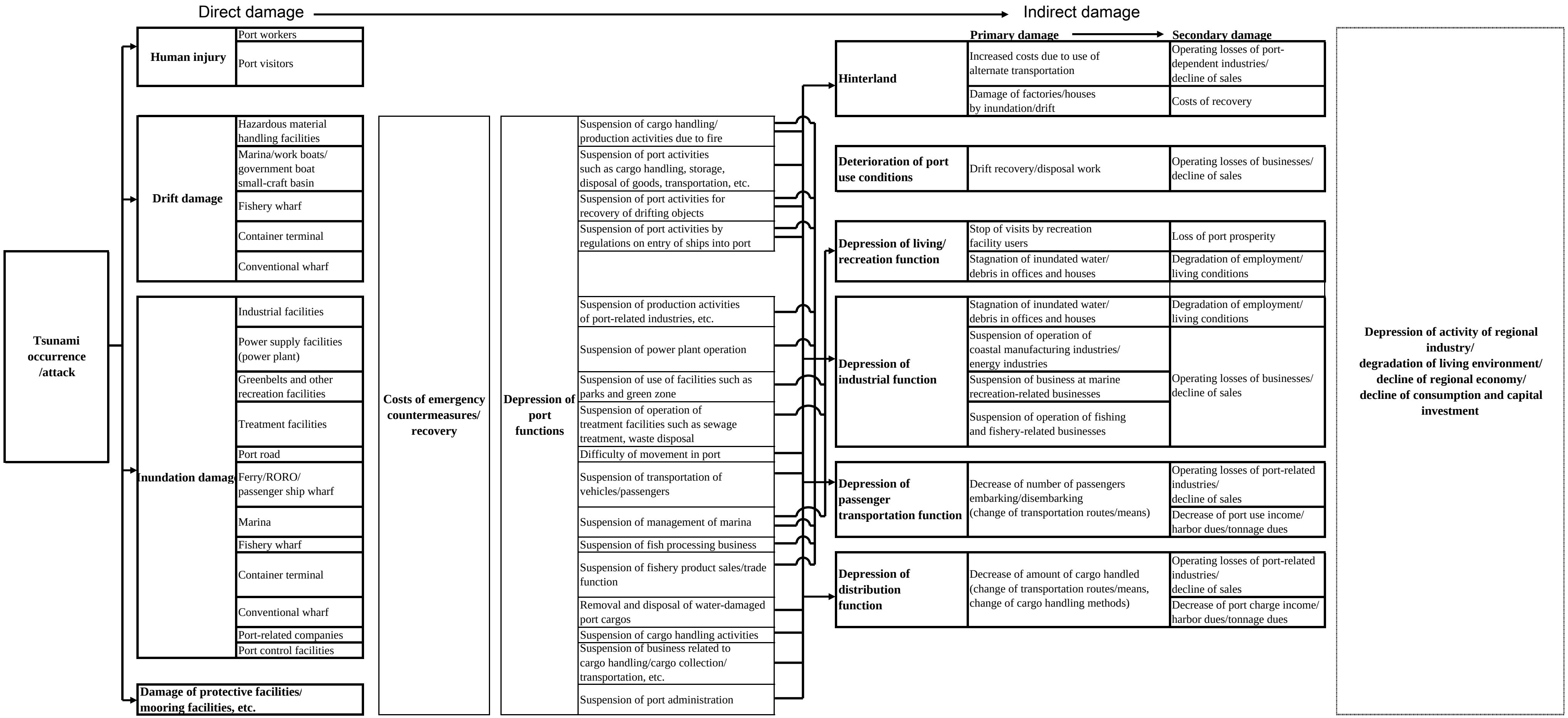

Fig.2 Spillover Process of Tsunami Damage

Table 3 Conditions of Tsunami Simulation

Calculation grid size	Minimum grid size 12.5m x 12.5m
Object earthquake	Assumed Tokai Earthquake
Uplifting of ground	Not considered.
Basic equation	Nonlinear long wave theory equation
Sea bottom friction	Manning's roughness coefficient n = 0.025m-1/3s
Ground friction	Roughness according to land use
Eddy viscosity coefficient	AH=10.0
Water level	H.W.L (T.P. +0.86m)
Calculation time	180min (3hr) after occurrence of tsunami

