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The 1st Asia-Pacific Region Global Earthquake and Volcanic Eruption Risk Management (G-EVER) International Symposium

Abstracts Volume

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The 1st Asia-Pacific Region Global Earthquake and Volcanic Eruption Risk Management (G-EVER) International Symposium

Abstracts Volume

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Preface

In February 2012, the 1st workshop of Asia-Pacific Region Global Earthquake and Volcanic Eruption Risk Management (G-EVER1) was successfully held in AIST, Tsukuba, Japan. This, the first G-EVER International Symposium is planned as a follow up activity of G-EVER1 and one of memorial events of the devastating 2011 earthquake off the Pacific coast of Tohoku, Japan. Once a disaster occurs, in today's highly globalized economy, it can create unpredictable turmoil all over the world, not just in the affected area. These global-scale disasters are crucial for the sustainable development of the global economy to ensure human security. Global scale natural hazards are not the fire of the other side of riverbank.

The Workshop of G-EVER1 focused on the formulation of strategies to reduce the risks of disasters worldwide caused by the occurrence of earthquakes, tsunamis and volcanic eruptions. More than 150 participants attended the workshop. During the workshop, the G-EVER1 Accord was approved by the all participants. The Accord consists of 10 recommendations, including the following items:

1. Establishment of a framework for cooperation of research institutes and related organizations in the Asia-Pacific region working on seismic and volcanic disaster prevention
2. Enhancement of exchange and sharing of various information on seismic and volcanic disaster prevention
3. Building the international standard for the database, data exchange and disaster risk assessment.

Soon after the workshop, the G-EVER Consortium among the Asia-Pacific geohazard research institutes was established in 2012, and the G-EVER Hub website (http://g-ever.org) was setup to promote the exchange of information and knowledge about volcanic and seismic hazards among the Asia-Pacific countries. Establishing or endorsing data interchange standards and standardized analytical methods for geohazard institutes of the world are important to promote data sharing and comparative analyses. G-EVER International Conference is scheduled every 2 years in the Asia-Pacific countries. Several G-EVER working groups and projects were proposed such as the following: (1) risk mitigation of large-scale earthquakes WG, (2) risk mitigation of large-scale volcanic eruptions WG, (3) next-generation volcanic hazard assessment system WG, and (4) Asia-Pacific region natural hazard mapping project.

The major activities of G-EVER include participation in global risk reduction efforts, such as the Integrated Research on Disaster Risk (IRDR) Program, Global Earthquake Model (GEM), Global Volcanic Model (GVM). G-EVER will seek a way to the new international platform of Future Earth: Research for global sustainability. Our knowledge will help to build a better future on Earth. Recently, it was announced that the 3rd United Nations world conference of disaster reduction is going to be held in Japan, 2015. I hope our efforts will be recognized during the UN conference.

After the Tohoku earthquake, large number of efforts for the prevention and reduction of the risks of natural disasters have been made all over the world. The Symposium aims to encourage extensive discussions on the present situation and future challenges of natural disaster mitigation in the Asia and Pacific regions, as well as the prospects for the coming decade. Through this, a clear direction for possible mitigation measures to reduce the risks of earthquakes and volcanic eruptions could be determined.

Eikichi TSUKUDA

President of the G-EVER Consortium

Director-General of the Geological Survey of Japan, AIST

The first workshop of Asia-Pacific Region Global Earthquake and Volcanic Eruption Risk Management (G-EVER1) at AIST, Tsukuba in February 2012

The 1st G-EVER International Symposium Program

[Earthquake and tsunami: records, catalog, and risk assessments/management]

Chairman: Yasuto Kuwahara (GSJ, AIST)

Learning from disasters: An Alaska perspective

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Rising cost of natural disasters

Japan and Alaska have in common the problem of hazards associated with subduction. Of course, with a population density in Japan that is 300 times greater than Alaska's, Japan's risk exposure (vulnerability x probability) is much higher. Nevertheless, Alaska's cold climate and great distance from sources of make the secondary impacts of earthquakes, tsunamis, and volcanic eruptions especially severe. Even healthy survivors of the event itself may remain in great danger, without heat, water, and food.

Learning from past events is an obvious key to reducing the impact of natural hazard events in the future, or in the spirit of the United Nations International Strategy for Disaster Reduction (UNISDR, 2007): *To prevent natural events from becoming natural disasters*. We are apparently not learning very well, because despite our great increase in geophysical knowledge, geophysical monitoring, and engineering and education efforts, the cost of natural disasters globally continues to climb. For many countries, the costs are unsustainable.

There appears to be more than population growth to the growth in cost of natural disasters. Urbanization, representing a concentration of people and infrastructure, means that a single event can have a higher impact. During the Cold War when fear of a nuclear attack was high, the U.S. Government dispersed many government operations to the suburbs in the interest of resilience, a move that now contributes to inefficiency. Concentrating people shortens local distribution systems but lengthens major supply lines, creating single points for major failure. Driven relentlessly by market forces, efficiency that is produced through "economies of scale", elimination of redundancy, and "just-in-time" supply chains also works against resilience.

In the face of rising disaster costs, countries have increasingly shifted emphasis towards reducing vulnerabilities, such as by relocating or hardening critical facilities and by providing early warnings systems; towards promoting preparedness through education, evacuation routes, emergency shelters, and towards detailed planning, including the development of disaster scenarios with "table-top" exercises. In the US, work on preparedness greatly intensified after the Katrina Hurricane disaster in New Orleans of 2005, which tragically illustrated a spectacular absence of preparedness.

In most countries, it is assumed that the national government will respond to a disaster with relief efforts and assistance in rebuilding after a "state of emergency" is declared, or in developing countries that international help will be forthcoming. Although assistance external to an impacted community is invariably needed because no community can afford to maintain a full response capability themselves, the assumption that help is always on the way can encourage people to take excessive risks. Examples are building near faults, volcanoes, exposed coasts, and flood plains. A problem is that the country as a whole then subsidizes a regional population. Over time, this may even out because the areas of impact shift for each event location and type, but in the short term there may be political opposition to national assistance in rebuilding. Such was the case recently in the US, when Congress was slow to approve financial help for the coastal areas of New Jersey and New York that were flooded and in some cases made unlivable by superstorm Sandy.

