

DEVELOPMENT OF A COMPREHENSIVE DISASTER SCENARIO SIMULATOR THAT CONSIDERS THE TIMEFRAME OF THE DISASTER

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Abstract: In order to execute effective disaster mitigation measures it is necessary to examine various problems such as; damage assumption, warning transmission strategy, and evacuation plan, etc. The purpose of this study is to develop a Comprehensive Disaster Scenario Simulator that expresses a regional situation during a disaster in order to manage these problems. This simulator expresses resident's activities during normal circumstances and their behavior during a disaster. The simulator also expresses the extent of damage, and number of casualties during the time of occurrence of the disaster. Therefore, the use of this simulator can be twofold; i. as a strategic tool for examining effective disaster prevention measures. ii. due to its visual presentation and easy-to-use interface, this simulator can be used as a risk communication tool to inform about the various characteristics of the disaster and the appropriate actions that should be taken to reduce the impact of disasters.

Keywords: *Disaster prevention measure, Damage Assessment, Risk Communication, Scenario Simulator*

1. INTRODUCTION

Recently, in 2004 disasters such as Typhoon No.23 which occurred in October resulted in extensive damage from storm centering in Kinki and Shikoku, and the Niigata-Chuetsu Earthquake in Japan claimed more than 50 lives. In addition, the Sumatra earthquake that occurred in Indonesia in 2004 killed more than 200,000 people in neighboring countries due to the occurrence of a tsunami. Lately, disasters that exceed current estimated scale have been occurring frequently.

In our country that is vulnerable to a number of hazards, it is important to implement effective measures for reducing the impact of hazards on the society. However, municipalities that actually accomplish disaster mitigation measures are being pressed to maintain several disaster prevention facilities such as; embankments, warning facilities, evacuation roads, shelter facilities, as well as, to estimate damage assumptions of disaster scenario and disaster prevention plans etc. On the other hand, it is necessary to carry out disaster educational activities in order to improve the resident's disaster prevention consideration. In that regard, measures that should be

examined for regional disaster prevention are numerous and are constrained by limited budget and time.

In this study, we recognized the usefulness of the simulation technology in aiding with disaster prevention problems, and therefore we developed the simulation model to express local conditions based on various scenario assumptions including the generation time of the disaster. The simulation model expresses the disaster progression and resident's activity during normal circumstances and evacuation behavior during a disaster, and estimates impact based on these factors. Therefore, this scenario simulator can predict extent of damage by considering the activity being carried out by the residents in the target city area. Moreover, this simulation model was implemented by using the Object-Oriented Programming Language (OOPL), and a system that considers the type of activity being undertaken was developed.

This paper discusses details of the simulation model that expresses disaster behavior and resident's activity and how the simulation system utilizes this information. Moreover, effectiveness of this simulator as a disaster prevention strategy and a risk communication tool was shown by showing the execution process of damage scenario assumptions using this simulator.

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2. UTILITY OF SCENARIO SIMULATOR IN DISASTER MEASURES

(1) Problems Identified in Disaster Measures

a) Problems Concerning Damage Assumption

It is important to grasp damage scale and generation patterns of the disaster that occurred in order to implement effective disaster measures. For instance, the special investigation committee for Tonankai-Nankai earthquake is part of the Central Disaster Management Council which is a committee responsible for planning disaster prevention measures for the Tonankai-Nankai earthquake, and it has detailed information of seismic intensities for various places, the circumstances of a tsunami, and the likely level of damage that is possible¹⁾. Moreover, some municipalities have predicted possible damage levels for various disasters such as flood, tsunami, and nuclear plants etc²⁾.

It is important to predict human casualties by scenario simulations in order to reduce human suffering due to a disaster, and to examine appropriate responses. It is believed that the scale and pattern of human suffering due to a disaster is greatly dependent on the resident's location, the activity being undertaken at the occurrence of the disaster and the characteristics of the disaster. Therefore, it is prudent to examine scenarios that consider residents action such as residents activity when the disaster occurs, their evacuation behavior in addition to predicting the characteristic of the disaster phenomenon in order to plan adequate disaster prevention measures suitable for the target region. Many municipalities have analyzed disaster phenomenon in detail, but residents' action has not been examined sufficiently. Moreover, the examination of residents only consisted of estimating total population in the area from statistical records, and doesn't consider the range of activities being carried out by individuals at generation time of the disaster.

b) Measures Requested for Disaster Education

An attempt to improve awareness of disasters through the distribution of hazard maps and by conducting disaster prevention lecture meetings is encouraged for disaster education. However, many tsunami and flood investigations have revealed that recently evacuation rate of resident is declining^{3),4)}. Therefore, even if effective evacuation plans are designed, problems can still arise from the residents' perspective.

The main reason why residents tend not to evacuate is because they often fail to recognize their level of vulnerability during a disaster, and as such they do not think it is necessary to evacuate. It is believed that these

problems tend to occur because resident perception of the disaster is inaccurate due to lack of knowledge of the disaster because of a lack of experience, incorrect knowledge based on past disaster experience and legend, and psychology characteristic under non-daily situation⁵⁾. Therefore, there is a need for an effective disaster education program to solve these problems.

(2) Utility of Comprehensive Scenario Simulator

There are some researchers^{6),7),8)} that have focused on aspects/issues such as resident's evacuation behavior and warning transmission in terms of the predicted disaster scenario. Generally, however, many of these researchers did not examine a series of events seen during a disaster such as hazard characteristics, warning transmission, and resident's evacuation behavior, etc. Certainly, there is a need to examine separately the issue of improving efficiency in resident's evacuation and warning transmission. However, there are many limitations that can be highlighted for the first time by analyzing the relationship between disaster phenomenon and social circumstances that vary with differences in time series. For example, would there be an increase in damage due to the delay of warning and evacuation behavior? The impact of this relationship is far more important than an individual event being compared by total damage scale. In addition, it is important not only to consider resident's behavior during the disaster but also their daily activities in order to estimate potential damage especially since some hazards tend to occur during unexpected times with little or no warning such as the occurrence of an earthquake. In light of the above, we believe that a scenario simulator that is capable of expressing two or more events such as a city's daily activities and disaster phenomena is much more useful for disaster management planning purposes. Moreover, we believe that the simulator is effective in helping residents to recognize that disaster phenomena are capable of changing greatly from scenario to scenario and that damage can be kept to a minimum if adequate response action is employed. A scenario simulator that expresses various situations during a disaster can be considered as a dynamic hazard map. The dynamic hazard map can express various results such as; disaster phenomenon that progresses with passage of time and scale of damage due to differences in social response which can be displayed visually and plainly. From this viewpoint, the comprehensive disaster scenario simulator is useful as a risk communication tool that plainly explains the disaster risk and disaster measures, and can effectively inform about an appropriate response action during a disaster.

