3-4 Development of Earthquake Damage Estimation System and its Result Transmission by Engineering Test Satellite for Supporting Emergency Response

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Drawing on its extensive experience with natural disasters, Japan has been dispatching Japan Disaster Relief (JDR) team to disaster-stricken countries to provide specialist assistance in rescue and medical operations. The JDR team has assisted in the wake of disasters including the 2004 Indian Ocean Earthquake and the 2008 Sichuan Earthquake in China. Information about the affected area is essential for a rapid disaster response. However, it can be difficult to gather information on damages in the immediate post-disaster period.

To help overcome this problem, we have built on an Earthquake Damage Estimation System. This system makes it possible to produce distributions of the earthquake's seismic intensity and structural damage based on pre-calculated data such as landform and site amplification factors for Peak Ground Velocity, which are estimated from a Digital Elevation Model, as well as population distribution.

The estimation result can be shared with the JDR team and with other international organizations through communications satellite or the Internet, enabling more effective rapid relief operations.

Keywords

Earthquake disaster, Digital elevation model, Landform classification, Site amplification factor, Earthquake damage estimation system

1 Introduction

A catastrophic earthquake that occurred in the Caribbean island nation of Haiti in 2010 was a tragic disaster in which over 300,000 lives were lost and more than 300,000 buildings were damaged. Further, it is fresh in our memory that over 90,000 were killed or missing in the 2008 Sichuan Earthquake in China and that more than 300,000 were killed or missing as a result of the tsunami caused by the 2004 Indian Ocean Earthquake. In such countries, and particularly developing countries, the reality is that performing an emergency response at their own initiative is difficult. Any economic capability that has been accumulated is hindered due to the disaster, and at the same time sufficient countermeasures have not been implemented. Therefore, emergency relief operations and international assistance including technologies for disaster response from countries that are advanced in disaster prevention, such as Japan, are urgently needed.

Given the occurrence of a large-scale disaster such as an earthquake overseas, a fire-and-rescue team may be dispatched from Japan as part of the international emergency relief effort. For instance, this was the case in the aftermath of the earthquakes in Sichuan, China (2008) and New Zealand (2011). It is necessary to perform such relief operations by accurately comprehending the extent of damage at the site, hurrying to the locations where rescuers are needed, and performing relief operations in cooperation with teams from other countries in order to arrive at the site within the "golden 72-hour" period that is considered to be the time limit for rescuing people trapped under collapsed houses and maximizing the positive results of such a dispatch. Accordingly, it is necessary to quickly estimate the area having major damage as well as to send information about the damage and support status of related parties to relief teams who are en route to the site.

An accurate estimation of earthquake damage requires a database that shows the characteristics of the landform in addition to a basic database of social conditions, such as population distribution and building distribution. In Japan, as an advanced country of earthquake disaster prevention, a method is proposed[1] for estimating the characteristics of the landform using digital national land information prepared for the entire country, and the Earthquake Damage Estimation System has been built[2] for use proactively, prior to the occurrence of a quake, and to carry out a quick but reasonable initial correspondence immediately after the quake by using the existing database (for example, a census region mesh). Whereas in many developing countries—including those in the Asian region—the preparation of basic data related to landforms, buildings, etc., as necessary for the earthquake damage estimation, is delayed and the earthquake damage estimation is hardly ever conducted. The dispatch of technical support to these regions is also an urgent matter.

In order to quickly send information about the damage and the support status of related parties to relief teams who have been dispatched to a foreign disaster site where they are geographically inexperienced, it is reasonable to send it via satellite while they are en route, particularly given the potential for a difficult communication environment at the site.

However, at the National Institute of Information and Communications Technology (NICT) the development of remote sensing technologies (to which electromagnetic wave technologies are applied) and the development of remote communication technologies have been conventionally performed using ultra-fast network technologies and satellites such as ETS-Ⅷ and WINDS.

NICT, in cooperation with the Fire and Disaster Management Agency (FDMA) of the Ministry of Internal Affairs and Communication (MIC), has performed research and development of earthquake damage estimation technologies based on a digital elevation model (DEM) and of sending the calculation result obtained from those technologies via satellite (such as WINDS) to relief teams who are in transit to a disaster site. The project has continued for three years since 2008 as part of the strategic research program. The present paper provides an outline of the strategic research project of "Development of Earthquake Damage Estimation System and its Result Transmission by Engineering Test Satellite for Supporting Emergency Response" Case analyses of foreign earthquakes, as well as the merging of earthquake damage estimation technologies and satellite communication technologies, are described as a system to support the operations of relief teams that are dispatched overseas.

2 Outline of strategic research project "Development of Earthquake Damage Estimation System and its Result Transmission by Engineering Test Satellite for Supporting Emergency Response"

The present project comprises the research and development of an international version of a Simplified Earthquake Damage Estimation System to rapidly estimate the distribution of rough seismic intensity of the earthquake and the structural damage distribution when an earthquake occurs overseas. The main purpose of the research and development is to contribute to the establishment of relief operation strategies by the Japan Disaster Relief (JDR) team, and it is promoted through cooperation with the National Research Institute of Fire and Disaster (NRIFD) of FDMA of the MIC.

In many developing countries, including those of the Asian region, the preparation of landform information and a building database, which serve collectively as basic data for earthquake damage estimation, is delayed in the present circumstances. Because huge amounts of money and time are necessary for the preparation of the basic data, it is necessary to establish a method of damage estimation that is permissible, even with somewhat rough accuracy, as opposed to the highly accurate, heavily detailed damage estimation that is performed in Japan. In that case, the construction and updating of the building data using a geographical information system (GIS), as performed in advanced countries such as Japan, and the establishment and updating of building data and preparation of the landform data by a field study, etc., are not realistic, and a method is desired in which the data essential for earthquake damage estimation can be quickly be prepared to cover a broad range.

Concerning earthquake events in Japan, there is a domestic version of a Simplified Earthquake Damage Estimation System (Fig. 1) that was developed at the NRIFD with the 1995 Great Hanshin and Awaji Earthquake as an impetus. It has already been put to use as a staff activation system of FDMA (MIC).

This is a system for the staff of the FDMA of the MIC for making a decision on the initial operation regarding the dispatch of an emergency fire-and-disaster relief team to the fire department headquarters of a local municipality outside the affected area. Because this system is based on detailed national land (basic) data from a drilling survey and a national census, it can be applied in Japan only. The system being developed by the present project aims to be an international version of the above-mentioned system.