Rather than trusting on favorable political conditions to restore a devastated community, New Zealand takes the novel approach of saving ahead for disasters through a country-wide tax on property for a self-insurance pool. The funds are administered by an independent board of the Earthquake Commission (EQC). For additional security, protection is obtained from the re-insurance industry. Even this was not enough, when a M_w6.3 destroyed downtown Christchurch in 2011 at a loss equivalent to about 10% of New Zealand's GDP. In contrast, some estimates of the financial loss in Japan from the Tohoku earthquake and tsunami are about 5% of GDP. The New Zealand approach only works if major disasters are well spaced in time. If a new disaster hits soon, New Zealand will not have ready funds to recover.

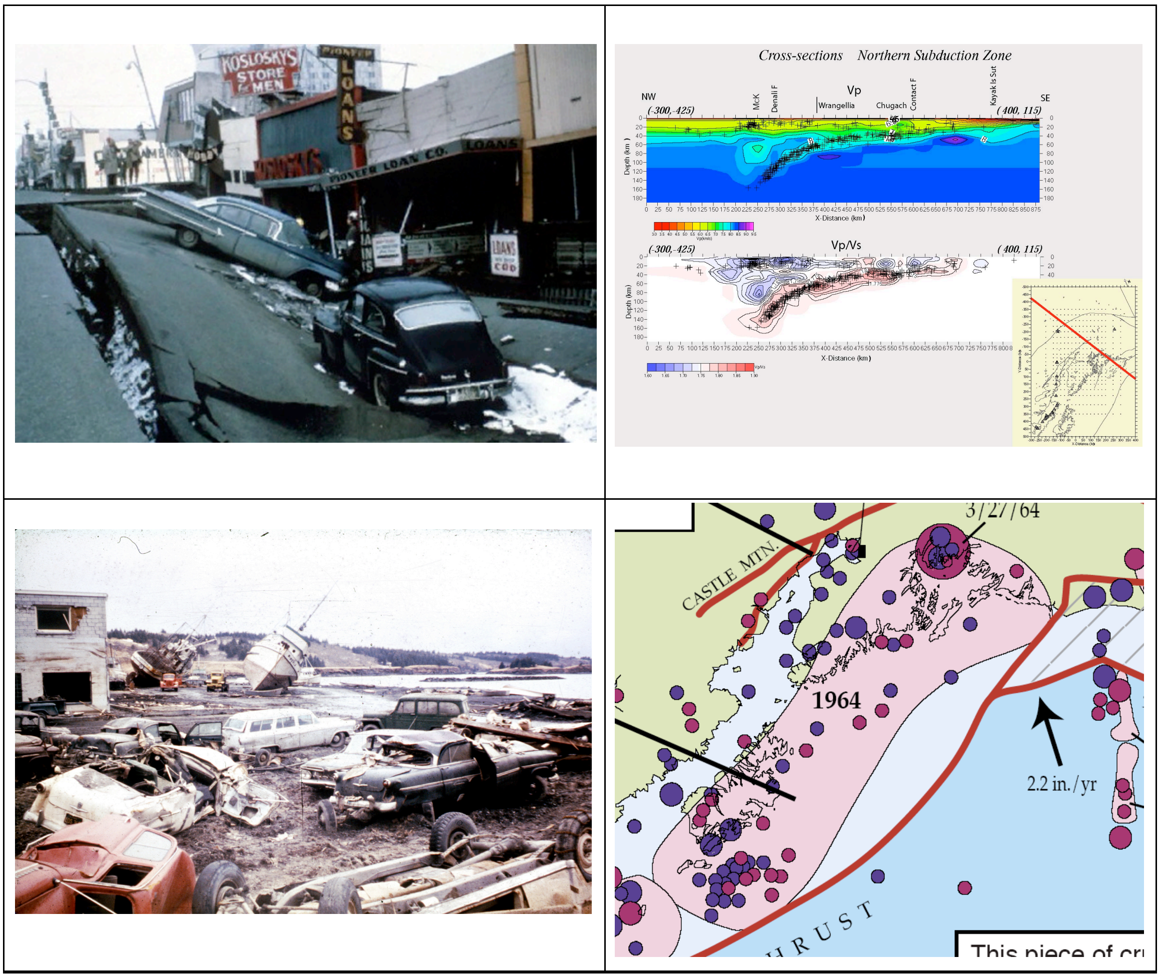

Fig. 1. Alaska's "Good Friday" earthquake of 1964. Clockwise from upper left: Street scene in downtown Anchorage; Cross section through subduction zone; Map of 1964 rupture; Kodiak after tsunami. (USGS, ADGGS, National Geographic)

Alaska 1964

Among the great historical events thus far in Alaska's statehood, which began in 1959, was the M_w 9.2 "Good Friday Earthquake" and tsunamis of March 27, 1964 (Plafker, 1965). The megathrust fault broke over a segment 800 km long and 250 km wide. Liquefaction and lateral spreading destroyed much of downtown Anchorage and a residential area. The "tectonic" tsunami caused some damage to coastal communities, but the major sources of destruction and loss of life were local tsunamis triggered by shaking that caused landsliding from both terrestrial and sub-sea sources (Haeussler et al, 2007). Oil storage tanks caught fire, buildings were jostled on shifting ground, and much of Valdez was swept away.

Scientific investigations following this earthquake, primary by the U.S. Geological Survey, contributed a great deal to the development of the subduction paradigm. The earthquake occurred at the time of the emerging discoveries and debates about plate tectonics. The 1964 earthquake was centered under Prince William Sound, an area of complex coastline and many outlying islands. This made it easy to map changes in elevation from the shift of the shorelines over the area that ruptured. The predominant view in the US then was that the earthquake represented movement on a high-angle reverse fault. However, the distribution of uplift and subsidence showed unequivocally that only the alternative solution to the seismic data was permissible: motion on a low-angle megathrust (Plafker, 1969). This result, though controversial then, was subsequently found to explain the Chilean M_w9.5 earthquake of 1960 well, ensuring acceptance of subduction as we conceive it today.

