16th World Conference on Earthquake, 16WCEE 2017
Santiago Chile, January 9th to 13th 2017
Paper N° 1320
Registration Code: S-J1463017782

DEVELOPMENT OF SYSTEM FOR DISTRIBUTING URGENT EVACUATION INFORMATION DRING TSUNAMI AND ITS APPLICATION

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Abstract

The 2011 Great East Japan Earthquake exposed limitations of present hazard maps and evacuation manual for unexpected earthquake and tsunami. In particular, information for the tsunami evacuation of residents was premised on mass evacuation, and this could be a major cause of delays in the tsunami evacuation. A system of distributing urgent evacuation information during tsunami has been developed by utilizing the Japan Meteorological Agency's "Earthquake Early Warning and Information on Earthquakes, Volcanic Activity and Tsunamis." Based on information about the earthquake and the tsunami height, the system identifies appropriate evacuation spots, disseminates information about them, and allows an administrator and family members to check on the safety of a registered user upon completion of evacuation. A series of tsunami evacuation drills were conducted, to examine the usefulness of the system, as well as to improve the details of the system.

Keywords: Tsunami disaster mitigation, Information for tsunami evacuation, Earthquake early warning

1. Introduction

The 2011 Great East Japan Earthquake exposed many limitations of the current practices and technologies for tsunami disaster mitigation. Figure 1 shows the damage to Arahama area in southeastern Sendai by the tsunami, clearly pointing out the limitation of the current design codes. As for tsunami evacuation, it was shown that tsunami hazard maps and evacuation manuals were not effective for unexpected earthquakes and tsunamis. This is inevitable because the hazard maps and the evacuation manuals were made for an assumed scenario of earthquake and tsunami. It is necessary to overcome this limitation and moving towards probabilistic scenarios.

In view of recent development of Information and Communication Technology, we expect that even right after an earthquake, we are able to use a mobile phone with which information about the earthquake characteristics (scale and epicenter location), the tsunami characteristics (height and arrival time at designated place) or the necessity for evacuation is delivered to each individual. Unlike a pre-made hazard map or an evacuation manual, we are able to provide to each individual the information about tsunami evacuation that is tailored to him/her. For instance, an individual receives information for urgent evacuation, depending on his/her location as well as the tsunami size, or information about the closest tsunami shelter and the access route to it. An individual could send the information about his/her situation to his/her family members and colleagues. At this moment, we evaluate that an e-mail service is the most appropriate when an individual sends/receives such information.

We are developing a system of distributing urgent evacuation information during tsunami [1]. The key function of this system is to generate precise evacuation information that is tailored to each individual and to deliver the generated information in a most secured manner. Earthquake Early Warning (EEW) [2] that is issued by the Japan Meteorological Agency (JMA) is used to invoke the system, and to gather information about the earthquake and tsunami characteristics; EEW includes alerts of an earthquake, a volcano activity, and a tsunami [3]. The system utilizes pre-made databases for the location of tsunami shelters that are authorized by local governments and identifies inundated area that is expected for a predicted tsunami height and the elevation of the area. Each user is able to automatically send information about his/her situation to his/her family members and colleagues via the system, registering e-mail addresses of the members and colleagues that will receive the information.

(a) Before the tsunami (b) After the tsunami

Fig. 1 - Arahama Area before and after the tsunami induced by the 2011 Great East Japan Earthquake (Photo: Tohoku Regional Development Association [4])

2. Development of System by Utilizing Earthquake Early Warning and Tsunami Warning

The proposed system of distributing urgent evacuation information has two key functionalities, information generation and information distribution. The following modules which work independently are developed for these two functionalities:

1) Information generation
   a) Building a database consisting of positional information of registered mobile phones,
   b) Building a database consisting of evacuation spots in the target areas,
   c) Processing EEW and information about tsunami issued by JMA;
2) Information distribution
   a) Sending information about earthquake and tsunami characteristics to registered mobile phones,
   b) Sending information about evacuation spots such as tsunami shelter and an access route to them to registered mobile phones,
   c) Receiving safety reply updates after evacuation is completed,
   d) Sending information regarding the lifting of a tsunami warning.