3. OUTLINE OF SIMULATION MODEL

This chapter outlines the simulation model which is the core of this simulator.

(1) Features and Development Policy of the Model

This model is capable of illustrating damage related to the generation time of the disaster, the resident's activity during normal circumstances and during a disaster occurrence etc. Moreover, the model was developed based on the following policies in consideration of generality and extendibility:

- To express residents' action based on individual attributes such as; age, sex, disability, etc. The simulator expresses residents as individual units.
- This simulator does not express time by using the elapsed time method but rather using normal time of day to express daily activities and disaster scenario.
- The results of previous calculation by other programs are used for expressing the changes in the progression of the disaster (tsunami and flood) in order to improve efficiency.
- The function is to reproduce population characteristics from statistical information so that resident information in the model correspond with existing population data for the area.
- GIS data is used to express geographical space such as altitude, road, building etc of the target area.
- Census⁹⁾ and housing map data, etc, which is available on a nationwide scale was used for regions where various data is not available.

(2) Flow of Model

This section discusses the outline of each process according to the flow of the simulation model depicted in **Fig. 1**. Part: c), d), e), f). The flow is expressed by improving the Comprehensive Tsunami Scenario Simulator¹⁰⁾ that the authors had previously developed.

a) Expression of Population

Initially, families and residents in the target region are expressed by using census information about the resident population, such as; sex, age, family structure, worker, student etc, so that the population information in the model replicate the existing resident population in the area. To put it more concretely, residents were first grouped using the attributes of sex and age. Secondly, families were reproduced based on: family size, type (alone, a couple, couple and children etc.), and the average number of each family type that exists in order to reproduce the type of family structure that exists in the target area. Residents were then allocated into family using attributes of; family

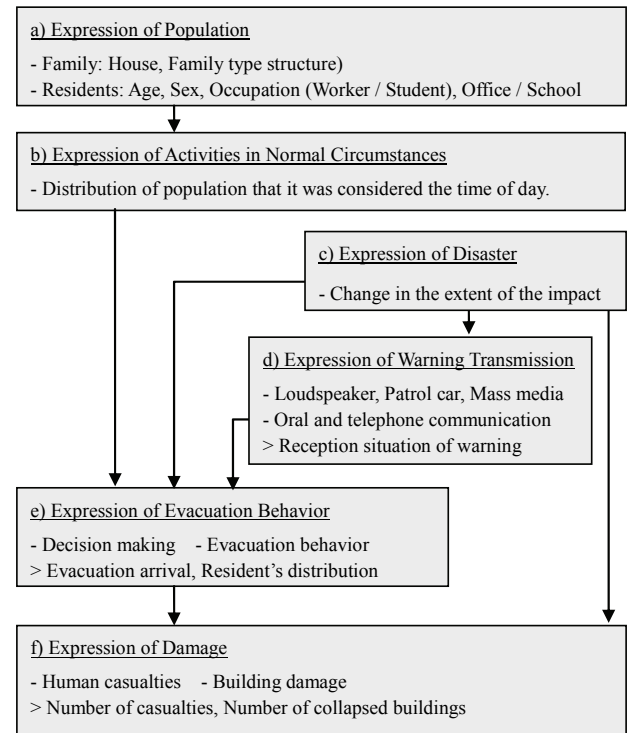


Fig. 1 Outline of Simulation Model

type, average age of the head of the household etc. The program was then used to extract each family's house at random from the housing map; however, the selection of commercial buildings was not done on a random basis.

Thirdly, resident's occupation i.e. worker, student, and other was obtained from statistical information. In addition, residents' place of work or learning was identified as being located at home, inside the region, or outside the region based on statistical information. In addition, statistical information was used to express residents (workers and students) who commute to the area from outside the region from.

b) Expression of Activities in Normal Circumstances

A city activity during normal circumstances can be expressed by the daily activities of individuals in that region. Traffic movement is dependent upon resident's occupation which is chiefly influenced by the daily activities of residents. This model expresses resident's traffic behavior by five types of traffic: commuter, student, business, private, and through traffic.

First of all, the commuter traffic shows how employed individuals' shuttle from home and work. The commuter traffic refers to information on the location of the office i.e. whether it is inside or outside the region. Using the housing map, the program randomly selects commercial buildings for workers who are employed in the city. The floor space of each commercial building was used to indicate the number of employees, since there is a relationship between

number of employees and size of floor space. Moreover, for persons who commute to the suburbs, edge points on the road network were treated as temporary offices, and an office was selected at random from these points. Because generation timing of the commuter traffic is controlled, the distribution time of commuting to work and the total working hours can be arbitrarily set in this model.

The student traffic shows how students shuttle from home and school. For elementary and junior high school students who attend school in the city, the school is selected by age and school district. On the other hand, for high school students, the school is selected at random in the region. Moreover, generation timing of student traffic is controlled according to parameters that relate to distribution timing of commuting to and from school.

The business traffic refers to personnel trips that involve commuting from the office to another building and back to the office or home in the target region. The private traffic refers to travel by which residents other than workers and students shuttle from home and other buildings. To control this traffic, this model uses parameters that decide a traffic generation probability according to; time of day, duration in destination, and travel frequency of each resident during the day and the floor space of buildings is used as an indicator of the number of visitors.