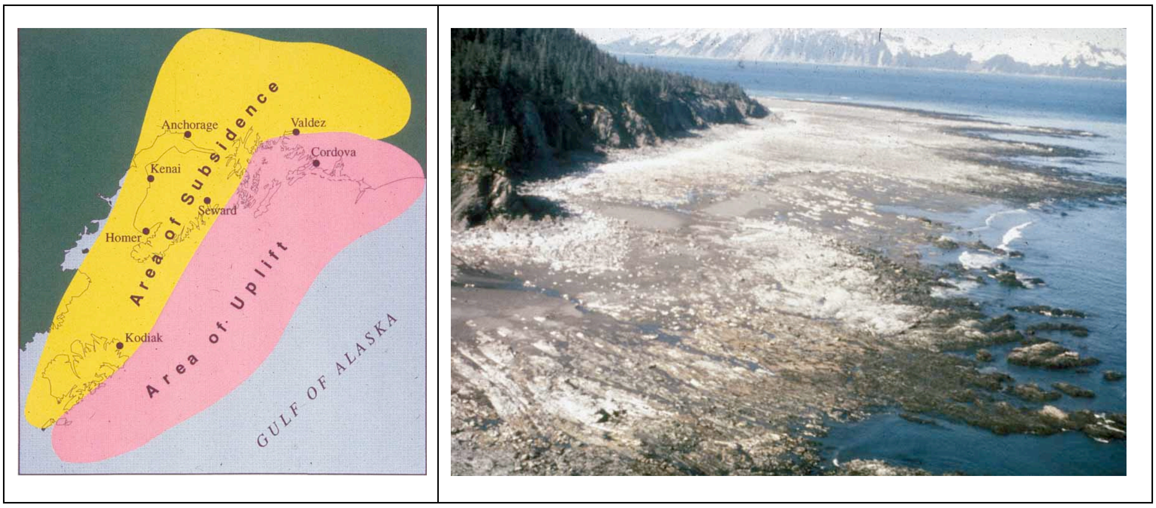

Fig. 2. Mapping elevation changes, Plafker (1969) showed that the earthquake had to be caused by a northwest-southeast low-angle thrust. Left: Generalized map of uplift and subsidence. Right: 10 m of uplift at the southeast-most island.

As we approach the 50th anniversary of this catastrophe, it seems appropriate to ask whether we have learned all we can from the events that have occurred since 1964. It appears that Alaska is more vulnerable to disaster than in 1964. Anchorage has rebuilt in place, presumably with the thought that great megathrust earthquakes have a recurrence interval of hundreds of years. The city now has an underground gas distribution system, which it lacked in 1964. Some 90% of supplies to the state pass through the Port of Anchorage and Anchorage's international airport, making rescue and recovery extremely difficult if these critical facilities are damaged. Valdez now boasts a huge oil terminal at the terminus of the 1300-km Trans Alaska Pipeline, the single most important factor in the economy of the state. A break in the line would be an environmental disaster. A cessation in flow, with subsequent cooling of the oil, would make it are to restart.

Case studies

A good way to evaluate Anchorage's current situation is to examine the geophysical record and preparation, response, and reconstruction record of analogous events. These records can be used to develop model-driven scenarios for plausible future events, which in turn can be used to explore the cost/benefit balance of various risk mitigation strategies.

The Tohoku earthquake and tsunami on March 11, 2011 is by far the best recorded great megathrust event in history. As such, it can improve our understanding of what happened in Alaska in 1964. It is also important that the whole world learn from the human response and toll from this event, because no nation has done more to prepare for such a catastrophe in terms of engineering, planning, and education than Japan. Yet these measures were less effective than anticipated and unfortunate "surprises" occurred.

Downtown Christchurch was devastated by a M_w6.3 earthquake on February 22, 2011, just as earthquake experts were celebrating how well the city had weathered a M_w7.1 earthquake that occurred a few months before. This earthquake was particularly well recorded because a temporary seismic network had been deployed to capture aftershocks from the larger earthquake. It occurred on a previously unknown fault and was characterized by extremely high ground accelerations and extensive liquefaction of unconsolidated fluvial sediments underlying the city. This is a cautionary tale for Anchorage. The geologic substrate is similar and the Christchurch earthquake illustrates that a modest event near a city can do as much damage as a more distant great earthquake would do.

Kamchatka and the northern Kuril Islands of Russia suffered a M_w9.0 and tsunami on November 4, 1952. The town of Severo-Kurilsk was completely destroyed by the tsunami, taking 2336 lives. The Anchorage-sized city of Petropavlovsk-Kamchatsky is now undergoing a massive construction campaign to strengthen existing apartment buildings and replace those that cannot be made compliant with revised seismic risk criteria. This contrasts to Anchorage, where large single-family homes have been constructed on parts of the Turnagain Heights landslide, on which houses were completely destroyed in 1964. It is important that we understand the societal and policy dynamics that have led to such a contrast in behaviors in response to a hazard threat that is at least of the same order of severity.

An interesting aspect of the Tohoku and Christchurch disasters, and the incredibly bad Haiti earthquake disaster of 2010, is that they were not in areas of their respective countries deemed to be at highest risk seismically. This is partly due to incomplete knowledge, both in terms of faults and their histories, but also because we are dealing with probabilities, not certainties. As was pointed out in a discussion at the G-EVER meeting last year, we map risk to best allocate limited resources for mitigation. Lower risk areas are not safe, but we cannot afford to provide protection against worst-case scenarios everywhere.