Each of the seven modules can updated separately for easier maintenance and improvement.

The system is operated by taking the following steps:

1) when an earthquake occurs and JMA issues an EEW, the system receives the EEW and sends “Earthquake Information” to all registrants; see Fig. 2 (a);

2) when JMA further issues a Tsunami Advisory or Major Tsunami Warning, the system sends to the registrants "Tsunami Information" including the location of the most suitable evacuation spot; the spot is selected from evacuation spots registered in the database (the spot is higher than the predicted height of the tsunami and closest to the registrants location), and the location of the selected spot is designated in a digital map sent to each registrant; see Fig. 2 (b);

3) the system checks whether a registrant safely arrives at the informed evacuation spot; and

4) after confirmation is completed, the system sends "Safety Information" to pre-registered family members and colleagues.

(a) Earthquake Information (b) Tsunami Information

Fig. 2 - Examples of delivered information to a mobile phone from system

Figure 3 shows the flow that the system processes an EEW of JMA and lifting of the alert, as well as a sequence of sending and receiving information for each registrant and delivering safety information to pre-registered family members and colleagues.

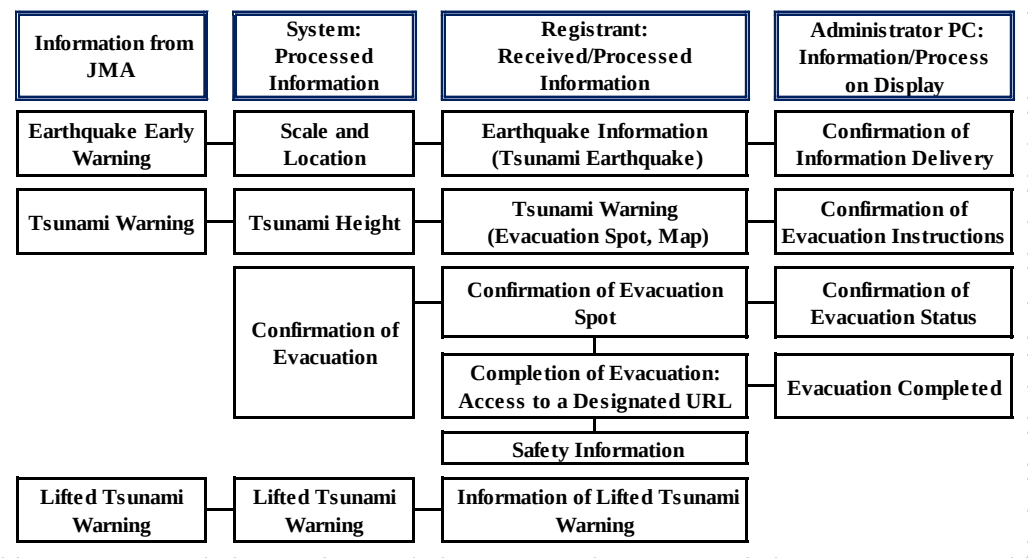


Fig. 3 - Flow of information generated and distributed by the developed system

3. Tsunami Evacuation Drill Using Developed System

In order to examine the usefulness of the developed system of distributing urgent evacuation information during tsunami, we have conducted a series of tsunami evacuation drills as a kind of a social experiment. The target of these drills is local resident community consisting of about 200 members, such as a private company, a local government office, or a group of residents. At this moment, 20 communities in different areas have participated in the drill, which are summarized as follows:

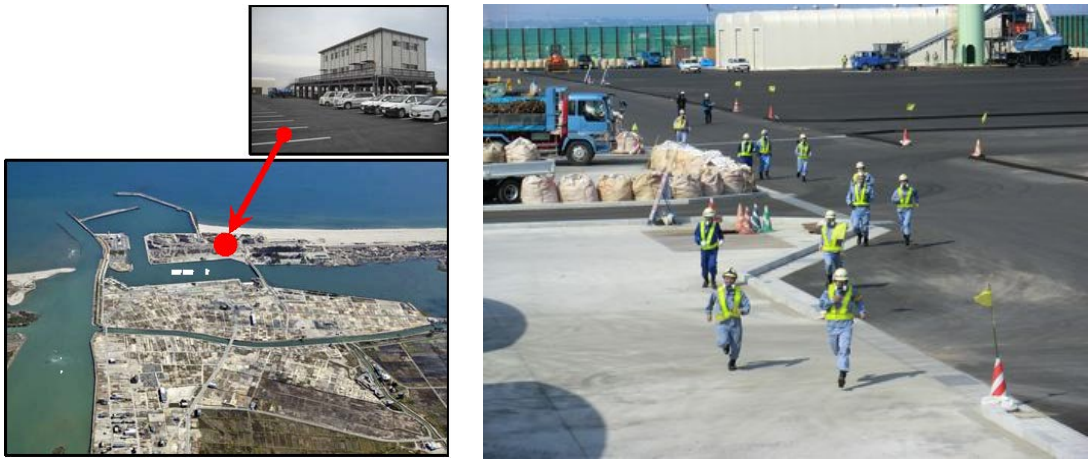
1) Private companies, such as Natori Ward Workplace, Miyako Consulting Company, Kirin beer brewery branches, Minami Sanriku Hotel Kanyo.
2) Local government offices, such as Kochi City, Ajigasawa Town, Ministry of Land, Infrastructure and Transport.
3) Local resident groups, such as voluntary organization for disaster prevention in Natori Area (Yuriage), Sanbonzuka Area, Kochi City. Also, the drills were made for participants of Earthquake Technology Expo YOKOHAMA in 2013, Engineering Exhibition Tohoku in 2015, and United Nation World Conference on Disaster Risk Reduction in 2015.

At each drill, some mal-functioning of the system, mainly due to unexpected usage of drill participants, was found, and suggestions of improving the usability of the system interface made by the drill participants were gathered. Necessary improvement, correction and modification have been made for the system.

We briefly explain some drills which contribute major improvement of the system for distributing urgent evacuation information against tsunami.

3.1 Private company in Natori Ward

In collaboration with the Miyagi Prefecture Natori Ward Natori/Watari Block Disaster Waste Disposal Treatment, an evacuation drill was conducted on May 14, 2012. The number of the participants was 54, including staff members of the treatment, workers and system engineers. Figure 4 (a) shows the area that was used for the drill; this area was damaged by the tsunami of the 2011 Great East Japan Earthquake, and the treatment had to work for this area. As an impressive scene of the drill, Fig. 4 (b) shows workers running on their way to the designated evacuation spot.



(a) Offices/Evacuation spot (b) Participants of drill practicing

Fig. 4 - Evacuation drill using a system in Natori Ward

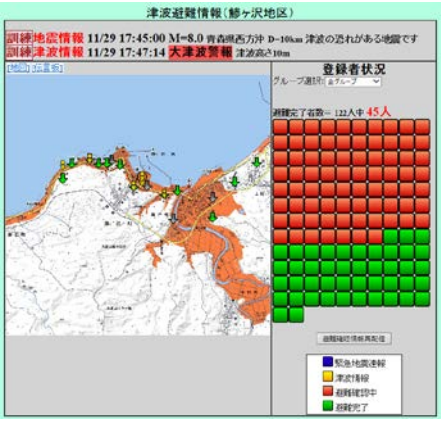
The earthquake and tsunami scenario used in the drill was an earthquake of Magnitude 8.0, originating in the Pacific Ocean, and a subsequent tsunami of 3 m height. A location next to the workspace, which is 7 m

above the sea level and large enough to accommodate all staff members, was chosen as a designated evacuation spot. Out of 45 participants, 25 participants could not confirm their completion of evacuation on Safety Information. This was due to their lack of experience with the mobile phone mailing system. A chief manager of the treatment had affirmative evaluation of using the system, saying that "even if we are very close to the sea, with this system, we can relax and focus on the work at hand."

3.2. Local government office in Ajigasawa Town

An evacuation drill for the local government office was conducted in Ajigasawa Town, located close to Sea of Japan in Aomori Prefecture. Ajigasawa Town has a population of 10.000 and is mostly (80%) covered by woods and mountains. The town center spreads along the coastal line. The drill was conducted on November 29, 2013, and the number of the participants was 122; 115 participants worked at the city hall, and remaining 7 partisans were volunteers who participated the drill.