Finally, through traffic refers to the commuting of residents from other areas that pass through the target region. This model developed traffic generation probabilities based on time and the ratio of people that visits building in the target region as a parameter for through traffic.

This model has many traffic parameters but many of these parameters were obtained from the person trip survey.

c) Expression of Disaster

This process expresses change in the extent of the impact of disaster and development due to the progress of time. Currently, an inundation situation due to tsunami and flood occurrence can be considered in this model. An inundation analysis is not calculated by this simulation model but it is calculated beforehand by another program, because an inundation analysis requires a long time to compute inundation information and up to several days to determine the range and accuracy of the data. Inundation analysis is not influenced by external factors such as warning timing or evacuation behavior etc.

d) Expression of Warning Transmission

The warning transmission module models both official (“broadcast”) and informal (“contagion”) processes. The informal network (person-to-person oral communications)

is the primary method of warning transmission, since official warnings (processed by government authorities and transmitted by loudspeakers, route alert vehicles, radio, and TV) are relatively slow in responding to disasters.

The simulation model for information dissemination that was previously developed by Katada et. al^{(8), (11), (12)} is used to express warning transmission. This model can calculate warning transmission situation for example, warning reception timing for each resident etc. by setting up parameters for each warning facility.

e) Expression of Evacuation Behavior

Resident’s evacuation behavior consists of two parts; i. expression of decision making related to evacuation, and ii. expression of action to when evacuee moves to shelter. For this model, every elapsed time can be set as a parameter that controls evacuation timing. Moreover, this model can set destination and speed for each individual. Evacuee’s arrival and resident’s distribution for each elapsed time is expressed in this process.

f) Expression of Damage

This process expresses the situation of human casualties and housing damage due to the condition of the hazard and resident’s evacuation status. In other words, residents and buildings that have received damage are extracted from the range of inundation and distribution of residents and buildings, in order to calculate the extent of damage which is determined by the fluid power of the inundation. This process output is total casualty and occurrence timing of each casualty, location of casualty and damaged buildings.

4. DEVELOPMENT OF SIMULATION SYSTEM

This simulator is expected to be used as a disaster management tool by the disaster manager officials, and secondly as a risk communication tool by residents. Therefore, an interface to execute the simulation for the user and to clearly display the calculation result is indispensable. This chapter discusses the method of implementing this simulation model and the details of the simulation system.

(1) Implementation

This paragraph describes the framework and the implementing method of the simulation model that expresses space and time.

a) Expression of Space

This simulator considers three basic elements that express object region; the first element is a geographical feature that expresses elevation, river and coast etc., the second element expresses buildings such as houses,

shelters, and the third element expresses road networks used when undertaking daily activities and evacuation. Additionally, this simulator expresses spatial features by building elements that express warning transmission facilities, such as loudspeakers, patrol cars, evacuation facilities, disasters such as tsunami and flood, and determining the condition of the hazard.

In this simulator, elements are modeled using points, lines, and polygons to represent the actual shapes. Each figure has coordinate values based on a geographic coordinate system, and can calculate the location of each element in space and the real distance between elements. In addition, this simulator can execute a spatial retrieval by location attributes like in GIS. Hence, this simulator can request household data that exists in the audible area of loudspeakers from a distance between two points, locate the nearest shelter by network path finding algorithm, and estimate casualties from the inundation region and distribution of evacuees.

b) Expression of Time

This simulator expresses events such as “resident realization that an earthquake has occurred” and “resident receipt of warnings from a patrol car”. This exchange of information is called a ‘message’ which takes place between elements. For instance, when an earthquake occurs, the earthquake element sends a message to resident’s elements to indicate the occurrence of an earthquake. A patrol car extracts the surrounding resident element by spatial retrieval, and a message is sent to indicate a warning transmission. Moreover, this simulator can specify generation time of each event such as, “depart home at 7:30am for school”. Residents’ element expresses a situation in which the resident element travels on road and a message with time lag is sent to oneself.

Such a mechanism has been achieved by manipulating the system that controls communication messages based on time between elements. This system arranges the order of transmitting the message by using Priority Queue. In addition, this system transmits the ‘message’ to an element according to the elapsed time of the simulation. The simulator explains the process by which each element functions through the use of such a mechanism according to passage of time.

c) Implementation in Program Language

We used object-oriented programming language in building the simulator. In addition, we identified abstraction classes that contain a common function to all elements, for example, the function that a message was sent and received etc. Then we derived the abstraction class

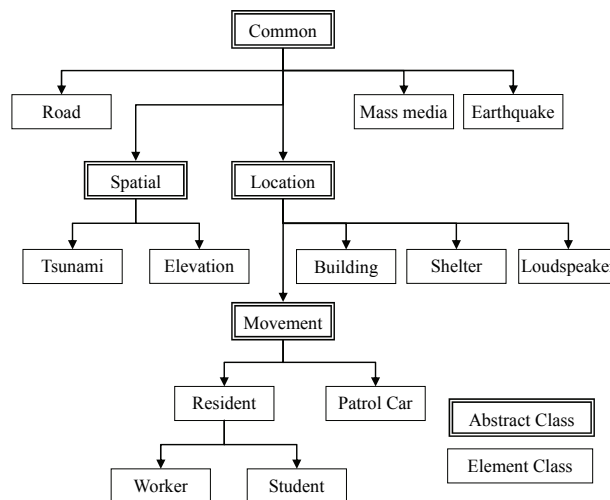


Fig. 2 Hierarchical Structure of Simulation Classes

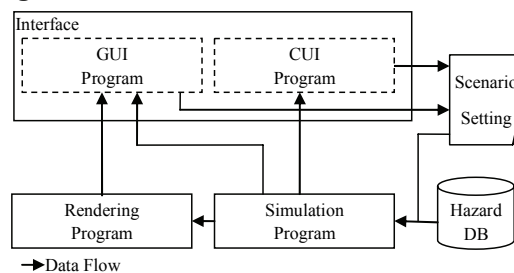


Fig. 3 Configure of Simulation System

with functions of element group, and are describing class that finally expresses each element (Fig. 2).