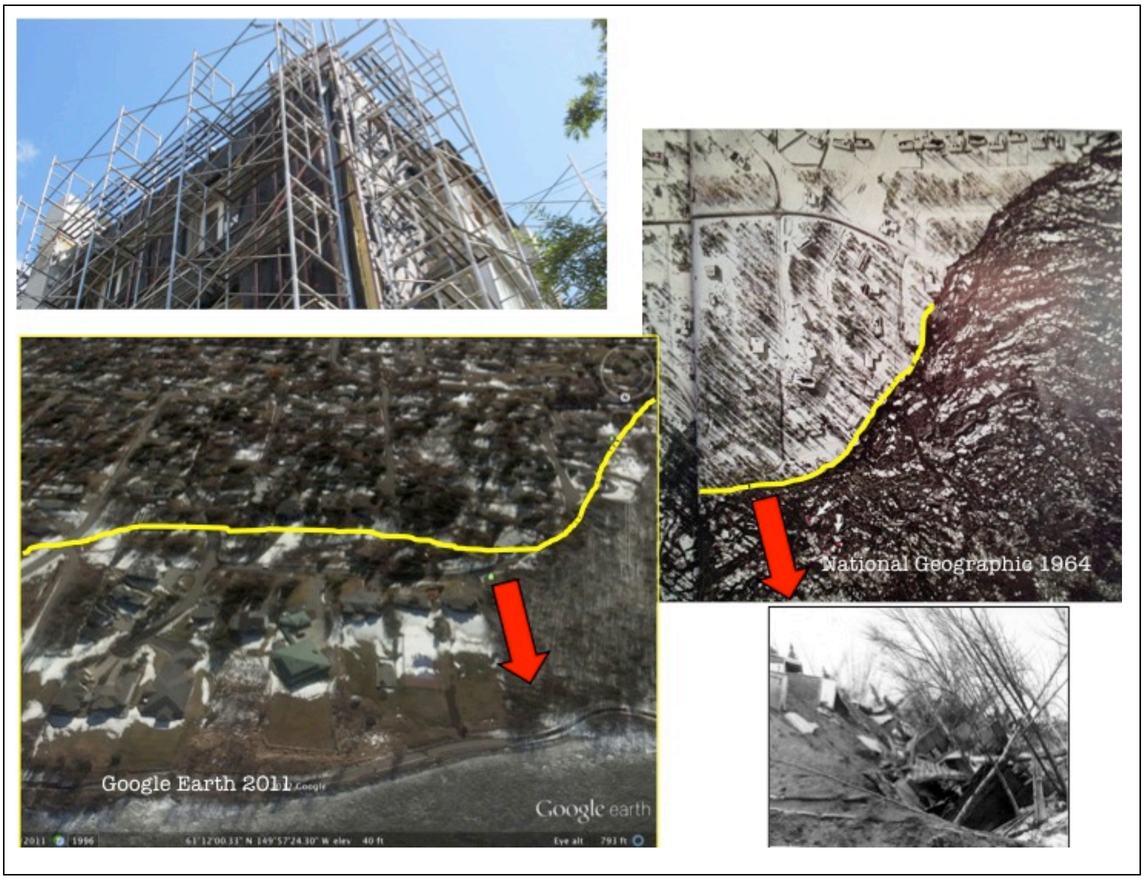

Fig. 3. Contrast between Anchorage and Petropavlovsk-Kamchatsky (P-K). Upper left: Reinforcement of an apartment building in P-K, one of many being strengthened for earthquake preparedness. Lower left to upper right: Turnagain Heights neighborhood in Anchorage, showing current conditions and shortly after the earthquake. Yellow line marks head of translational landslide. Note houses newly built on the landslide at lower left. Lower right: The residential area on the landslide after the earthquake.

Ultimately, our goal is that our communities be sustainable. We have no choice but to live in relatively hazardous places because of the benefits they offer for livelihood. This is not so bad for the individual, because the risk is comparable to other risks encountered over a lifetime, for example of accidents and disease. But for a community, which should endure for many lifetimes, extreme events are a major threat. But just as a community may be irreversibly damaged by an extreme event, it can also be made unsustainable through the cost of maintaining mitigation measures.

A proposed approach in Alaska

What is the "best bet" for disaster risk reduction? Rerunning the last disaster-producing event is not the answer. Development of model-based scenarios, with sensitivity analysis to determine the most cost-effective mitigation strategies, is a promising way to plan for the future. Scenarios permit communities to think about the almost unimaginable and to incorporate the experiences of others (Jones et al, 2008). Sensitivity analysis of scenarios is made possible by the tremendous increase in computing power now available. And unless the government is to simply dictate all actions, scenarios must include analysis as to how social and economic forces can produce positive rather than risk-increasing outcomes. We have proposed to take this approach in Alaska, with the help, and we hope also to the benefit, of colleagues in Japan, New Zealand and Russia.

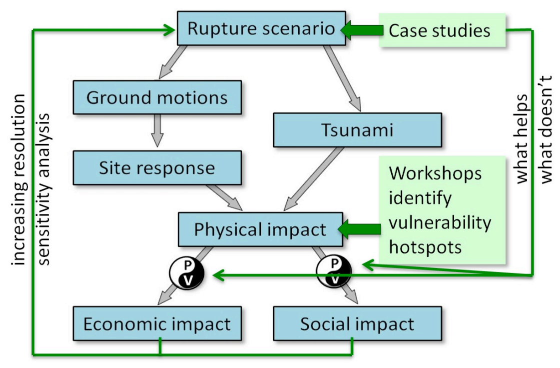

Fig. 4. An iterated scenario approach to evaluating mitigation measures. Rupture models based on case studies drive seismic wave propagation and tsunami waves, leading to predictions of physical impact. Impacts are attenuated by preparedness (P) and vulnerability reduction (V) to yield a social and economic cost. Repeated cycles are conducted to understand the role of unknowns, increase resolution on vulnerability hot spots, and understand efficacy of mitigation measures.

Acknowledgement

This is a synthesis that depends heavily on discussions with colleagues, particularly (in no particular order): Peter Haeussler (USGS), Mark Myers (UAF), Amy Lovecraft (UAF), Matt Berman (UAA), Zhaohui Yang (UAA), Jeff Freymueller (UAF), Carl Tape (UAF), Chanda Meek (UAF) and many others.