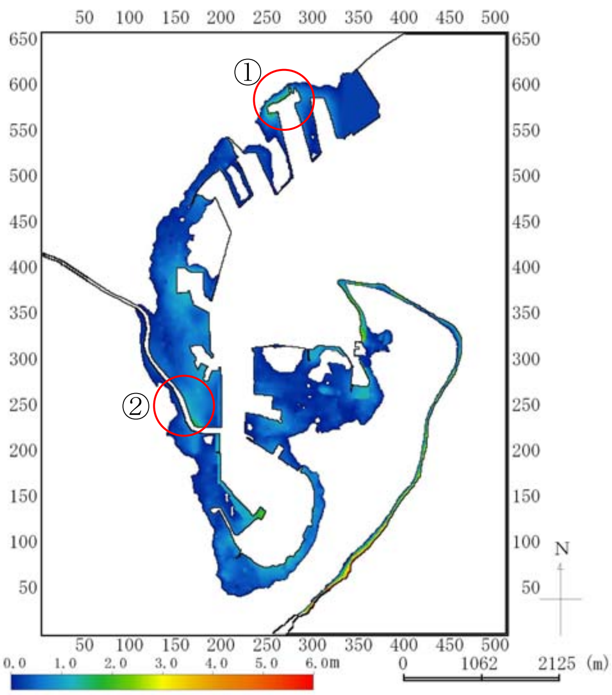

Fig.3 Inundated Area and Inundation Depth

Empty containers were assumed to be stacked four high. Based on the relationship between the buoyancy of the containers and the weight of the stacking levels, the depth of inundation required to cause the containers to drift is assumed to be 0.8m.

The drift damage rate of automobiles in wharf parking lots was assumed to be 1.0 at inundation depths of 50cm and greater, as this is the depth at which passenger automobiles float.

In determining the damage rate for boats, based on the relationship of the tsunami height and damage ratio of all fishing boats in fishing ports (Fig.5) compiled by the Japan Association of Marine Safety (JAMS), it is considered that (a) the damage rate shows a high correlation with the tsunami height, (b) damage occurs when the tsunami height exceeds approximately 1m, and (c) the damage rate increases with the tsunami height, and all vessels are damaged when the tsunami height reaches 7m or more [2]. From this, the solid line shown in Fig.5 was set as the damage rate of boats.

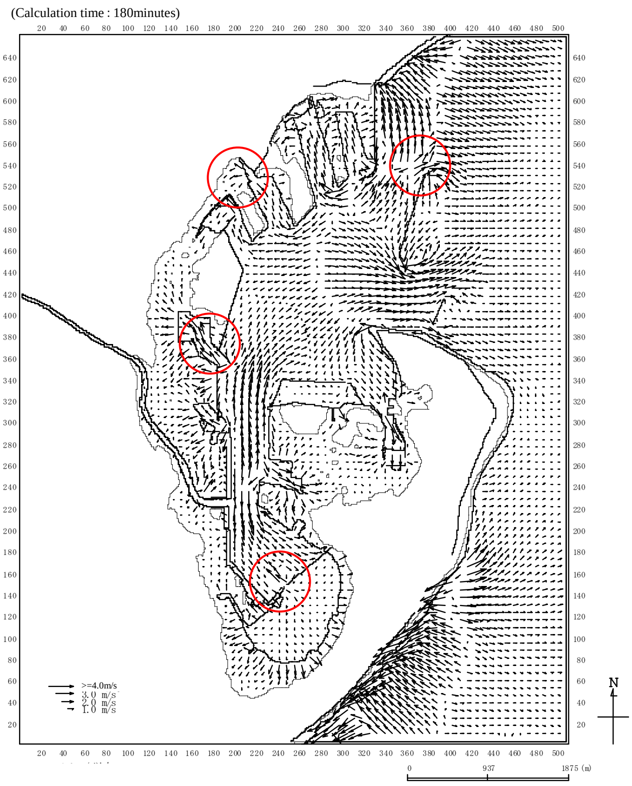

Fig.4 Distribution of Velocity Vector at the Moments When Maximum Velocity Occurs

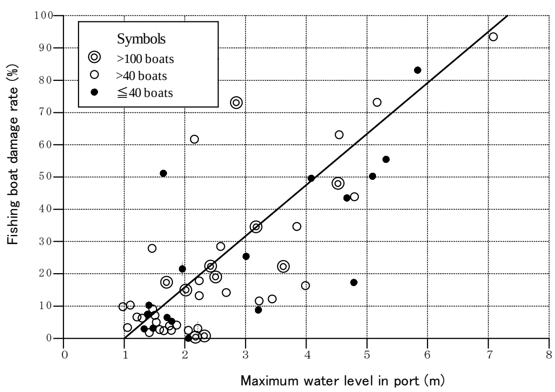

Fig.5 Damage Rate for Ships [2]