In each element class expression of action (i.e. go to school, warning transmission, evacuation) according to the element’s role in each event is triggered by the receipt of a message. The entire simulation model is shown as operating as an element generating the events of each other.

However, we calculated beforehand some elements that represented a disaster phenomena such as a tsunami and flood, because it takes a very long time to calculate, and it is unaffected by other elements. Therefore, only the interface of the database, which results from the calculation, is implemented for these element classes.

(2) Development of System

a) System Components

Fig. 3 shows the configuration of this simulator. This simulator is composed of three programs; simulation, rendering, and interface program.

Firstly, the simulation program is a mounting part of the simulation model explained in foregone paragraphs. To make the simulation program correspond to two or more interfaces, the simulation program was separated from the interface. This program reads the condition from the configuration file, and calculates the simulation. Moreover, the program expresses the progress of the disaster and refers to the database that accumulates inundation analysis

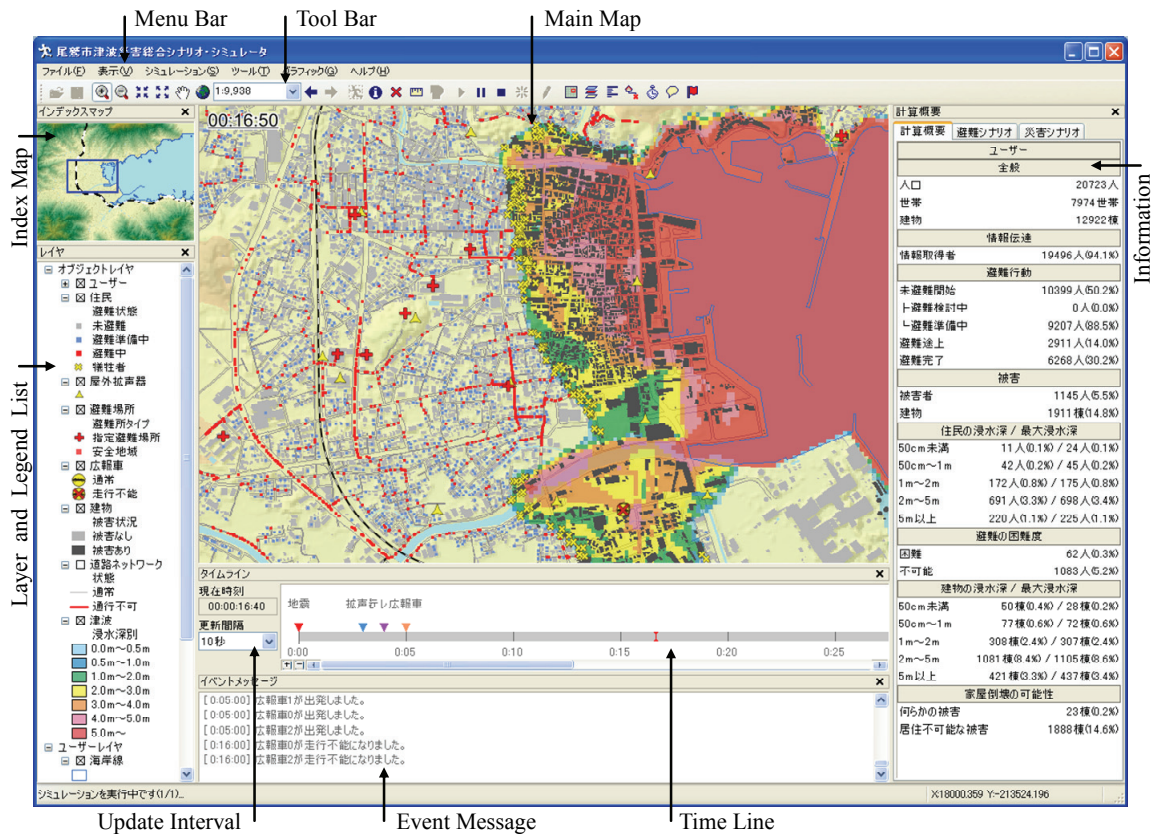


Fig. 4 Screenshot of Simulation System

when executing the simulation. Secondly, the rendering program displays the calculation results of the simulation program that is, the resident's distribution, disaster behavior, and hazard impact on the base map. Finally, we created two types of programs; Graphical User Interface (GUI) and Character-based User Interface (CUI) as the interface program. The GUI program visually displays the results of the calculation of the simulation program by using the rendering program. Moreover, this program provides an interface to edit the scenario configuration file, and can visually control the scenario. On the other hand, the CUI program can control the scenario by using the command line interface. Using the CUI program two or more scenarios can be calculated at once. It is necessary to execute many scenarios that change various parameters in order to discover the best option. By calculating two or more scenarios at once it helps to ensure efficiency and rapid results.

b) Interface

Fig. 4 shows the main window of this simulator. In the upper part of the screen, there is a menu bar and a toolbar to operate each function of this simulator such as; scenario setting and to begin the simulation. The function to operate the main map screen is similar to general GIS software and can be accessed from the toolbar such as to: change map

scale and change display area. In addition, from the toolbar it is also possible to start and stop the simulation.

Next, there is an index map located in the upper left hand corner of the screen that shows the extent of the region and the area of the main map on the screen. The left hand side of the screenshot simulation system contains both the layer list and the legend. The layer list contains the list of layers which are displayed on the main map, and the legend contains the various symbols used on the map. Using the layer list we can choose to display or not to display various layers and to change symbols on the map. The Time Line and event message are located at the bottom of the main map. The Time Line displays the icons that show the occurrence time of the disaster and the transmission of evacuation order etc. By dragging this icon the generation timing of events can be changed, therefore confirming the relationship that exists between elapsed time and occurrence of other events. Also, when executing the simulation model, the simulation time is displayed below the time line. On the lower left side of the screenshot is the controller which is used to confirm the simulation time by numeric characters, and to set update intervals for the main map.