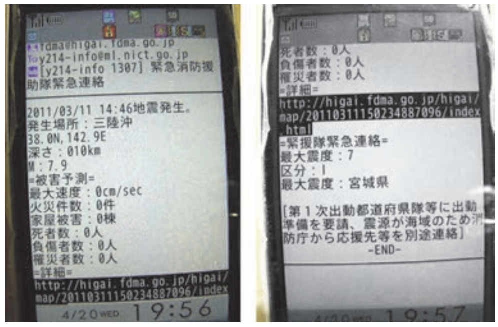

Fig. 1 *Example of the display screen of a cellular phone when information is received from the Simplified Earthquake Damage Estimation System (domestic version) of the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications; the information is from the initial operation that was sent in response to the 2011 off the Pacific coast of Tohoku Earthquake of March 11, 2011.*

Contrastingly, the JDR teams are often forced to conduct relief operations without information on the surrounding area and information on the damage that has occurred, because they are so quickly dispatched to the affected area. As a result of listening to and surveying the need from organizations that have experience in dispatching teams during previous disasters, it was found that many have expressed a need for basic map data such as topographical maps and roadmaps. This data can be produced through the application of remote sensing technologies. However, it often takes a great deal of time to acquire and analyze the data, and its effectiveness has been questioned even in Japan, where the information is relatively easy to collect. However, the effectiveness of the remote sensing data can be exhibited (Fig. 2) if the data acquisition and analysis are carried out while the relief teams are en route to a disaster site overseas and the results are shared with the teams on the ground as information to support the operation using communication satellites.

Accordingly, the research and development of a supporting system in which this information is shared as the on-site operation supporting information, in addition to the earthquake damage estimation result using

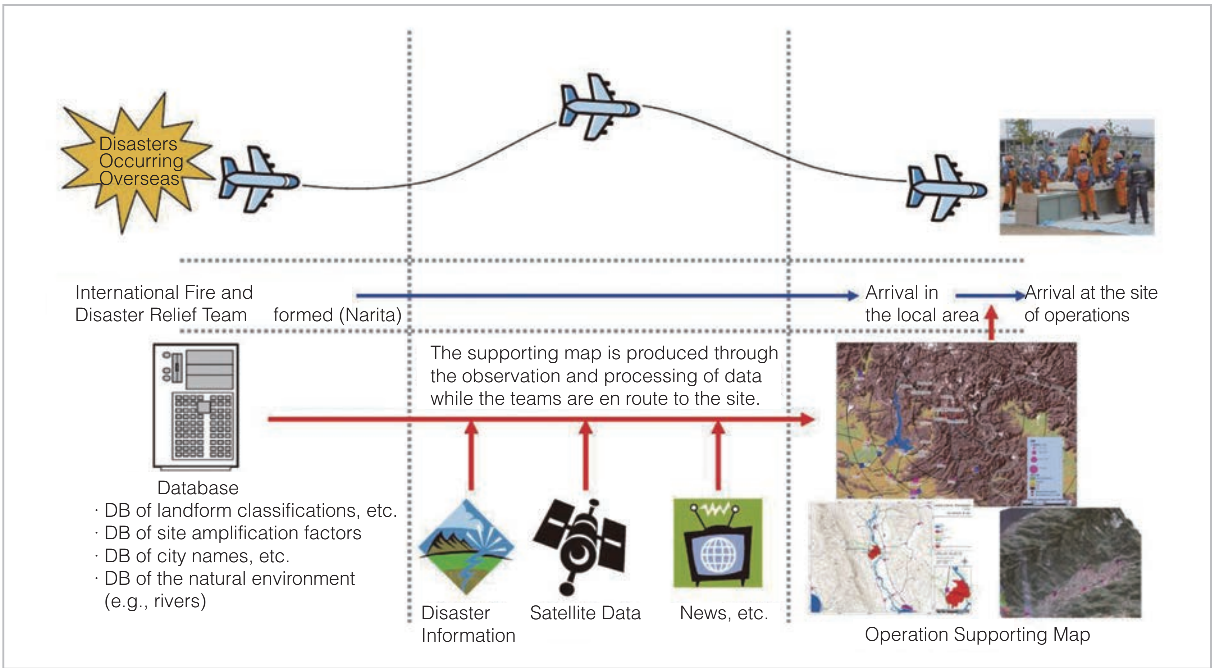

Fig.2 *Image of international fire and disaster relief operation support*

communication satellites, is pursued in the present project.

3 Earthquake damage estimation without basic data for the area

It is possible that the JDR team corresponding to a natural disaster that suddenly occurs overseas will have to select an operation site by itself. In order for the JDR team to perform operations more effectively when it is dispatched overseas to which the members are geographically unaccustomed, it is first necessary to understand the location of the intensive area of the disaster, etc., as soon as possible and then quickly make an accurate decision as to where the limited disaster resources should be introduced.

In order to quickly understand a large affected area, the estimation process and accuracy analysis of the seismic intensity distribution of the 2011 Christchurch Earthquake (which occurred on February 22, 2011) are introduced, and the analysis result of the 2010 Haiti Earthquake of January 12, 2010 is described here using SRTM-3, which is a digital elevation model (DEM) data set acquired by the Space Shuttle[3].

3.1 Estimation of landform classification and site amplification factor using SRTM-3

Based on the landform classification method using DEM, as proposed by the authors of this paper[4], five landforms—a mountain, a plateau, a lowland including a valley plain, a back marsh and a natural levee—were extracted by performing landform classification around Christchurch, New Zealand using SRTM-3.

The classification process is summarized below:

a) Before performing the landform classification using SRTM-3, the altitude of a section comprising an ocean area was set at zero meter (0 m) and the value of the altitude of a section adjacent to the ocean area and wetlands, having an altitude of 0 m to 1 m, was made to be 0.1 m. A median filter using a 3 cell × 3 cell space window was activated for noise removal. The median filter is usually used to remove the spike noise of an image, serving to round out and fill an isolated projection or hole (called a peak or a pit) when applied to SRTM-3.

b) The landform can be classified roughly into a mountain and a plain. A mountainous (e.g., volcanic) hill is included in the mountain, and a plateau and lowland are included in the plain. These are determined to be substituted as a sloped land (mountain) and a flat land (plain), whereby the angle of the slope to an adjacent cell is calculated for each cell and its maximum value is determined in order to judge whether the land surface is flat or not. The land surface can be classified into a flat surface, a gentle slope, a steep slope, a cliff, an overhanging cliff, etc., and the angle of the boundary between any two surfaces will differ, depending on the researcher or the research field. However, the criterion of whether the land has a flat surface was made to be 5º, so that a sloped land of 5º or more was considered to be a mountain and land having a slope less than 5º was judged to be flat in the present research, because the angle of the slope of an alluvial fan, which is a slightly elevated portion of the lowland, is 3º or more. Additionally, there has been research that the criterion of a gentle slope and a steep slope is made to be an angle of the slope of 5º[5], and mountains and landforms other than mountains in the landform classification data of 250 m mesh of the Niigata area, as produced by Wakamatsu et al.[6] can be classified using approximately 5º as a criterion.