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G-EVER Consortium activities and the next-generation volcanic hazard assessment system

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1. G-EVER Activities

The first Workshop on Asia-Pacific Region Global Earthquake and Volcanic Eruption Risk Management (G-EVER1) was held in Tsukuba, Japan from February 22 to 24, 2012. The workshop focused on the formulation of strategies to reduce the risks of disasters caused by the occurrence of earthquakes, tsunamis and volcanic eruptions worldwide. More than 150 participants attended the event. During the workshop, the G-EVER1 accord was approved by the participants. The Accord consists of 10 recommendations like enhancing collaboration, sharing of resources, and making information about the risks of earthquakes and volcanic eruptions freely available and understandable. The G-EVER Consortium among the Asia-Pacific geohazard research institutes was established in 2012. The G-EVER Promotion Team of GSJ was also formed on November 2012. The G-EVER Hub website (Fig. 1; http://g-ever.org) was setup to promote the exchange of information and knowledge about volcanic and seismic hazards among the Asia-Pacific countries. Establishing or endorsing standards on data sharing and analytical methods is important to promote data and analyses results sharing. The major activities of G-EVER include participation in global risk reduction efforts such as the Integrated Research on Disaster Risk (IRDR) Program, Global Earthquake Model (GEM) and Global Volcanic Model (GVM). The G-EVER international conference would be held every 2 years in the Asia-Pacific countries. On the other hand, one to two days G-EVER international symposium would be held annually. The 1st G-EVER International Symposium is held in Tsukuba, Japan on March 11, 2013. The 2nd Symposium is scheduled in Sendai, Tohoku Japan, on Oct. 19-20, 2013. Several G-EVER Working Groups and projects were proposed such as the following: (1) Risk mitigation of large-scale earthquakes WG, (2) Risk mitigation of large-scale volcanic eruptions WG, (3) Next-generation volcanic hazard assessment WG, (4) Active fault catalogue WG, and (5) Asia-Pacific region earthquake and volcanic hazard mapping project.

Fig. 1. G-EVER Hubsite (http://g-ever.org)

2. Asia-Pacific region earthquake and volcanic hazard mapping project

The Asia-Pacific region earthquake and volcanic hazard mapping project aims to make an advanced online information system, which provides past earthquake and volcanic hazards records (eg. age, location, scale, affected area due to earthquake, tsunami, ash fall, and pyroclastic flows, and fatalities), recent earthquake and volcanic eruption information, risk assessment tools for earthquake and volcanic eruption hazards, and links to global earthquake and volcanic eruption databases. The hazard mapping project is planning to make the system with the cooperation of the Asia-Pacific countries.

3. Next-generation volcanic hazard assessment system

The next-generation volcanic hazard assessment WG is planning to provide a useful system for volcanic eruption prediction, risk assessment, and evacuation schemes at various eruption stages. The assessment system is planned to be developed based on volcanic eruption scenario datasets, volcanic eruption database and numerical simulations. Development of a volcanic hazard assessment system is a priority effort for the near future.

3-1. Volcanic eruption scenarios

Defining volcanic eruption scenarios based upon precursor phenomena leading up to major eruptions at active volcanoes is quite important for the future prediction of volcanic eruptions. Important datasets to use include precursor phenomena such as dates of minor eruptions, distribution of tephra fall deposits, amount of essential materials, chemical composition variations, volcanic tremors, and GPS measurement. Compiling volcanic eruption scenarios after the major eruptions is also important. The Newhall's group is presently developing precursor events database (WOVOdat).

For prehistoric volcanic eruptions, detailed geological field work and dating are essential. Eruption dates, vent positions, and distributions of each volcanic deposit should be examined. Eruption volumes of each deposit should be reevaluated using a standard estimation method based on the more precise distributions. Well-constrained volumes and eruption age data are important inputs in making a high-quality volume-age diagram for the probabilistic analysis of future eruptions.

3-2. Volcanic eruption database

A high-quality volcanic eruption database, which compiles eruption age, eruption volume, and eruption styles, is important for the next-generation volcano hazard assessment system. Current volcanic eruption database is not enough for this purpose. More precise datasets of volcanic eruptions of Quaternary volcanoes, such as the ages of large and small-scale eruptions, eruption mass, distributions and chemical compositions are needed. The Global Volcano Model project is an ongoing effort, which includes the compilation of volcanic eruption database and makes risk assessment worldwide. Volcanic eruption deposits, which are older than a few 10 ka, are relatively hard to distinguish as small-scale eruptions. Therefore careful investigations are necessary. Formulating international standards on how to estimate the volume of volcanic products (eg. tephra and pyroclastic flow deposits) is needed in making high quality volcanic eruption database. Spatial distribution database of volcanic products (eg. tephra, pyroclastic flow, debris avalanche, and lahar distributions) that are encoded on Geographic Information System (GIS) is necessarily for more precise area and volume estimation and risk assessments. For example, tephra fall distribution database of major eruptions in the world with estimated total volume, column height and flux are important for the future tephra fall risk assessment during volcanic eruptions.

3-3. Numerical Simulations

The volcanic eruption database is developed based on past eruption results, which only represent a subset of possible future scenarios. Hence, different distributions from the previous deposits are mostly observed due to the differences, such as vent position, volume, eruption rate, wind directions and topography. Therefore, numerical simulations with controlling parameters are needed for more precise volcanic eruption predictions. Numerical simulations of pyroclastic flows, pyroclastic surges, debris avalanches, lava flows, tephra falls, ballistic, and lahars should be done for major past eruptions at the major active volcanoes, and key parameters should be evaluated. Furthermore, risk assessments should be done on major active volcanoes using numerical simulations. The "best-fit" parameters of the past major large-scale eruptions in the world have to be estimated and the simulation results database should be made. Using these best-fit parameters is quite useful for emergency situation especially when similar-style eruptions happened before.

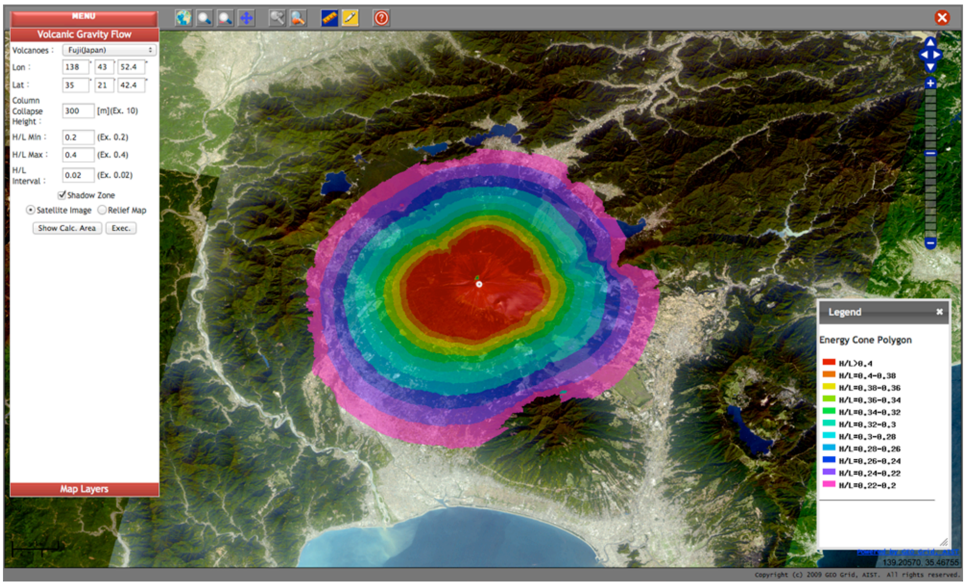

Fig. 2. Online GEO Grid simulation system. Simulation result at Fuji Volcano.