Table 4 Drift Damage Rate

<table>
<tr><td colspan="2">Drifting Object</td><td>Drift Damage Rate</td></tr>
<tr><td colspan="2">Mooring facilities (pontoon pier)</td><td rowspan="3">Set by tsunami water level in port(Fig.5)</td></tr>
<tr><td colspan="2">Surveillance service boats (small) , patrol boats</td></tr>
<tr><td>Fishery</td><td>Fishing boats</td></tr>
<tr><td rowspan="2">Cargo</td><td>Lumber, chips, etc.</td><td>When inundation depth is 0.0m or more, damage rate = 1.0</td></tr>
<tr><td>Empty containers</td><td>When inundation depth is 0.8m or more, damage rate = 1.0</td></tr>
<tr><td colspan="2">Pleasure boats</td><td rowspan="2">Set by tsunami water level in port(Fig.5)</td></tr>
<tr><td colspan="2">General ships in port</td></tr>
<tr><td colspan="2">Automobiles</td><td>When inundation depth is 0.5m or more, damage rate = 1.0</td></tr>
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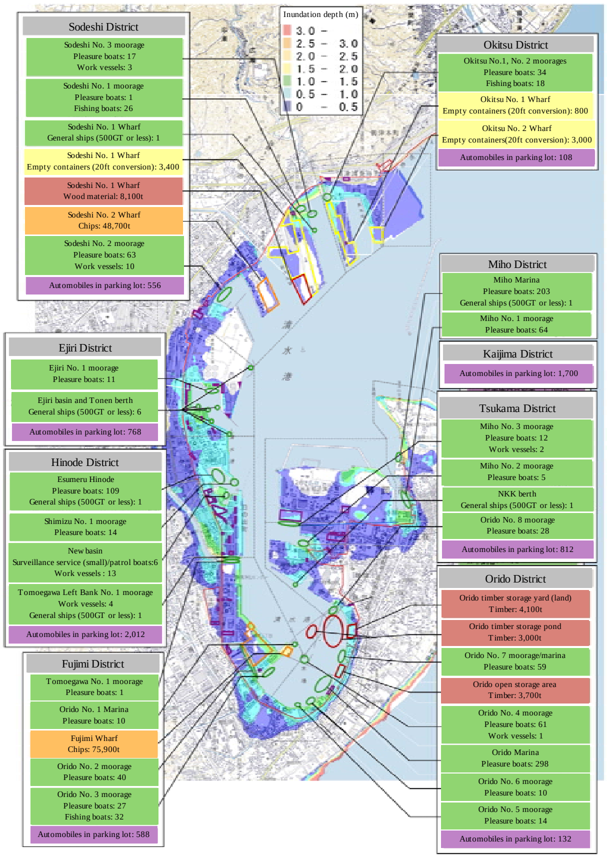


Fig.6 Amount and Location of Drifting Cargos

The drift damage rates of drifting objects are shown in Table 4. The position and amount of drifting objects in the model port were determined based on the field survey, as shown in Fig.6.

(3) Human injury

Fig. 7 shows the boundary between whether a person can walk safely in floodwater or not. This relationship is determined by both the inundation depth and flow velocity [3]. Using the region where it is possible to walk in water when evacuating in a flood shown in the figure as a criterion, the area where safe evacuation is difficult was set and the area affected by human injury due to a tsunami was calculated. The body height used in calculating the area where safe evacuation is difficult was assumed to be 165cm, which is the average height of the Japanese population.

The number of port workers/visitors and the area where safe evacuation is difficult in the model port are shown in Fig.8.

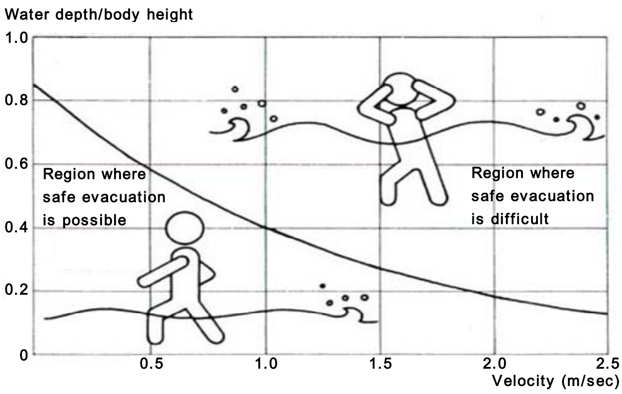


Fig.7 Criterion of Safety Evacuation; Relation between Safety Evacuation and Flood Conditions [3]