c) A plateau, natural levee, lowland, valley plain, etc., are included in the area classified as a flat surface other than the mountain of b). This area can be classified into a plateau and lowland, including a back marsh and a natural levee, and the difference between the plateau and the lowland is the relative height above the rivers therein. The height of the lowland is nearly the same as that of a river flowing through the land (the difference in elevation is a few meters or less), and it is formed by the influence of the river. A plateau is a landform that is a step higher than the rivers flowing in the surrounding area and the lowland, and it has a gentle slope even though it is not affected by the rivers. In the present research, the area having a slope angle of 5º or less and in which the absolute difference in the elevations of the rivers located at the geometrically shortest distance is 7 m or more is classified as a plateau, and others are classified as lowland. The river referred to here is not an actual river but is instead a virtual river produced using SRTM-3[7]. The EucAllocation function of ArcInfo, as produced by ESRI, was applied to the virtual river in order to calculate the absolute difference in elevation.

d) A natural levee and reclaimed land are included in the lowland extracted in c). A levee, a back marsh that is a source of flooding, and a valley plain, etc., are included. The natural levee is a smooth, slightly elevated land whose apex extends in a fan-like shape along one or both sides of the river, and the relative height of a normal water level is several tens of centimeters to more than 10 m. In the present research, a landform having an absolute difference in the elevations of the river located at the geometrically shortest distance of 2 m to 7 m is classified as a natural levee, while other landforms are classified as valley plain and landforms having no absolute difference in elevation from the river (1 m or less) are specially classified as back marsh.

Figure 3 contains a classification in which the area surrounding Christchurch, New Zealand, was analyzed based on the proposed method. Christchurch, around which the Avon and Heathcote rivers flow, is classified as a back marsh. Moreover, it can be found that the landform of Christchurch is a Canterbury plain consisting of various soils such as volcanic soil on a sedimentary alluvial fan of glacial origin, while the outermost layer consists of marshland.

Considering the individual characteristics, one can see a detailed volcanic landform body (the Lyttelton and Atroa volcanoes) of Banks Peninsula, located south of Christchurch, and a valley can be discerned therein. Further, an alluvial fan around Rolleston and Rakaia

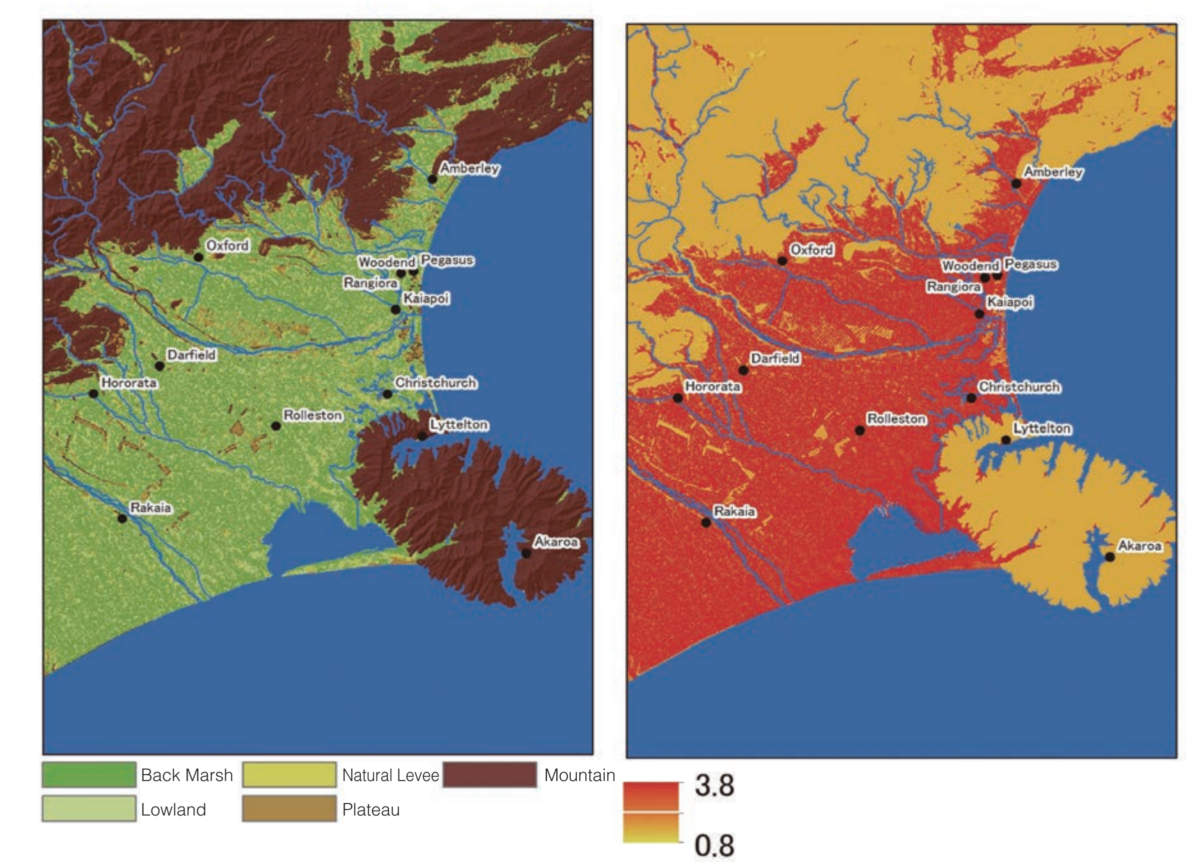

Fig.3 *Landform classification result and amplification factor using SRTM-3*
left: landform classification result;
right: amplification factor estimated based on landform classification

(which are located west of Christchurch) is not classified and therefore suggests room for improvement.

To show that the classification result obtained through the proposed method is effective for earthquake damage estimation, it was applied to a peak ground velocity (PGV) amplification factor estimation by landform.

According to Matsuoka and Midorikawa[1], the velocity amplification factor (*AVR*) of PGV by the landform can be obtained from the following formula (1).

$$\log AVS_{30} = a + b \log H \pm \sigma \quad (1)$$

$$\log AVR = 1.98 - 0.71 \log AVS_{30} \quad (2)$$

where AVS_{30} is the average velocity (m/s) of S wave from the ground surface to 30 m below ground, a and b are coefficients of every landform section, *H* is the altitude (m) and *AVR* is the velocity amplification factor from the ground surface to 30 m below ground.