Currently, many numerical simulations, such as Energy cone, LaharZ, PDAC, Titan2D, and VolcFlow are used for volcanic gravity current assessments. Appropriate simulation model should be selected with the consideration on the model's merits and demerits and on the purpose of the assessment. Online numerical simulations are presently provided by the GEO Grid volcanic gravity flow simulation system (Figs. 2, 3) and the V-Hub project. The GEO Grid volcanic gravity flow simulation system provides an interactive user interface to evaluate the probability of an area to be affected by volcanic gravity flows using the energy cone model. Presently, the volcanic gravity flow simulations are available for 14 volcanoes, such as Unzen, Kirishima, Fuji, and Merapi. The system will be upgraded and any volcanoes in the world can be simulated next May using ASTER Global DEM. This simulation system will be the base of future next-generation volcanic hazard assessment system.

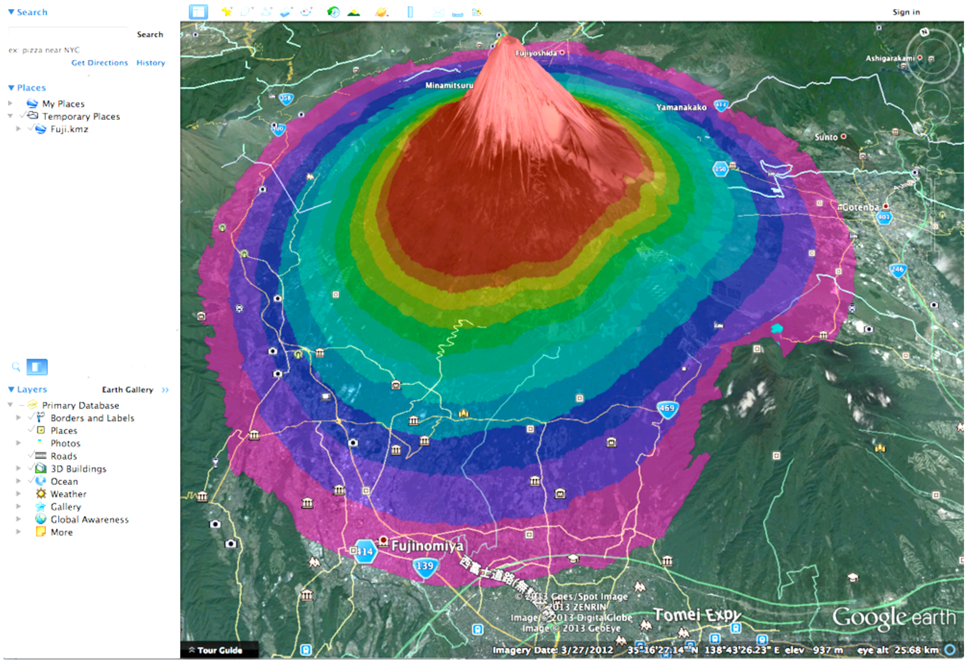

Fig. 3. Simulation result in 3D view, showing on the Google Earth.

3-4. Volcanic hazard assessment system

The next-generation real-time volcano hazard assessment system (Fig. 4) is should be developed based on volcanic eruption scenario datasets, volcanic eruption database, and numerical simulations. The use of next-generation system should enable the visualization of past volcanic eruptions datasets such as distributions, eruption volumes and eruption rates, on maps and diagrams using the timeline and GIS technology. Similar volcanic eruptions scenarios should be easily searched from the eruption database archive.

In the system, prediction of arrival time and area affected by volcanic eruptions at any locations near the volcanic area should be possible, using numerical simulations. The system should estimate the volcanic hazard risks by overlaying the distributions of the volcanic deposits on major roads, houses and evacuation areas using a GIS enabled systems. Probabilistic volcanic hazards maps at active volcanoes sites should be made based on numerous numerical simulations. The next-generation real-time volcanic hazard assessment system would be implemented as a user-friendly interface, making risk assessment system accessible online anywhere in the world.