The earthquake and tsunami scenario used in the drill was an earthquake of Magnitude 8.0, originating in Sea of Japan, and a subsequent tsunami of 10 m height, which was much higher than the Natori drill. The time interval for the tsunami arrival after the earthquake, during which completing evacuation was confirmed and lifting of the tsunami warning was made, was set 4 minutes. The registrants who received Earthquake Information followed the instructions and chose their evacuation location from the instructed options (to go out of the office or to move to home). Tsunami Information was sent out to the participants 4 min after Earthquake Information was sent. A successful evacuation was confirmed once the registrants completed the instructions on the mobile phone display. Completing the evacuation was easily recognized because the console of the system showed an icon for each participant, which changed its color from red (un-safe) to green (safe). Figure 5 shows the number of registrants who have evacuated safely (green) and those who are still in the process of evacuating (red). In this drill, 40 participants (roughly 30%) managed to complete the evacuation after 30 min after the earthquake.



Red: those who haven't completed evacuation Green: those who have completed evacuation

Fig. 5 - The number of drill participants who completed evacuation in Ajigasawa Town

3.3 Local resident group in Sanbonzuka Area

In cooperation with a group of local residents, a tsunami evacuation drill was carried out in Sanbonzuka, a town neighboring to Sendai City. As there were a relatively larger number of elderly residents who were unfamiliar with using a mobile phone and its mailing services, a studying session for receiving information and using a mobile phone was made before the drill. The date of the drill was November 2, 2014, and the number of the participants was 49.

The participants of this drill had experienced tsunami before, and they were particularly interested in the functionality of checking the safety information of the family members provided by the system. As a vivid

example of the drill, Fig. 6 shows the residents evacuating to a highway road. Figure 7 shows the number of the participants who safely evacuated.

Fig. 6 - Residents ascending stairs to a highway road

Fig. 7 - State of evacuation in Sanbonzuka

4. Evaluation and Applications of Developed System

4.1 Evaluation of Developed System

Figure 8 shows the time and percentage of the safety information that is delivered to family members at the drill held in Yuriage, Yaizu, Sanbonzuka and Kanyo. In the drills at Yuriage and Yaizu, many participants found it difficult to operate mobile phones after they completed the evacuation; this was mainly because they were occupied with evacuation actions. However, in Yuriage, not many participants made similar comments. We understand that the partisans of the Yuriage drill were the members of a local merchandise association and were able to use mobile phones and e-mail systems.

In the Sanbonzuka drill, a large percentage of the participants were aged and were not used to handling a mobile phone. Thus, we simplified the interface of the system, so that the registrant's safety information can be provided much easily to his/her family members. Due to this improvement of the system, 80% of the participants succeeded confirming completing of the evacuation. As well expected, improvement of the system interface to a user is a key issue for the practical usage. In the Minami Sanriku Hotel Kanyo (which was used as a refuge place on the 2011 Great East Japan Earthquake) drill, the participants were employees of the hotel and experienced of the earthquake. All participants did refuge completion operation; see Fig. 8.

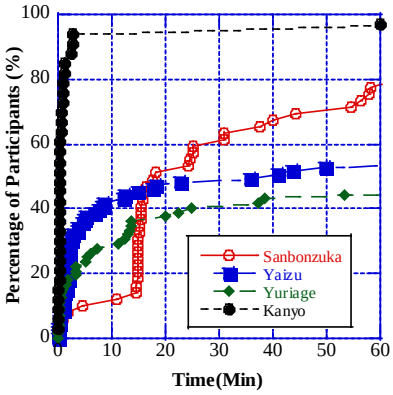


Fig. 8 - Time and percentage of completed evacuations

After these drills, we made questionnaire for the participants, regarding whether they received the e-mails, whether they well handled the system, and whether they felt inclined to use it themselves, etc. The evaluation of the usability of the system is summarized in Fig. 9. As well expected, it is seen that younger generation did not have any particular problems in handling the system via their mobile phones, whereas the older generation was in part not used to sending out e-mails via such phones.