Because there isn't a landform amplification parameter for every landform section in New Zealand, the parameters were used that were obtained through the modification of parameters by Matsuoka and Midorikawa.

The estimation result of the site amplification factor to the peak ground velocity is shown in the right of Fig. 3. This result is temporary because approximately twice the difference is indicated depending on the area, even for the same landforms, and it is necessary to investigate through comparison with the data of actual landform surveys.

3.2 Estimation and accuracy of seismic intensity distribution

There is hypocenter information from the USGS (United States Geological Survey) and

New Zealand GeoNet for the 2011 Christchurch Earthquake of February 22, 2011. The hypocenter of GeoNet is shifted northward approximately 2 km relative to the hypocenter of USGS[9][10]. The distribution of the seismic intensity of the Meteorological Agency was evaluated by adopting the hypocenter information of GeoNet to compare the seismic intensity of the Meteorological Agency, containing a strong motion record, with the seismic intensity of the Meteorological Agency, which is estimated as described below. A formula for the peak ground velocity using the shortest distance from the fault plane by Si and Midorikawa[11] was used as a distance attenuation formula (3).

A formula (4) was used to obtain the peak ground velocity showing the intensity of the earthquake at the ground surface. The seismic intensity (I_{JMA}) of the Meteorological Agency was calculated from the peak ground velocity of the ground surface using a formula showing the relationship of the peak ground velocity and the measured seismic intensity shown by Midorikawa et al.[12], and its distribution was obtained.

$$\log PGV_b = 0.58\,Mw + 0.0038\,D - 1.29 - \log(X + 0.0028 \times 10^{0.50\,Mw}) - 0.002\,X \quad (3)$$

$$PGV_s = PGV_b \cdot AVR \quad (4)$$

$$I_{JMA} = 2.68 + 1.72 \log PGV_s \quad (5)$$

PGV_b : Peak Ground Velocity (cm/s) at hard ground
Mw : Moment Magnitude
D : Depth (km) of the hypocenter
X : Distance (km) to the hypocenter
I_{JMA} : Measured Seismic Intensity
PGV_S : Peak Ground Velocity at the ground surface

The peak ground velocity *PGV* in the formula showing the relationship of the peak ground velocity and the measured seismic intensity of the Meteorological Agency is a peak ground velocity in which the two components of horizontal motion are superimposed.

The seismic intensity of the Meteorological Agency, as estimated by the present research, is shown at the right in Fig. 4, and the seismic intensity of the Meteorological Agency in which the peak ground velocity *PGV*, as officially announced by the USGS, is evaluated with a formula (5) shown at the left in Fig. 4. The peak seismic intensity is shown with Christchurch as the center in both figures. However, the seismic intensity by USGS is estimated to be 6 (strong) to 5 (weak), while the seismic intensity around Christchurch by the present research shows 7 (very strong) to 6 (strong).

While the seismic intensity of Lyttleton, a fishing village approximately 10 km south of the hypocenter, where significant damage was reported, is 5 (weak) to 6 strong in the present research result, the estimated result of USGS shows 5 (weak). The actual damages by the earthquake can be more easily explained from the estimation result by the present research than by the estimation result of the USGS.

A difference of one grade is observed in the seismic intensity of Kaiapoi and Rangira (which are north of Christchurch) and of Rolleston (west of Christchurch) between the result of the present research and the estimation by the USGS.

New Zealand's Severe Earthquake Observation Network, which covers all national land, is implemented by the project GeoNet, which is conducted by the GNS Science and Earthquake Commission (EQS). Many strong-motion seismographs are in place, particularly around Christchurch, where the earthquake occurred, and the observed data, etc., can be downloaded from GeoNet.

The PGV and seismic intensity of the Meteorological Agency are evaluated from an accelerogram of the strong-motion earthquake record obtained within 20 km of the epicenter and are compared with the value estimated in the present research in Fig. 5. There can be a tendency to acknowledge that the value by the USGS is underestimated while the value by the present research is generally overestimated. However, it can be said that in the present

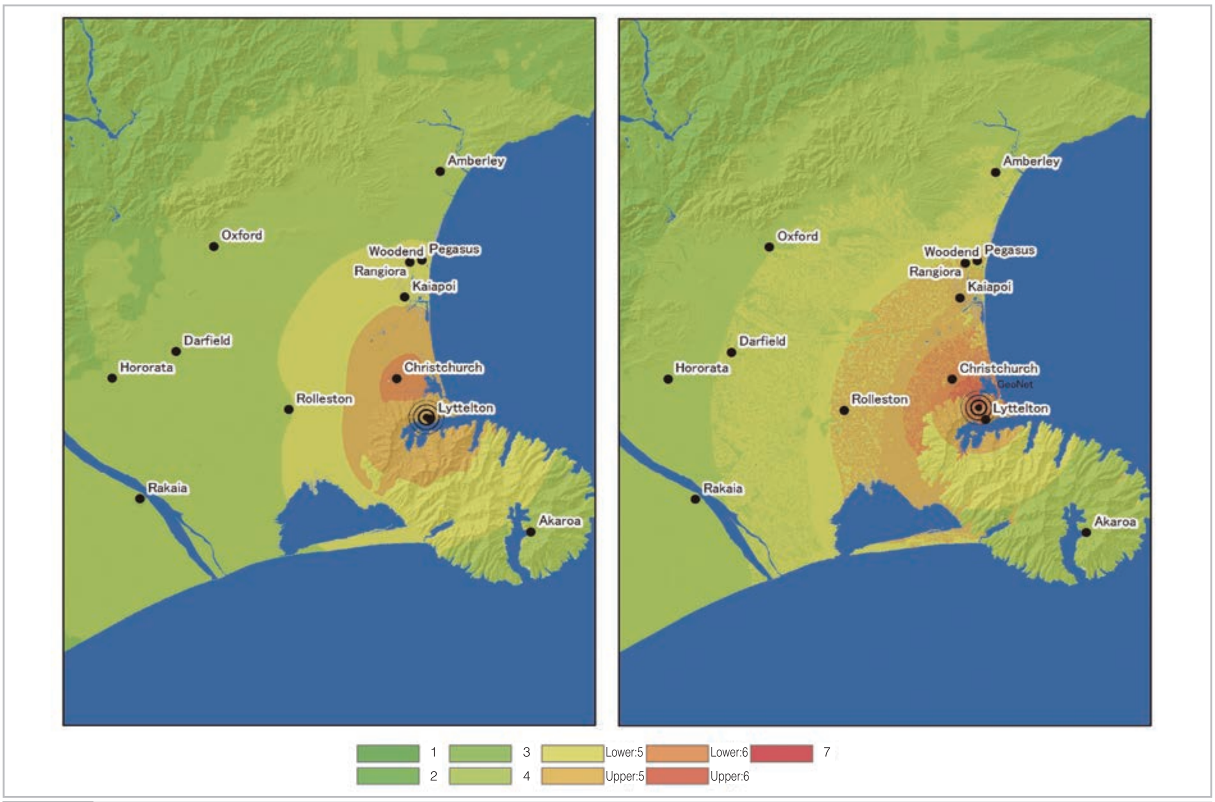

Fig.4 *Estimated Seismic Intensity of the Meteorological Agency*
left: The PGV estimated by the USGS is evaluated with the formula (5);
right: seismic intensity based on the present research