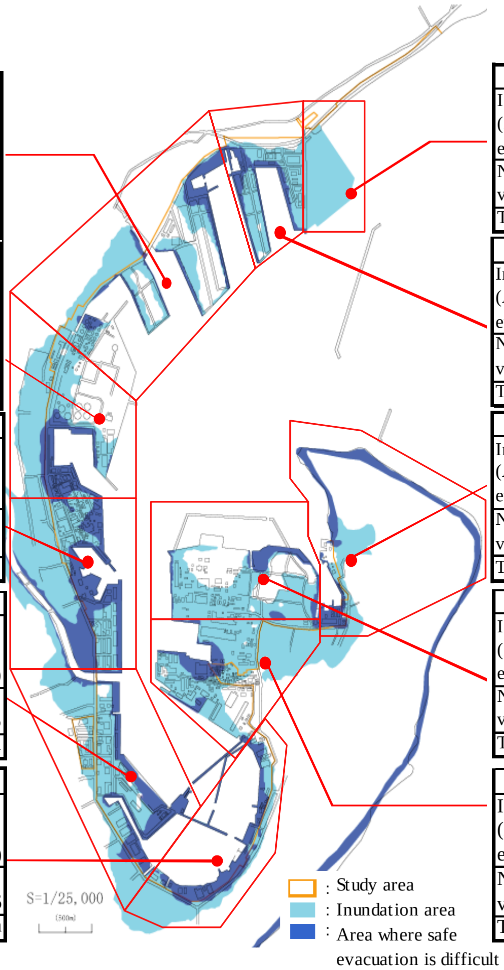
Sodeshi District (939,000m2)	
Inundated area (Area in above where safe evacuation is difficult)	422,000m2 (104,800m2)
No. of port workers/ visitors at risk	731
Time of arrival of tsunami	12min

Ejiri District (659,000m2)	
Inundated area (Area in above where safe evacuation is difficult)	383,100m2 (156,100m2)
No. of port workers/ visitors at risk	1,346
Time of arrival of tsunami	14min

Hinode District (481,000m2)	
Inundated area (Area in above where safe evacuation is difficult)	451,900m2 (214,400m2)
No. of port workers/ visitors at risk	17,526
Time of arrival of tsunami	14min

Fujimi District (614,000m2)	
Inundated area (Area in above where safe evacuation is difficult)	515,800m2 (180,300m2)
No. of port workers/ visitors at risk	1,606
Time of arrival of tsunami	18min

Orido District (210,000m2)	
Inundated area (Area in above where safe evacuation is difficult)	208,900m2 (137,000m2)
No. of port workers/ visitors at risk	716
Time of arrival of tsunami	20min



Shin-Okitsu District (306,000m2)	
Inundated area (Area in above where safe evacuation is difficult)	306,000m2 0m2
No. of port workers/ visitors at risk	165
Time of arrival of tsunami	9min

Okitsu District (443,000m2)	
Inundated area (Area in above where safe evacuation is difficult)	341,600m2 (88,400m2)
No. of port workers/ visitors at risk	978
Time of arrival of tsunami	9min

Miho District (81,000m2)	
Inundated area (Area in above where safe evacuation is difficult)	71,700m2 (41,700m2)
No. of port workers/ visitors at risk	253
Time of arrival of tsunami	14min

Kaijima District (1,172,000m2)	
Inundated area (Area in above where safe evacuation is difficult)	573,900m2 (80,600m2)
No. of port workers/ visitors at risk	238
Time of arrival of tsunami	14min

Tsukama District (596,000m2)	
Inundated area (Area in above where safe evacuation is difficult)	495,600m2 (91,900m2)
No. of port workers/ visitors at risk	1,253
Time of arrival of tsunami	15min

Fig.8 Area affected by human injury

3. STUDY OF COUNTERMEASURES FOR MITIGATION OF TSUNAMI DAMAGE

3.1 System of Tsunami Damage Mitigation Countermeasures in Ports

Tsunami countermeasures can be divided into preventive measures before a tsunami and recovery measures after a tsunami. Preventive measures are considered to include “evacuation measures to ensure the safety of port workers and visitors” and “preventive measures to secure port functions and mitigate property damage in ports,” and can be arranged as shown in Fig.9.