Finally, the progress of the results of the simulation such as; warning transmission, evacuation and extent of impact

is displayed on the right side of the screen as textual information. Using tab control, this part can be switched and can be changed to interface to visually set the scenario.

5. APPLYING THE SIMULATOR TO OWASE CITY

This chapter discusses the Input and Output data and the application of the simulator in a tsunami prone area.

(1) Applied Region

Owase City is a mid-sized coastal community in Japan, (population 23,000; area 193 km²) along the Pacific coastline (Fig. 5). Approximately 90% of the area is steep, mountainous terrain, with 80% of the population residing in the vicinity of Owase's port. Due to the rugged nature of the coastline the occurrence of a tsunami locally is amplified therefore resulting in the community being affected by several tsunami events in the past. For example, the 1944 Tounankai and the 1946 Nankai tsunamis were both generated along the Nankai Trough Seismogenic Zone, approximately 150 km offshore from Owase. On the other hand, if a similar event were to occur in the future, such as a 7m-high tsunami this could possibly hit the city within 20 minutes of the occurrence of the earthquake.

(2) Input Data

Table 1 shows input data made for Owase City, and Fig. 5 shows the location of various facilities. The data concerning building, road and elevation was created by processing and referring to the digital housing map and the laser profiler data. Then, warning and evacuation facilities were made utilizing the information etc. obtained from Owase city office. Within the region, areas above 30 meters sea level or higher were designated as an evacuation site because residents are expected to evacuate to public shelters and other areas that are on high ground. Moreover, we prepared the tsunami inundation data using four patterns that changed with the presence of breakwater and earthquake scale (Table 2). This data consists of information on the wave height and the flow velocity of the tsunami every ten seconds with an accuracy of 12.5 meter mesh. Finally, the population was reproduced using the function of this simulator from the statistical information obtained from the Census data. Because the target region is not the complete area for Owase city, other statistics such as worker and student population were required for comparison between the total population of Owase City and the population of the target region.

(3) Scenario Setting

For the scenario setting, we set three possible times for the generation of an earthquake (i.e. 4:00am, 8:00am and

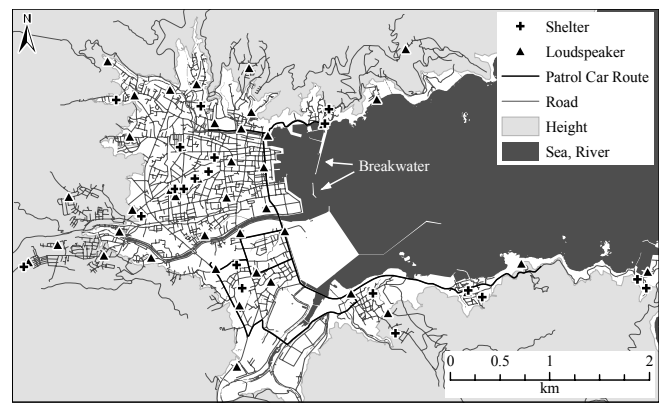


Fig. 5 Owase City

Table 1 Input Data

Category	Item	Amount	Reference
Spatial Info.	Building	12,922	Digital housing map
	Road	176 km	
	Elevation	6m mesh	
Warning transmission facility	Loudspeaker	42	Owase disaster prevention plan ¹³⁾
	Patrol Car	3	
Evacuation facility	Shelter	24	Owase disaster prevention plan
	Height	103	Elevation
Hazard	Tsunami	4 patterns	Central disaster management council ¹⁴⁾
Population*	Household	7,974	H12 Census ⁹⁾ ,
	Resident	18,520	Owase disaster prevention plan
	Inflow Pop.	2,203	

*Presumption result with this simulator.

Table 2 Scenario Patterns of Tsunami Hazard

No.	Type of earthquake	Breakwater
1	Tonankai-Nankai earthquake	With
2	Tonankai-Nankai earthquake	Without
3	Sumatra earthquake class*	With
4	Sumatra earthquake class*	Without

*To assume the tsunami due to Sumatra earthquake in December 2004, fault displacement of Tonankai-nankai earthquake was increased by factor of 1.5.

noon/midday). At 4:00am many residents are at home. At 8:00am many residents are commuting and at noon many residents are not at home. The transmission scenario for an evacuation order has two patterns; evacuation orders are transmitted three minutes or ten minutes after an earthquake occurrence. Finally, for the evacuation scenario, we have four patterns; 5 and 10 minutes after an evacuation order is received, and 5 and 10 minutes after the earthquake has occurred. Table 3 shows the above-mentioned scenario patterns, and a common condition is shown in Table 4. In this application, only damages resulting from the impact of the tsunami are considered, damages due to the earthquake are not considered. A Monte-Carlo simulation of 20 trials

Table 3 Scenario Patterns

Item	Scenario patterns
Earthquake Timing	4:00am, 8:00am, noon
Tsunami	Four pattern shown as Table 2
Evacuation Orders	Three minutes after the earthquake, Ten minutes after the earthquake
Evacuation Timing	Five minutes after an order is received, Ten minutes after an order is received, Five minutes after the earthquake has occurred, Ten minutes after the earthquake has occurred

Table 4 Common Condition

Item	Condition	
Resident	Telephone communication	Not available
	Evacuation speed	80 meter/minute
	Shelter	Nearest shelter
Loudspeaker	Audible area, rating	250 meter, 30 %
	Transmission timing	Immediately after official announcement
Patrol Car	Audible area, rating	100 meter, 40 %
	Speed	20 kilometer/hour
	Start timing	Immediately after official announcement
Mass media	Audience rating	60 %
	Transmission timing	Five minutes after official announcement

was conducted and average values were compiled.