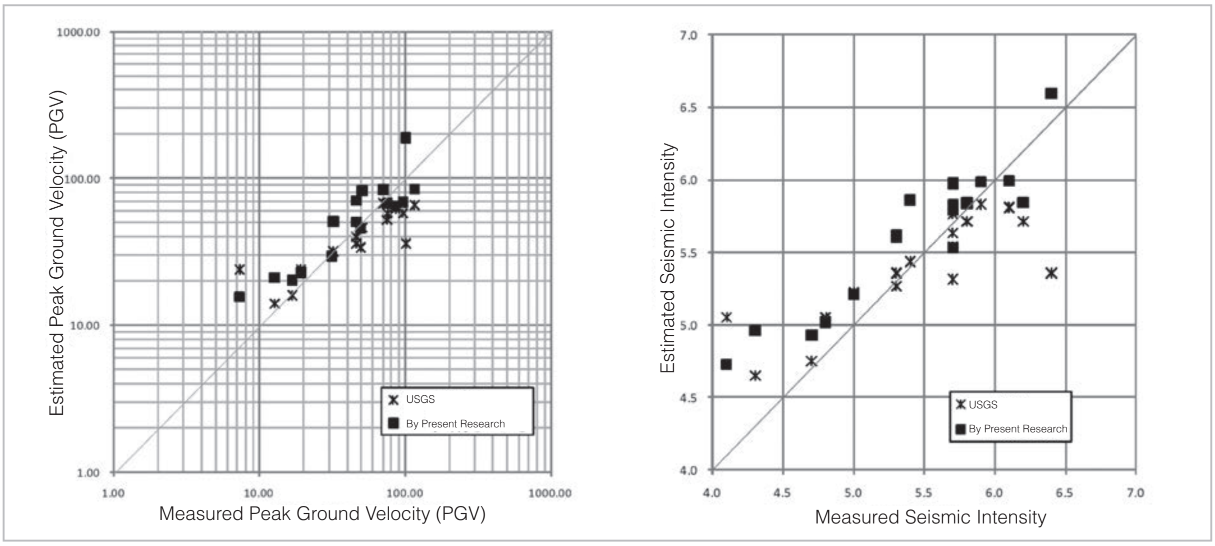

Fig.5 *Comparison of the strong-motion earthquake record at observation points with estimated results*
left: peak ground velocity; right: measured seismic intensity

research there are fewer observation points showing a large difference with the observed value.

The distribution of estimated structural damage and the spatial distribution of actual damage in the 2010 Haiti Earthquake of January 12, 2010 are compared in Fig. 6. LANDSCAN (2006), which is the world population statistics data published by the Oak Ridge National Laboratory in the U.S., is processed and used as the structural data for calculating the distribution of structural damage. Howev-

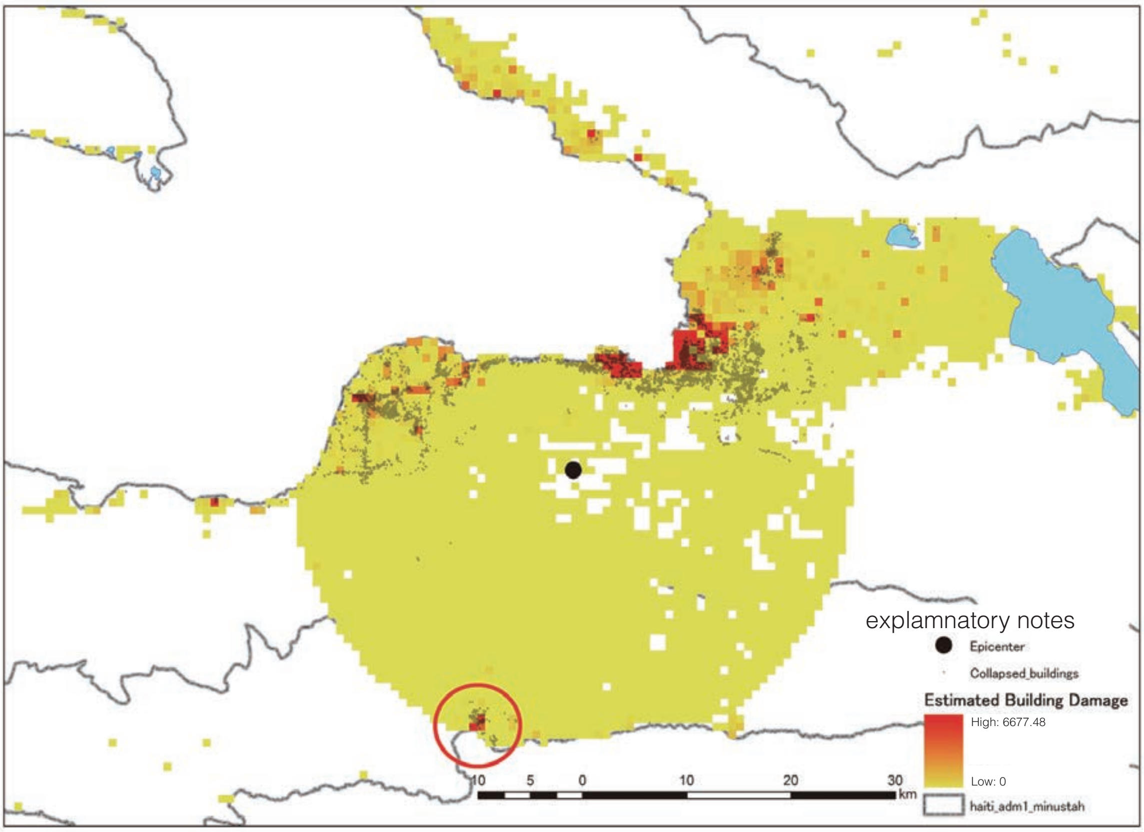

Fig.6 *Comparison of the distributions of estimated building damage and actual damage of the 2010 Haiti Earthquake of January 12, 2010*

er, the distribution of structural damage is estimated here by using the damage function employed by the Cabinet Office in Japan because the structures of Haiti's buildings, the damage function, etc., are not understood.