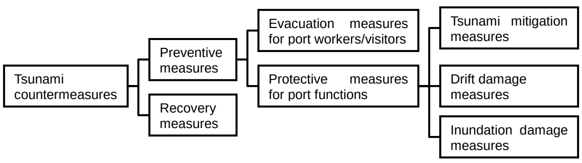


Fig.9 Classification of Tsunami Countermeasures

3.2 Evacuation Measures for Port Workers and Visitors

In areas where human injury due to a tsunami is expected, measures aimed at securing adequate safety for port workers and visitors and preventing human injury have to be developed. A procedure for consideration and establishment of these measures are shown in Fig.10. To enable prompt evacuation of port workers/visitors, quick communication of information is necessary. Establishment of communication methods such as installation of simultaneous wireless broadcasting devices and tsunami alarm bulletin board, coupled with the tsunami observation system, should be considering.

A fundamental concept for designation of refuge facilities is to select the adequate facilities from existing facilities which have earthquake resistance and tsunami resistance and enable smooth evacuation from outside. In areas where it is not possible to evacuate to refuge facilities

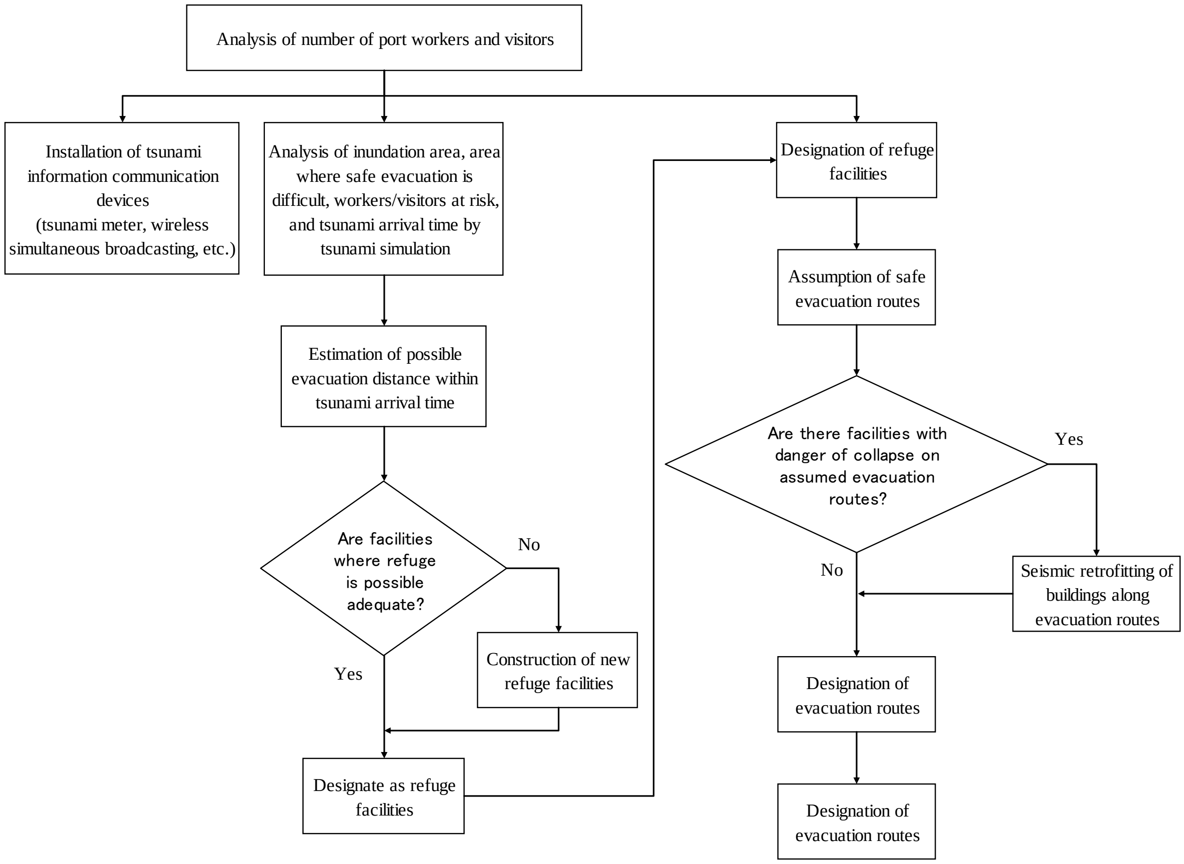


Fig.10 Planning Procedures of measures for safety evacuation and prevention of human injury

by the tsunami arrival time, it is also necessary to study the construction of new refuge facilities.