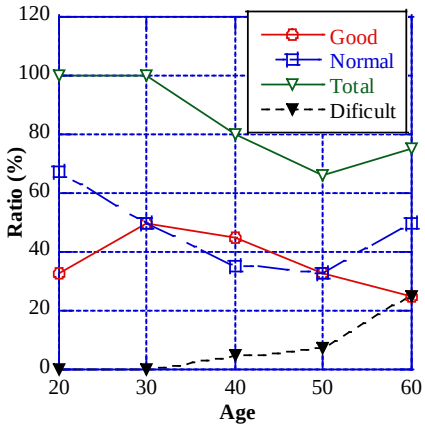


Fig. 9 - Usability evaluation of operating system via mobile phone

Table 1 shows the general evaluation results of Yuriage, Sanbonzuka local residents, and Kanyo (Minami Sanriku) on the developed system. We emphasized that in Yuriage, 89% of the participants evaluated the practicability of the system as “very useful” or “useful,” and that in Sanbonzuka and Kanyo, more than 96% of the participants gave a high appraisal rate to the system.

Table 1 - Review of the tsunami system

Area	Very Useful	Useful	Not Useful
Yuriage	32%	57%	11%
Sanbunntuka	72%	25%	3%
Kanyou	56%	40%	4%

4.2 Applications of Developed System

To confirm the validity of the system, we present some operation results with the system in actual earthquakes.

A tidal wave warning was announced from the JMA in each of the following 3 earthquakes, namely, 2013 Solomon Islands earthquake, February 6, 2013, off the coast of Fukushima-ken earthquake, October 26, 2013, and Sanriku-oki earthquake, February 17, 2015.

4.2.1 2013 Solomon Islands earthquake, February 6, 2013

Until rubble processing ends this work site at the end of March, 2014, the developed system was used experimentally. The system worked by Solomon Islands earthquake. The Solomon Island earthquake on February 6, 2013 at 10:12 were M=8.0 and depth 33 km.

JMA issued a Tsunami Advisory at 14:41. Then the system sent to the registrants “Tsunami Information” including the location of the most suitable evacuation spot; the spot is selected from the evacuation spots

registered in the database as the one that is higher than the predicted height of the tsunami, and the location is designated in a digital map sent to each registrant in the Natori Site.

Figure 10 (a) shows the number of the participants who evacuated safely as of 15:19.

4.2.2 Sanriku-oki earthquake, February 17, 2015

The scale of earthquake by EEW was M=7.0 for this earthquake and the earthquake information were sent to all registrants. And then JMA issued Tsunami Advisory or Major Tsunami Warning, the system sent to the registrants "Tsunami Information" including the location of the most suitable evacuation spot; the spot was selected from the evacuation spots registered in the database as the one that is higher than the predicted height of the tsunami, and the location is designated in a digital map sent to each registrant in the Miyako Site. The system in Miyako worked and indicated the number of the participants who safely evacuated in Fig. 10 (b).

(a) St. Cruise Solomon Islands earthquake in Natori (b) Sanriku-oki earthquake in Miyako

Fig. 10 - States of evacuation due to two earthquakes

5. Conclusions

In order to realize prevention and mitigation for tsunami disasters, especially for human causality prevention, we have been developing the system of distributing urgent tsunami evacuation information, by utilizing EEW and tsunami warnings. This system is able to generate precise and effective evacuation information to each individual. The system is web-based, consisting of the seven modules each of which automatically is invoked one by one. The module can be updated separately for easier maintenance and improvement.

The system can dispatch the urgent tsunami evacuation information, including the location of the safest and nearest evacuation spot, to each individual. The spot is displayed on a digital map via mobile phone. The spot is selected from the evacuation spots registered in the database at usual time.

We have conducted tsunami evacuation drills using the developed system. Based on the experiences of these drills, we are confirming that the system is ready to be used. However, the following two improvements must be made for a better use of the proposed system:

1) by using estimated information about the scale of an incoming earthquake, enabling the system to distribute evacuation information faster; and

2) extending the system to be used for evacuation of other natural disasters such as flooding, land sliding, and volcano activities.

The system of distributing urgent tsunami evacuation information is effective for not only emergency but also for enlightening and learning in peace time. In order to realize natural disaster prevention and mitigation, continuous education is necessary in usual time.

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