(4) Results of Simulation

a) Transition of Population

First of all, we determined resident’s activity during the occurrence time of each earthquake. **Fig. 6** shows the population and the percentage of the population that stays at-home at each time, and **Fig. 7** shows the distribution of population at each time. From these figures it can be concluded that at 4:00am, the stay at home-percentage is almost 100 % with just a few workers existing. At 8:00am there is an increase in worker and student population, however, about 80 % stay at home. At 8:00am approximately 1,000 people (workers and students) are traveling. At noon there are about 9,000 workers, 2,500 students, and 600 free activity people (neither going to work or school). At this time, the stay at home-percentage is approximately 45 %, in other words more than half of the stay at home resident has gone out. The distribution of the population at noon shows that many residents are distributed in the urban area which infers that the concentration region of the population compared with nighttime has changed. Moreover, the population has increased from approximately 18,500 to 20,000 people

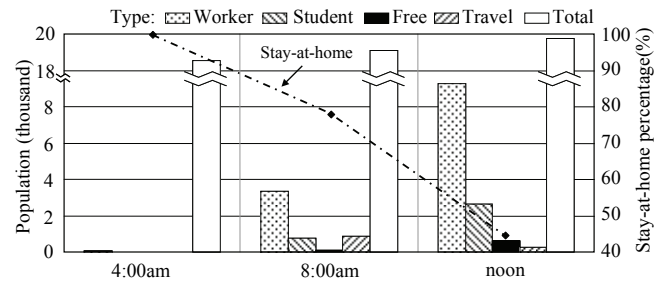


Fig. 6 Population and Stay-at-home Percentage

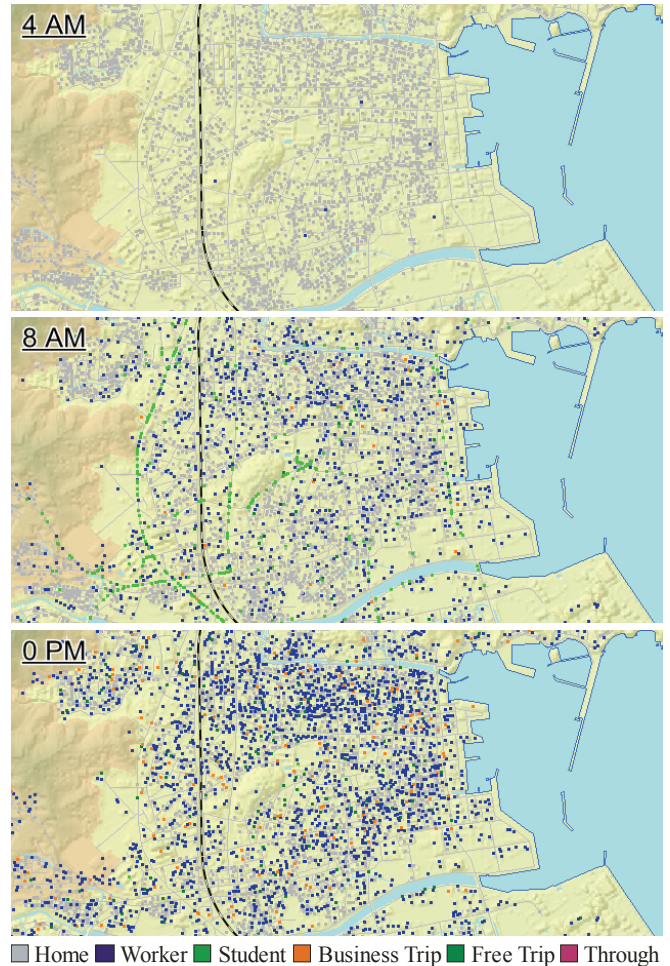


Fig. 7 Distribution of Population

from 4:00am to noon. Therefore, the inflow of population to this region during the daytime is more than a thousand during the nighttime.

b) Result of Warning Transmission and Evacuation

We examined reception rate/time of evacuation order and evacuation circumstances of each scenario. The result for each time is summarized in **Table 5**. In this case, we assumed that all residents who received the evacuation order evacuated so as to ascertain the effect of information timing and evacuation timing on residents.

Fist of all, a remarkable trend is not observed from the orders reception rate which shows the ratio of residents who received the evacuation order. However, orders

Table 5 Result of Warning Transmission and Evacuation

Time	4am	8am	noon
Order Reception Rate (%)	97.6	97.0	97.2
Order Reception Time (min.)	3.4	4.0	4.6
Evacuation Time (min.)	4.5	4.7	4.8

Table 6 Evacuation Completion Time

Order Timing (after earthquake)	Evacuation Time (min.)						
	-		3 min.		10 min.		
Evacuation Start Timing (min.)	After Earthquake		After Order is Received				
	5	10	5	10	5	10	
Time	4am	9.5	14.5	14.0	19.0	21.0	26.0
	8am	9.7	14.7	14.8	19.8	21.9	26.8
	noon	9.8	14.8	16.1	21.1	23.1	28.1

Table 7 Number of Casualties

Order Timing (after earthquake)	Number of casualties						
	-		3 min.		10 min.		
Evacuation Start Timing (min.)	After Earthquake		After Order is Received				
	5	10	5	10	5	10	
Time	4am	0	40	85	305	530	1,440
	8am	4	174	309	552	867	1,651
	noon	0	393	645	967	1,292	1,935

reception time which indicates the average time that will pass before residents receive the evacuation order has slowed when approaching noon and the distribution of population during the daytime tends to require more time to transmit information. Also, evacuation time tends to slowdown when approaching noon and it can be assumed that this is due to the fact that distance from the shelter during the daytime is greater than at other times. **Table 6** shows the evacuation completion time which was calculated in consideration of the above-mentioned factors and each scenario condition. The time indicated in the table is the elapsed time from the occurrence of the earthquake. According to the table, ten minutes are required to complete evacuation safely when evacuation begins five minutes after the earthquake. On the other hand, 26 to 28 minutes are required to safely complete evacuation when both evacuation order transmission and evacuation are delayed.

c) Result of Human Impact

Finally, we will discuss the impact on humans for each scenario. **Table 7** shows the total casualty for the tsunami that resulted from the Tonankai-Nankai earthquake in relation to the presence of breakwater. According to the table, when an evacuation order is announced three minutes after the earthquake, and residents evacuate five minutes