Evacuation routes are designated so as to avoid buildings which may collapse. It is necessary to implement seismic retrofitting of buildings which may collapse. It is also necessary to lead a smooth evacuation of port visitors and others using evacuation route signs.

3.3 Protective Measures for Port Functions

Protective measures for port functions also should be developed, assuming protection on a priority basis of the functions which must be secured during a tsunami disaster such as emergency material transportation function, critical logistics function and reduction of damage to a degree where ”functions are not impaired” or “immediate restoration of functions by emergency measures is possible.”

Because the breakwater at the port entrance can be expected to reduce the energy of a tsunami and thereby have a damage mitigation effect in the port as a whole, its effect in reducing inundation in the port and reducing flow velocities should be studied. As tsunami mitigation measures at the waterfront, it is also necessary to consider improvement of seawalls such as raising the height.

In areas where inundation damage was identified establishment of measures for inundation in land areas is necessary. These measures include increasing the ground height, raising the level of floors, constructing watertight doors, waterproof walls, waterproofing or raising the floor level of power supply facilities, etc.

As measures for drift, in areas where there is a possibility that cargos, small boats, and automobiles may drift, it is necessary to study construction of drift prevention fences, while continuing to consider use under normal conditions, and to strengthen countermeasures for automobiles and small boats, etc. which are left unattended and may possibly drift in a tsunami.

3.4 Recovery Measures

The aim of recovery measures is to enable appropriate emergency response/recovery after a disaster, thereby minimizing spillover to indirect damage due to direct damage, and early recovery of port functions. It is considered that sharing disaster information regarding the damage such as status of port facilities, drift/scattering of cargos and other objects, whether the quays are in service or not with related organizations will contribute to smoothing the recovery work. Furthermore, it is also important to calculate in advance the time required to remove the debris which were stranded on lands or washed away into basins based on the expected amount of drifting objects and the capability to collect and remove drifting objects in the port.

4. USE OF RESEARCH RESULTS

This research has analyzed the potential damage of a tsunami on ports and the spillover damage from the affected port to the surrounding area by classifying and systematizing the modes of damage caused by tsunamis in ports and the tsunami damage spillover process. Methods of quantifying tsunami damage in ports were also proposed by studying the tsunami damage in a model port. It is thought that these results will be useful in evaluating the effects of countermeasures in future studies of tsunami countermeasures for ports.

In the study of tsunami countermeasures, it is possible to define the viewpoint of countermeasures and clarify the objects for which effects can be obtained by systematizing the countermeasures and proposing countermeasures which correspond to respective purposes. However, it is difficult to achieve the purposes of countermeasures and eliminate tsunami damage by implementing single countermeasures. For this reason, in tsunami countermeasures, it is important to implement comprehensive countermeasures in ports, including nonstructural soft countermeasures.

The Port and Harbor Bureau of the Ministry of Land, Infrastructure and Transport (MLIT) is compiling the research results introduced in this paper for the purpose of publication as “Basic Concepts of Tsunami Countermeasures in Ports.” It is hoped that tsunami countermeasures will be implemented at all ports based on these “Basic Concepts” through cooperation mainly of the national government, port administrators, related businesses, and other stakeholders.

5. PREPARATIONS AGAINST MEGA-RISK COASTAL HAZARDS

5.1 What are Mega-Risk Coastal Hazards?

In a tsunami, storm surge, or other natural disaster affecting a coastal area, there is a possibility that the event may exceed the design external force used for planning and design of protection works such as seawalls, dikes and other structural countermeasures using coastal conservation. This is due to uncertainty in the assumptions related to earthquakes which cause tsunamis, limitations on past typhoon data used in probabilistic evaluations, the effects of global warming, and other factors. The probability of occurrence of a gigantic tsunami or storm surge exceeding design external forces is low, but the damage if such a disaster occurs, the effects can be catastrophic. In other words, in spite of the low frequency of such events, the risk of damage is large.

Photo1 Damage in Sri Lanka resulting from the Indian Ocean Tsunami (Courtesy of Penta-Ocean Construction Co., Ltd.)