When superimposing the structural damage data (the black points in Fig. 6), as interpreted using the satellite photograph (resolution 50 cm) by GeoEye, which was taken the day after the earthquake, and the distribution of estimated seismic intensity in the present research, it is found that the estimated distribution closely matches the actual damage. However, it shows a possibility of damage in the area such as the Jakmel area (marked with a circle in the figure), where the damage information was not reported by the news media, etc., even though a severe quake had been predicted and the damage could also be confirmed from the satellite photograph. When we compare the amount of structural damage (approximately 300,000 buildings), which international organizations had ascertained visually using satellite images and aerial photography, to the amount of damage (approximately 200,000 buildings) in the present research, there is a difference of about 100,000 buildings.

When the landform data and the landform amplification factor are estimated from DEM in advance as described above, the scale of the disaster such as the distributions of seismic intensity and damage can be predicted within a short time same, as in the Japanese domestic version of the Simplified Earthquake Damage Estimation System from the earthquake information provided by the USGS, etc. These estimation results are considered useful in decision-making for emergency correspondence during the period of time just after a disaster strikes, when “the disaster information is absent”.

4 Construction of the international version of the simplified earthquake damage estimation system

In keeping with Chapter **3**, a prototype of a web server system was structured to facilitate an understanding of damage from an earthquake, tsunami and flooding, as well as the sharing of damage information and operation supporting information in Asia (including Japan). As shown in Fig. 7, the present Damage Estimation System is a real-time system in which the USGS receives the hypocenter information sent by e-mail in real time, whereupon the damage is estimated using the hypocenter information, the estimation is sent to a registrant by e-mail and, at the same time, an outline of the earthquake and information such as the distribution of the estimated damages can be put on the web. Figure 8 shows an example of an e-mail that is automatically sent to the registrant. This follows the structure of the domestic version of the Simplified Earthquake Damage Estimation System (Fig. 1), which has already been used by the FDMA of the MIC. The user who received the e-mail of Fig. 8 can see the estimation result of the international version of the Simplified Earthquake Damage Estimation System by clicking the link in the e-mail. However, the database of landform amplification factors based on landform classifications is currently in place only for a limited region of Asia. It is necessary to complete the database in order to put the system into full-scale operation in the future.

5 Development of the supporting system using satellite communication

When the relief team enters the affected area, it is possible to directly confirm the damage that has occurred in the surroundings. However, it is difficult for an individual team to independently ascertain the situation in any remote area and the situation of the entire

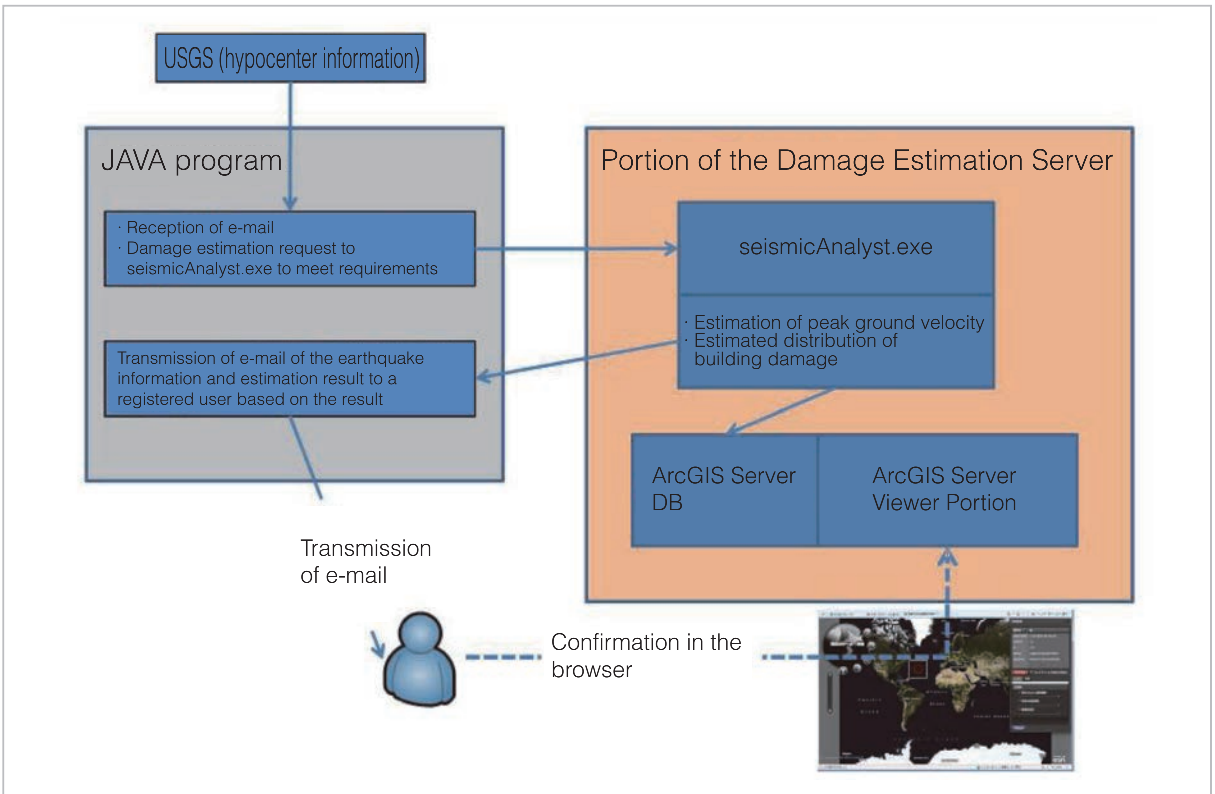

Fig.7 *Configuration of the international version of the Simplified Earthquake Damage Estimation System and the flow of information*

affected area. Therefore, in order to perform appropriate emergency correspondence it is preferable to share the disaster information collected through various methods and the operation status of the relief team with the related organizations and between the teams. The research and development of the information system (Fig. 10) that can support the international relief operation is necessary in the present research by sharing the disaster information via satellite communication and the web server of Fig. 9 with the earthquake damage estimation technologies as a basis, as shown below:

(1) The landform data and site data are collected on a global scale and made into a database in advance as preparation before a disaster occurs; thus it becomes possible to