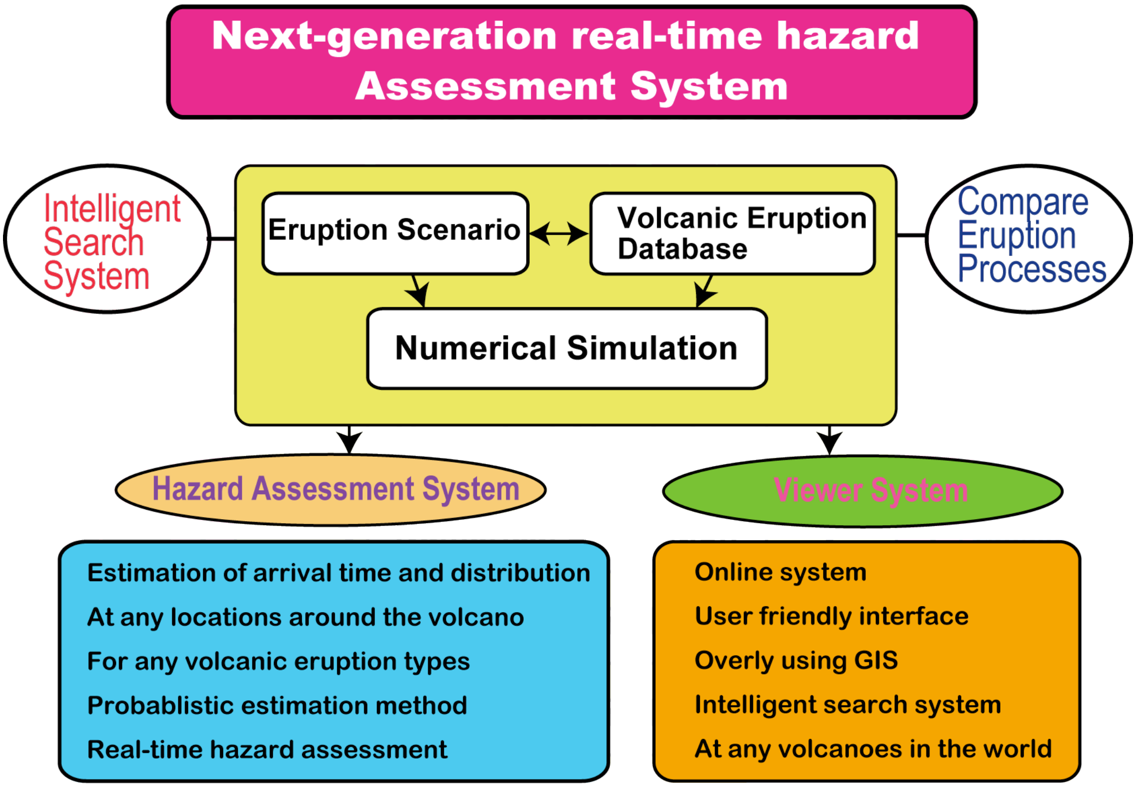

Fig. 4. Concept diagram of the next-generation real-time volcanic hazard assessment system.

GEO Grid volcanic gravity flow simulation system

http://volcano.geogrid.org/applications/EnergyCone

Reconsiderations after Tohoku earthquake and international collaborations for seismic hazard assessment

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Under guidance of the Earthquake Research Committee (ERC) and Headquarters for Earthquake Research Promotion of Japan, we have been carrying out the mission of Seismic Hazard Assessment (SHA) for Japan after the 1995 Kobe earthquake (MEXT, 2006; Fujiwara *et al.* 2009). Many efforts have been made for updating the seismic activities, remodelling of active faults, and establishing the Japan Seismic Hazard Information Station www.j-shis.bosai.go.jp/en/ (J-SHIS, 2006).

Examination from strong-motion observation of the Tohoku earthquake

The 2011 Tohoku *M* 9-class earthquake devastated huge regions but its treasurable kinematic processes of strong ground-motions were first-time captured by more than 1200 K-NET and KiK-net stations. It provides an irreplaceable chance to examine the SHA maps from the point view of strong-motion observation. In the Probability SHA (PSHA) map, the seismic intensity 5- or 5+ in a return period of 2500 years (with 2% probability of exceedance within 50 years) were evaluated in the Fukushima Prefecture

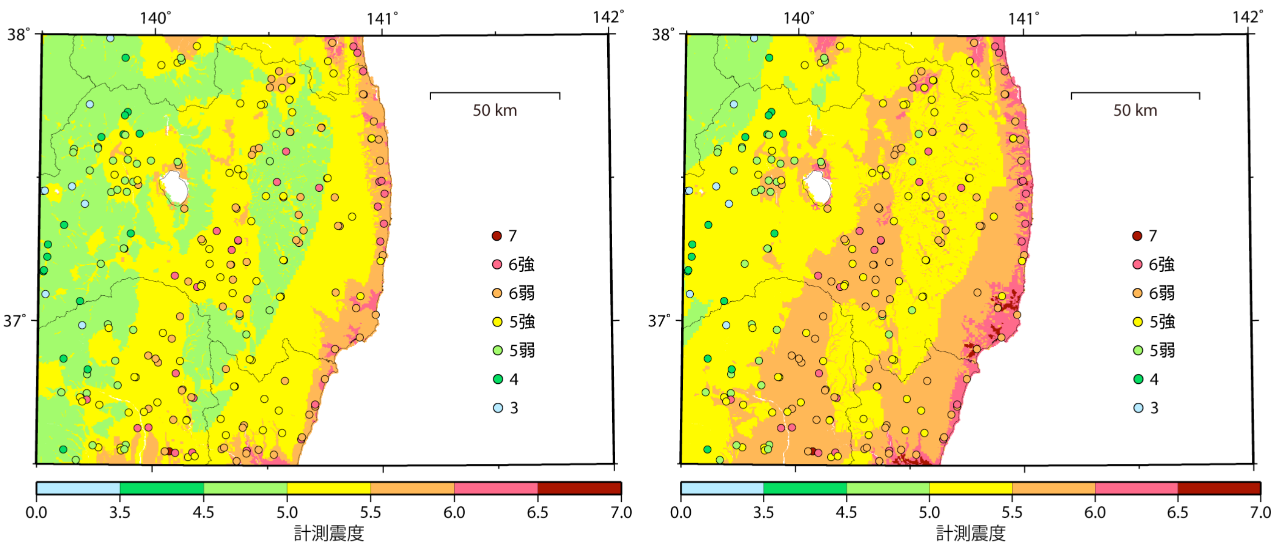

Fig. 1. Comparison of the seismic intensities in JMA scales observed (○ coloured) during the Tohoku earthquake with the assessed PSHA maps (with 2% probability of exceedance within 50 years) for the cases: (a, left) not considered and (b, right) if consider the Tohoku earthquake.

and in northern area of Ibaraki Prefecture, but much stronger seismic intensity 6- or 6+ (red cycles) were observed in these regions as shown in Fig. 1. The predicted ground motion level in PSHA map was clearly underestimated in Fukushima Prefecture and the northern part of Ibaraki Prefecture for the case of the Tohoku earthquake. The main reason is because the occurrence of great earthquake *M* 9.0 had not been evaluated as shown in Fig.1(a) and it would be improved by considering the case of the Tohoku earthquake as shown in Fig.1(b). Moreover, the cause of underestimate also lies in the inability to well establish the whole framework of PSHA methods under the circumstances that many issues are left unresolved in seismology.