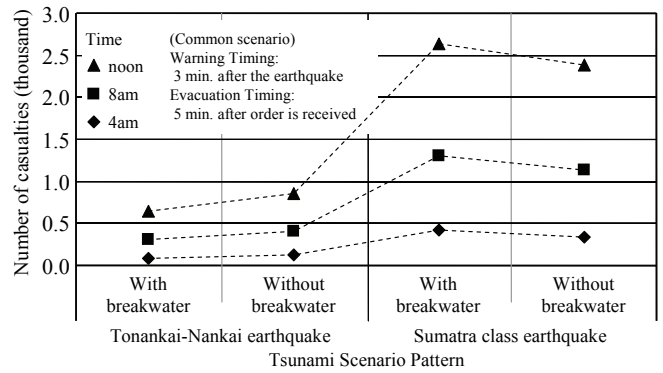


Fig. 8 Casualty Toll of Each Tsunami Scenario

after they receive the information, there is a difference of seven times or more in the total number of casualties that occurs when compared with the generation time of the earthquake for 4:00am and noon. It is believed that changes in the distribution of the population in the inundation region and changes in the evacuation completion time influences these results. Furthermore, when evacuation begins ten minutes after information reception, casualty tolls for an earthquake which occurred at 4:00am are 305 people. Therefore, the number of casualties increases by approximately 200 people when resident’s evacuation behavior is delayed by five minutes. On the other hand, when the evacuation order is announced ten minutes following an earthquake occurrence which was generated at noon, the number of casualties is about 20 times the scenario simulated for an earthquake occurrence at 4:00am, evacuation order time announced 3 minutes following the earthquake and evacuation commencing 5 minutes after the warning was received. On the other hand, the casualty toll ranges from 0 to a few people in the scenario where residents take evacuation in five minutes following an earthquake. This result suggests that damage can be suppressed to a minimum if evacuation is undertaken promptly.

Fig. 8 shows changes in the casualty toll of each tsunami scenario. In this simulation, we assumed that the evacuation order is announced three minutes after the earthquake, and evacuation begins five minutes after order is received. The result shows that the casualty toll of the Sumatra Class Tsunami is four times that of the tsunami from Tonankai-Nankai earthquake. Moreover, the number of casualties decreases to 70 percent due to the presence of a breakwater in the case of the Tonankai-Nankai earthquake tsunami confirming the importance of the breakwater. However, in the case of the Sumatra class earthquake tsunami the presence of the breakwater had the opposite result.

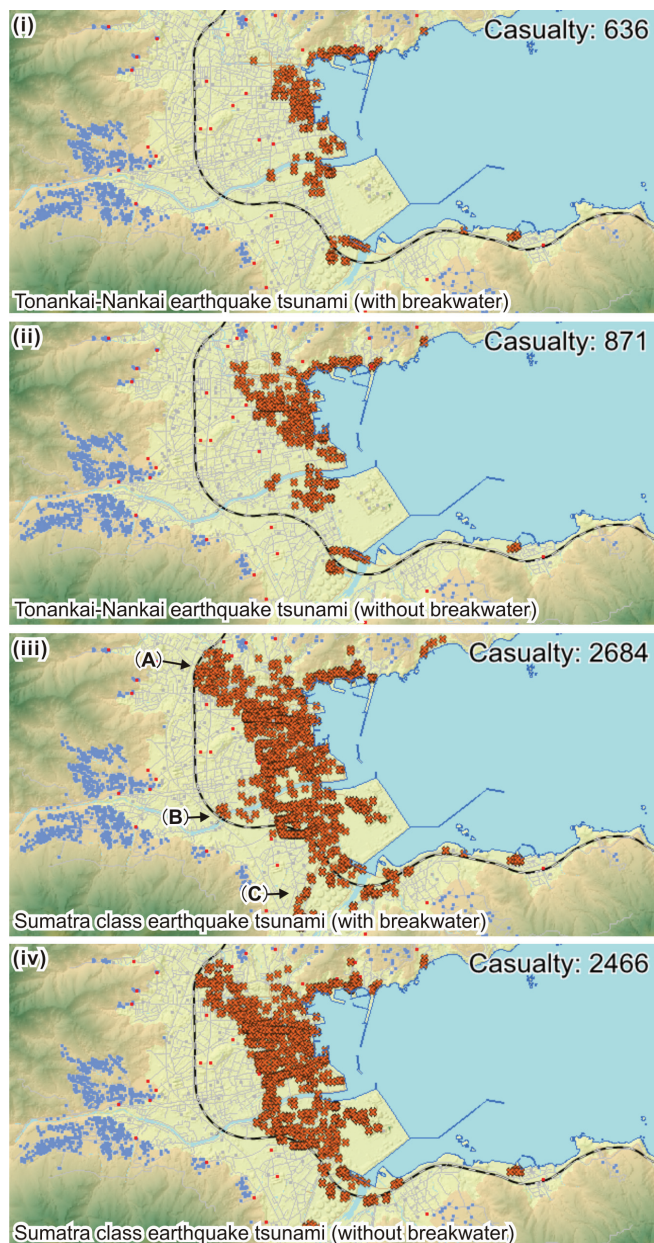


Fig. 9 Distribution of Casualties

Fig. 9 shows the distribution of total number of casualties for each tsunami scenario at noon. In this figure, many of the casualties occurred around the vicinity of the coast on the north side of the Tonankai-Nankai earthquake tsunami that had breakwater. On the other hand, in the case of the Sumatra class tsunami, casualties are distributed over the entire coast, and casualties are generated even in the vicinity of the railway especially on the north side of the river (**Fig. 9** iii A). In order to examine the extent of human impact due to the presence or absence of breakwater, the images labeled iii and iv are compared. In image iii, due to the presence of a breakwater, casualties have been generated within a wide range around both the central and the southern river (**Fig. 9** iii B, C). When we assumed the Sumatra Class Tsunami, the breakwater will expand the

inundation area to the southern part because the breakwater is located in the northern part of the coast (**Fig. 5**) and as such it will deflect the tsunami waves to the southern part resulting in the possibility of increased damages.