The disaster caused by the Indian Ocean Tsunami which struck the coastlines of the nations on the Indian Ocean in December 2004 (Photo1) can be termed a infrequent mega-risk coastal disaster. Likewise, Hurricane Katrina, which made landfall near New Orleans in the United States on August 29, 2005, caused damage that was said to be the worst in US history due to a natural disaster. Because a substantial part of New Orleans lies at or below sea level, the city suffered devastating damage after the levees were breached by the storm surge accompanying the hurricane (Photo–2).

What is the situation in Japan? Estimates of damage by giant earthquakes and tsunamis accompanying these earthquakes have been published for Tokai, Tonankai/Nankai earthquakes, earthquakes in the areas of the Japan Trench and Kuril Trench, and others where occurrence is considered imminent. However, because these damage estimates are based on given scenarios, such as the setting of the scale of the earthquake, the location and dimensions of the fault and so on, there is a possibility of damage on a scale exceeding these damage estimates. Furthermore, there is also concern regarding larger and more frequent typhoons striking Japan. Over the long term, an increase in damage due to rising sea levels is also feared. Because the population and city functions are heavily concentrated in areas lying below sea level in major Japanese cities, that is, in the so-called zero-meter region, an enormous effect on society and the economy is feared in the event of a storm surge exceeding the planned level of protection works in such areas, which are particularly vulnerable to coastal disaster.

Photo2 Area where levee was breached in New Orleans (photo by the authors)

5. 2 Countermeasures for Infrequent Mega-Risk Coastal Hazards

Because endangered areas have long depended on hard countermeasures against infrequent mega-risk coastal hazards, the cost of investment is enormous. Even assuming that various types of hard countermeasures against infrequent mega-risk coastal hazards are implemented, the disaster-mitigating effect is not apparent as long as a major disaster does not occur, and criticism as excessive measures/wasted investment is possible. Therefore, proposals of measures which are effective in mitigating damage during a disaster and also have social utility under ordinary conditions have been demanded.

A wide range of concrete countermeasures are conceivable. These can be broadly divided into measures which diminish the energy or delay the arrival time of a tsunami, etc. by using existing port and harbor facilities such as wharfs, sheds, and warehouses and buildings, forests, aforestation, and plantation sited in the front line, and land use planning and layout planning by introducing regulations and inducement mechanisms for land use which considers disaster mitigation, for example, by arranging promenades and greenbelts which have the function of dikes/refuge areas when redeveloping or converting the use of idle land in coastal areas. Fig.11 shows an image of these countermeasures.

5.3 Efforts by NILIM

Based on the background described above, the National Institute for Land and Infrastructure Management (NILIM) is engaged in “Research on Evaluation Method of Countermeasures with Various Utilities against Infrequent Mega-Risk Type Coastal Hazards” as a project research, which has been promoted on a priority basis since FY2006. In this research, NILIM will propose countermeasures which are effective in mitigating damage in the event of a disaster and also have social utility under non-disaster (normal) conditions as countermeasures for infrequent mega-risk coast hazards, and will also construct an evaluation method for such multi-utility countermeasures and a method of building a consensus between local residents,