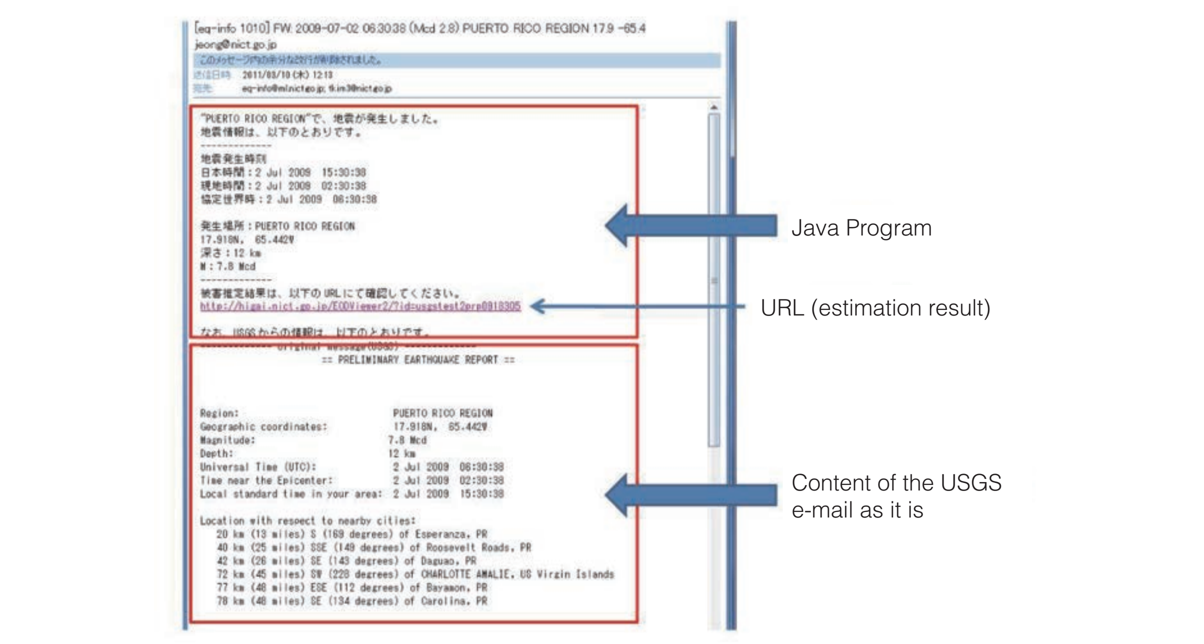

Fig.8 Example of an e-mail automatically sent to a registrant

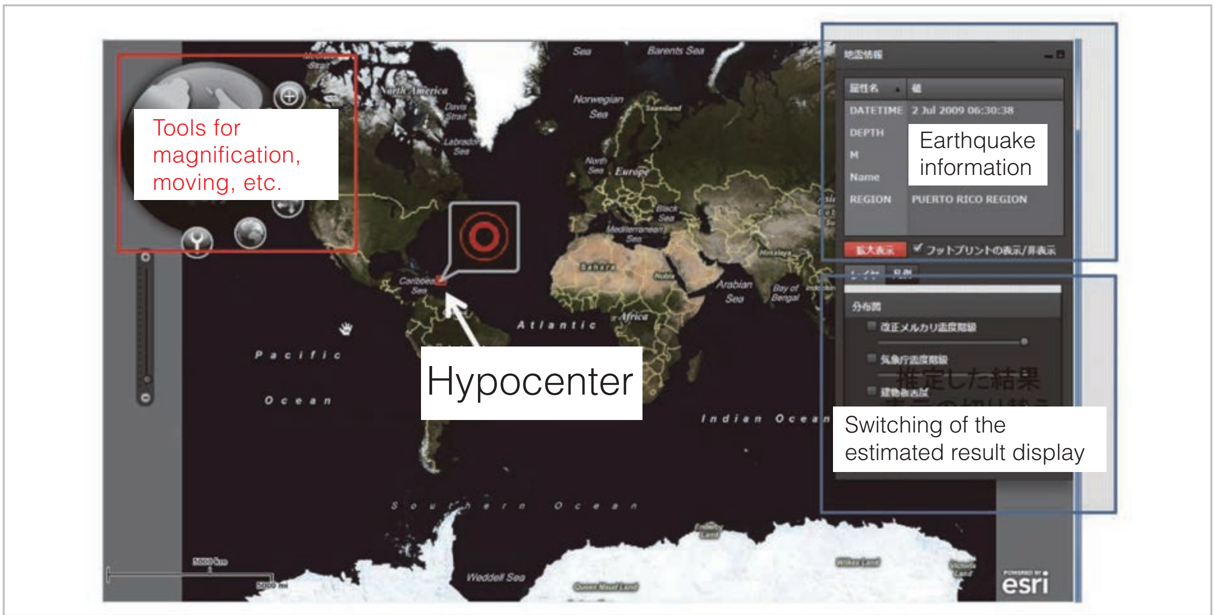

Fig.9 Example of a web published version of the initial screen of the international version of the Simplified Earthquake Damage Estimation System