6. APPLICATION AS A DISASTER EDUCATION TOOL

This simulator displays a regional disaster situation which was calculated using the simulation model which displayed the results in animation format. **Fig. 10** shows the snapshots of the animation made using this simulator. This animation shows resident's distribution immediately following the earthquake (**Fig. 10** A), scene (B); shows the relay of warning transmission information to the residents from the warning transmittal facilities, scenes (C, D & E), shows residents who have received the information evacuating from the tsunami and going to shelters. Scene (D, E & F) shows the generation and raid of the tsunami and the creation of casualties. At the upper right side of the screen, the numbers indicate the total number of casualties.

Such animation is useful for its visual confirmation of the results of the scenario simulated. In addition, it is effective as a tool to be used in disaster education to educate a general resident who doesn't have technical knowledge on the subject matter. For example, residents are better able to grasp various concepts, such as changes in the inundation region and depth of the water with the passage of time, which cannot be obtained from a static hazard map. Moreover, because the content of the scenario expressed can be easily modified, residents can better understand the various phenomena of the disaster and how to effectively respond during a disaster. For example, the safe area in the disaster struck area can change quickly only because the scale of the disaster changes a little, and the damage scale can change greatly depending on the administrators and the resident's response.

Authors have used this simulator to educate the Owase City residents about disaster prevention. For example, the model has been made available over the Internet so that residents can view it freely (**Fig. 11**). Moreover, this simulator has been used as a risk communication tool during a tsunami lecture meeting held on May 6, 2004.

Two earthquakes had occurred in Owase City on September 5, 2004, and an evacuation order was officially announced after the second earthquake. The evacuation rate of residents living near the coast exceeded 70 percent according to a follow-up investigation conducted. Therefore, it can be said that many residents have proper

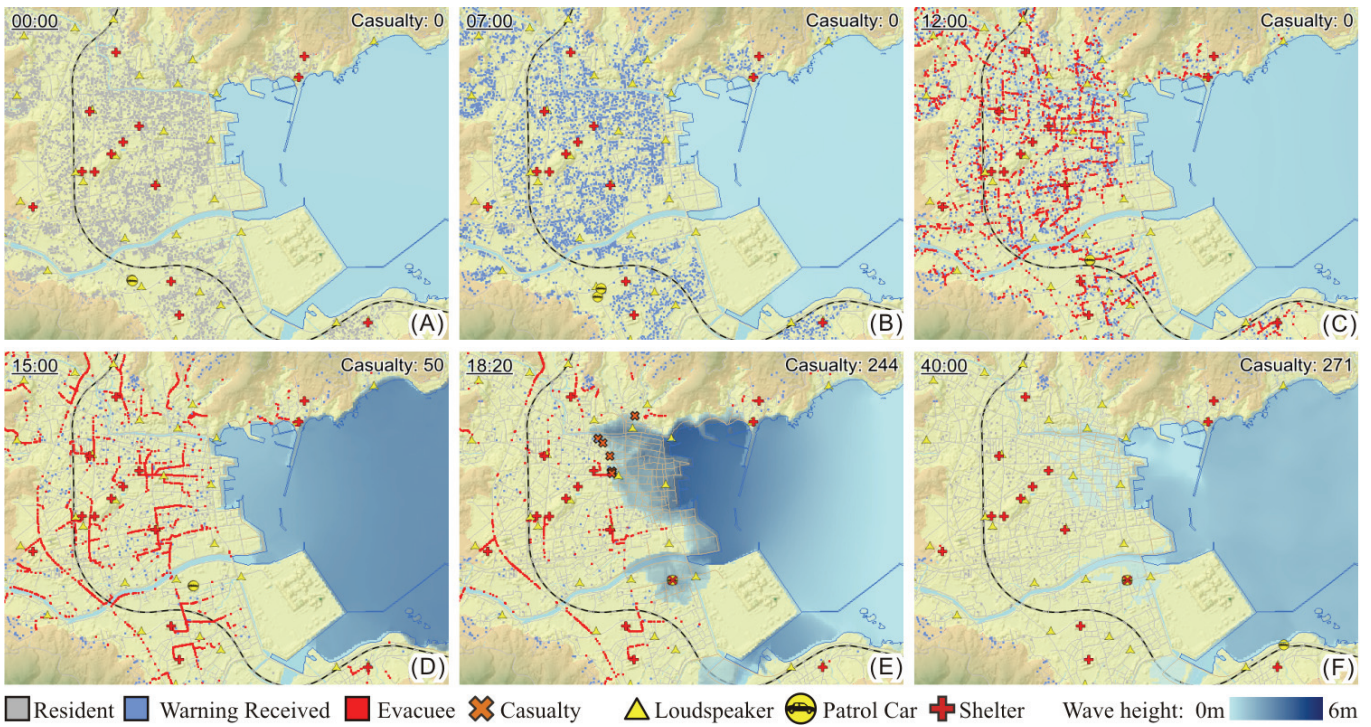


Fig. 10 Snapshots of Animation



Fig. 11 OWASE Dynamic Tsunami Hazard Map¹⁵⁾

image of the potential threat posed by a tsunami.

7. CONCLUSION

It is necessary to take various measures into consideration in order to plan an effective disaster prevention strategy. In this study, the scenario simulator that expressed social circumstances during normal circumstances and during a disaster was developed as a strategy tool for disaster prevention measures. Due to its visual presentation, this simulator can be used as a risk communication tool that can effectively teach the appropriate response action needed during a disaster. Since this simulator expresses the status of progress of the disaster phenomenon and society based on usual activities during normal circumstances, this simulator can be applied to various situations to indicate problems that are likely to

result from an individual or society perspective.

In the future, we will aim to further improve the accuracy of the simulation model and extend its applications to other natural hazards such as; floods, earthquake, typhoons etc. Moreover, we will further advance the system function such as its interface, animation etc. in order to make it more user friendly when being used as a disaster strategy or risk communication tool.

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