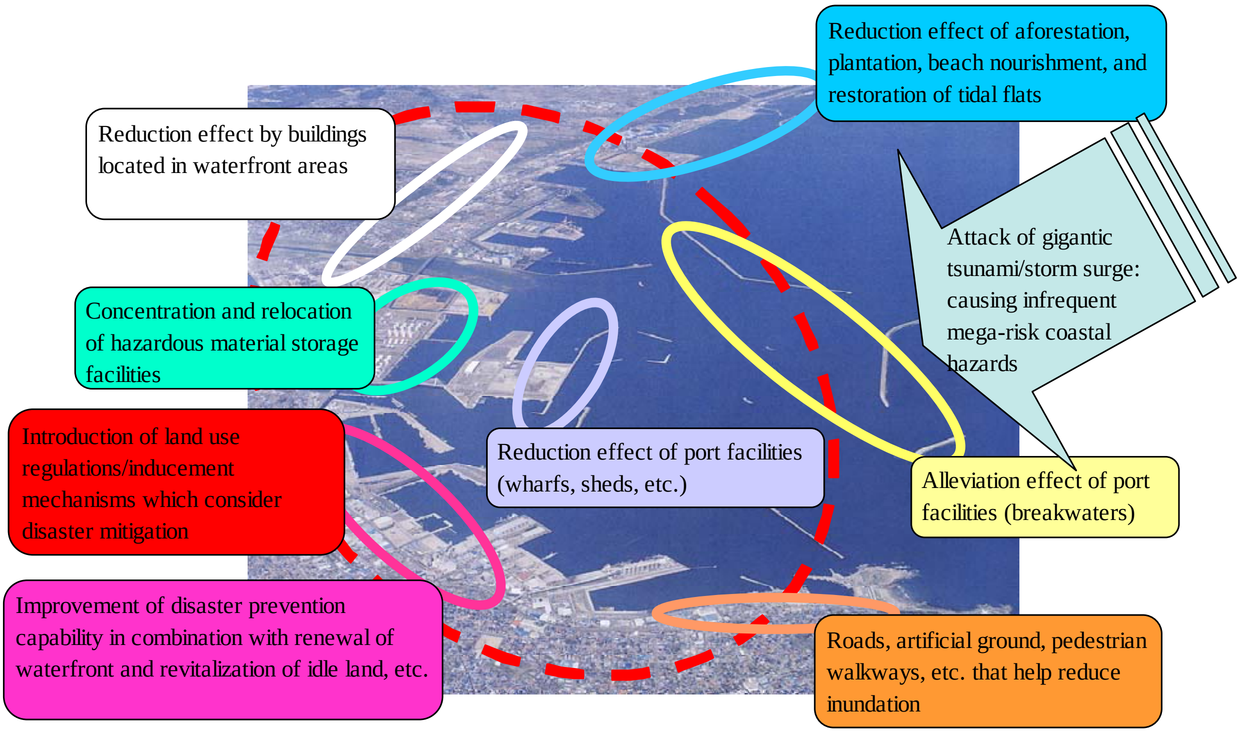


Fig.11 Image of multi-utility countermeasures

administrative authorities and other stakeholders. The objective is to propose guidelines for planning based on the results of these efforts. A facility management system and its operating measures based on life cycle management of storm surge and high wave countermeasure facilities will be proposed. In addition, NILIM will study measures for the construction of a system which integrates risk management in coastal regions, enabling joint use of facility management for storm surge and high wave countermeasure facilities and other infrastructure having a disaster-mitigating effect. NILIM is currently carrying out a study related to the establishment of scenarios for infrequent mega-risk coast hazards, and verification of the disaster mitigation effects of port and harbor facilities and other structures by numerical simulation and experiments. Normally, a 2-dimensional model which expresses shore and land topography using only ground height is employed as a simulation model for estimating tsunami/storm surge inundation behavior. However, in order to verify the disaster mitigation effects of port and harbor facilities, buildings, and others, it is necessary to use a more detailed topographical model which considers the 3-dimensional nature of the shapes of the facilities, as shown in Fig.12.

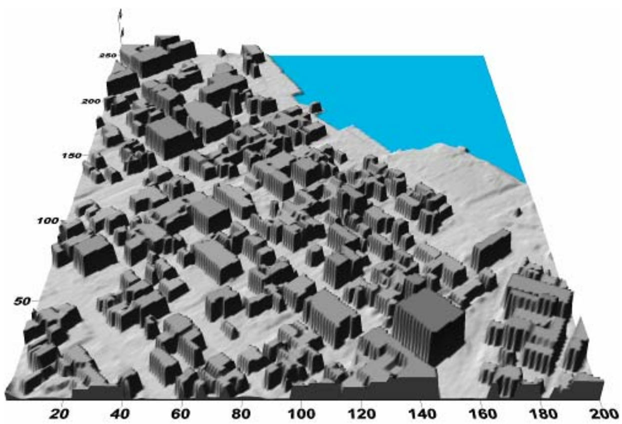


Fig.12 Example of topography in three-dimensional model

5.4 No Regret Policy

The objective of the No Regret Policy advocated in this research is to ensure that there are no regrets in the future to the effect that "preparations were lax" in the event that a major disaster occurs due to external forces exceeding the protective levels of existing countermeasures, and at the same time, there are no regrets about “wasted investment” if a disaster does not occur during the service life of the facilities and equipment. From this viewpoint, we would like to inquire widely about the validity of the No Regret Policy in countermeasures against infrequent mega-risk coastal hazards.

If the results of this research are applied practically, the following effects can be expected: (a) diversification of countermeasures to large-scale tsunamis and other disasters based on the features of the region (expansion of the options of the region), (b) enhanced safety and resilience of the coastal hazard-prone areas and restoration of the coastal environment and urban/residential environments, (c) improvement of accountability for investments in disaster prevention/mitigation, (d) early manifestation of the effects of disaster prevention/mitigation projects by smooth project implementation.

6. REFERENCES

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