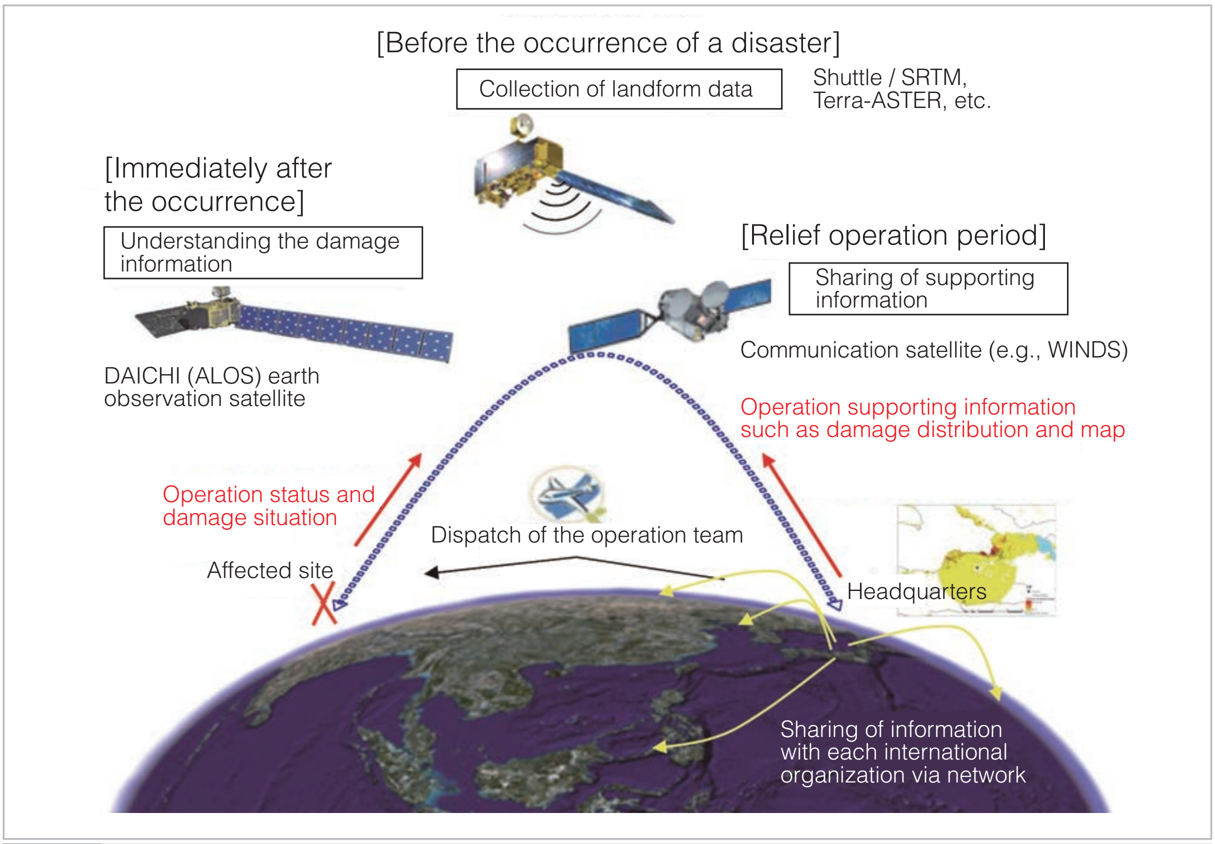

Fig.10 *Information system supporting the international relief operation*

quickly calculate the damage estimation result after the earthquake. It is a system of supporting the disaster correspondence in which the acquisition of hypocenter information, etc., and delivery of the damage estimation result, etc., are processed automatically.

(2) Actual damage information from remote sensing data (satellite image) and from the affected site is thoroughly collated and analyzed; moreover, it can be registered on the supporting information system after an earthquake occurs, even while the relief team is en route to the affected area overseas.

(3) The damage estimation result and disaster information, such as a map of the affected area and the satellite image, are shared with the relief team and the dispatch headquarters via satellite (such as WINDS) that is capable of high-speed data transmission.

6 Evaluation experiment and system demonstration

A verification experiment and a demonstration of the system were performed during the 8th APEC Ministerial Meeting on the Telecommunication and Information Industry (TELMIN8), which was held October 28 to 31, 2010 with participation of the NRIFD, Tokyo Fire Department, National Electronics and Computer Technology Center (NECTEC) and NICT [13]. An information-sharing experiment during an international relief operation was performed by connecting Bankoku Shinryokan in Nago, Okinawa, and NECTEC in the suburbs of Bangkok, Thailand, using the Earthquake Damage Estimation System, a high-vision TV conference system, etc. A demonstration was performed in which the JDR relief team, as dispatched to Thailand, and the dispatch headquarters in Japan used the present system for command and support based on the assumption that a catastrophic earthquake had occurred near Chiangmai, in the north of Thailand. The headquarters and the JDR relief team consisting of members of the Tokyo Fire Department, as dispatched to Thailand, shared command-and-support information such as confirmation of the operation site and the paths necessary for transfer in the event of a change in the plan by mutually confirming the estimation result of the Earthquake Damage Estimation System, satellite images of Chiangmai, etc. A good evaluation was obtained from the relief team participating in the experiment concerning the effectiveness of the system in determining the site to which the team was dispatched and the operation during the change in the plan. The result shown in Fig. 11.

7 Conclusion

In response to the occurrence of a large-scale natural disaster, it is desirable to evaluate the disaster risk in advance, rapidly understand the disaster situation once it has occurred, and quickly provide all team members with correspondence and resources. Global disaster observation technologies and the construction of a network for the use of such technologies are therefore necessary. Given this perspective, cooperating with the FDMA of the MIC, a research-and-development project was performed on earthquake damage estimation technologies based on a digital elevation model (DEM) that was developed using remote sensing, with the transmission of the calculation result obtained from these technologies via satellite (such as WINDS) to relief teams en route to disaster sites over a three-year period since 2008, as one of the strategic research projects.

Fig.11 *Demonstration in APEC-TELMIN8*

As a means to quickly understand a catastrophic earthquake affected area, the seismic intensity distribution and structural damage distribution of the 2011 Christchurch Earthquake of February 22, 2011, the 2010 Haiti Earthquake of January 12, 2010, etc., were estimated using SRTM-3 of NASA, and the estimation was compared with the data obtained after the earthquake occurred, and as a result it was confirmed that both groups of data were reconciled. Thus the estimation can be considered useful as a data source for decisions such as those concerning the dispatch of international fire and disaster relief team and the selection of operation sites.

However, when the desired situation is considered regarding earthquake damage estimation in many developing countries (including those of Asia), it is not always necessary to have highly accurate, detailed earthquake damage estimation such as is performed in Japan. A damage estimation with a reasonable degree of accuracy is established at an early stage, considering the cost of conducting the damage estimation, etc., and the estimation can be considered useful for the establishment of earthquake disaster countermeasures in advance, so that limited resources should be introduced selectively, etc.

Given the above viewpoint, the present research shows that spatially detailed earthquake damage can be estimated with a reasonable degree of accuracy by applying the landform classification method using DEM proposed by authors of the present research to SRTM-3, which covers most of the earth.

In the 2011 off the Pacific coast of Tohoku Earthquake of March 11, 2011, communication disturbances occurred in most of the affected areas and there was difficulty in the collection and transmission of information. It is possible that a relief team that normally operates in domestic urban areas will face a communication situation that is the same as an international relief team overseas when operating in a mountainous area or when there is difficulty in the communications infrastructure due to a large-scale disaster.

An idealistic form of a system during a large-scale disaster may be a communication system in which satellite communication, which enables communication at any time regardless of the operation site, is seamlessly merged with terrestrial communication.

Accordingly, in the quest for a practical use of the supporting system introduced in this manuscript, improvement in the accuracy of the damage estimation will be pursued along with the development of an operation interface adapted to the operations during future relief operations.

Acknowledgments

The verification experiment and demonstration in the APEC-TELMIN were carried out in cooperation with related organizations such as members of the Tokyo Fire Department and the Japan International Cooperation Agency (JICA). We wish to express our deepest gratitude for their assistance.

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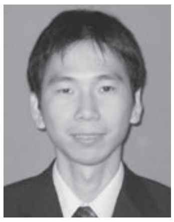

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