Updated of PSHA maps considering the Tohoku earthquake

An on-going long-term evaluation of seismic activity model for Japan has been modifying under the authorization by ERC. We then recalculate seismic hazard based on the revises. Regarding the seismic hazard assessment for low probability, at present, it is insufficient to evaluate the uncertainty of ground motion prediction for low probability *M* 8 class earthquakes and it is necessary to improve techniques for them. Fig. 2 shows the exceedance probability difference for the cases: (a) not considered, (b) if consider the Tohoku earthquake, and (c) their difference.

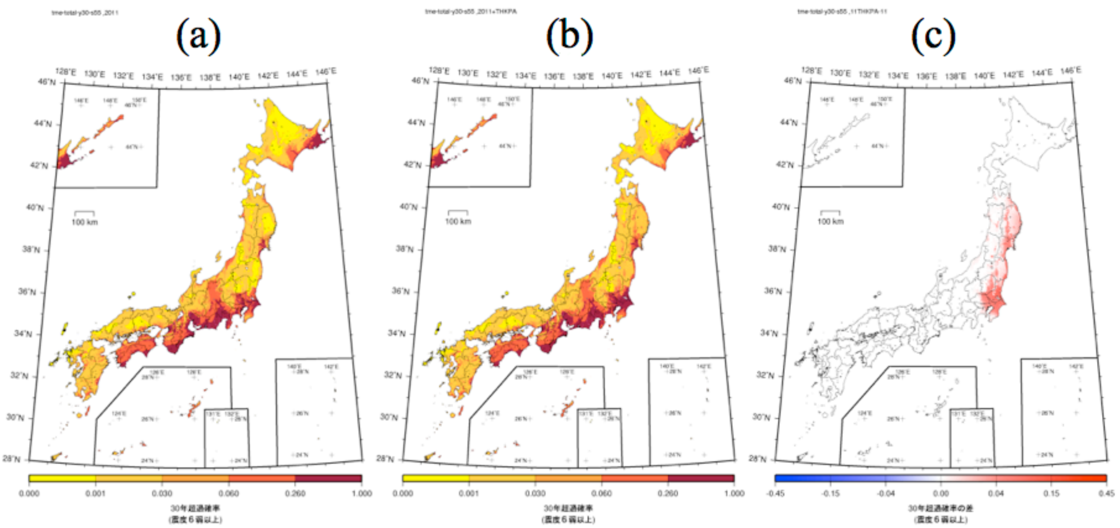

Fig. 2. The maps show distribution of exceedance probability within 30 years for JMA seismic intensity 6-. (a) Model 1: the old 2011 version. (b) Model 2: the modified 2011 version with the earthquake of Tohoku type. (c) The difference between (a) and (b).

Preparation of PSHA maps considering low-probability earthquakes

For earthquakes occurring both in subduction zones and in active faults, it is necessary to aim to model seismic activity that can be considered to large events in a return period of several thousands (or tens thousands) of years. To achieve this goal, we need to model background earthquakes that include a low probability of earthquakes by using the Gutenberg-Richter formula or other statistical techniques to compensate the long-term evaluation.

In addition to emphasize the urgency of the earthquake occurrence by showing the seismic hazard probability, we should prepare the maps that show the strong-motion level for earthquake preparedness. For example, based on the averaged long-term seismic hazard assessment, we evaluate JMA intensities for a return period of 10,000 year as shown in Fig. 3. The map for 10,000 year indicates the degree of shaking caused by not only subduction zone earthquakes but also earthquakes in major fault zones. For long return period, we can understand that almost all regions of Japan could be possibly hit by strong shaking of seismic intensity 6- or even large.

International collaborations

Over 90% of natural disasters have occurred in Asia and millions of people have lost their lives and homes by the recent mega-earthquakes, tsunami and natural disasters. Over 10 years PSHA missions especially after the lesson of the Tohoku *M* 9.0 earthquake, we have been strongly feeling responsibility to share our earthquake experiences and lessons, and contribute our best knowledge to the neighborhood countries and all of countries as well (NIED, 2011).

Collaboration with China and Korea

The same Low-probability earthquakes issues also raised in China as the 2008 Wenchuan China *Mw* 7.9 earthquake claimed 90,000 fatalities and the 1976 Tangshan China *Ms* 8.0 earthquake where 240,000 fatalities claimed.

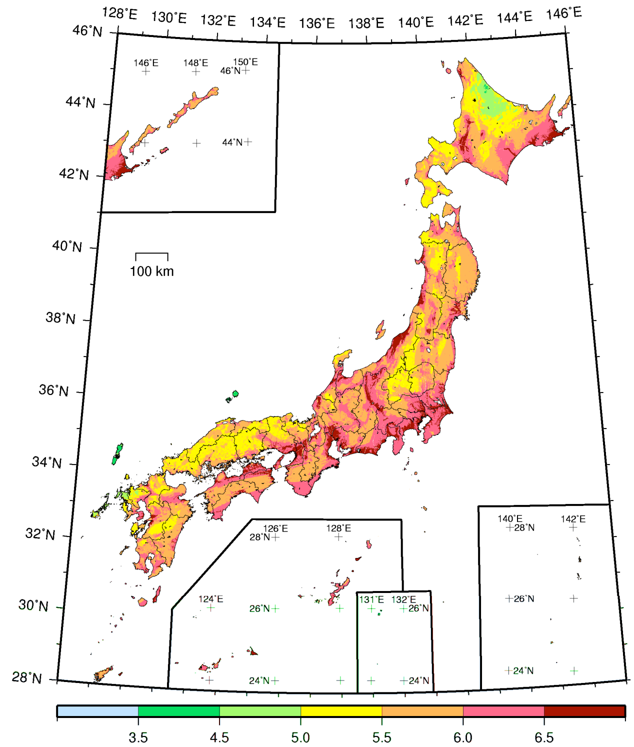

Fig. 3. Map for distribution of seismic intensity corresponding to (a) return period of 10,000 year. The map for 10,000 year indicates the degree of shaking caused by not only subduction zone earthquakes but also earthquakes occur in major fault zones.

We reviewed the PSHA related researches in China and Korea, and convinced core researchers in HIT and KIGAM to promote collaborative research. Under tense competition of over 50 applicants of strategic cooperative programs, the Seismic Hazard Assessment for the Next Generation Map (2010~2013) won final examinations by domestic and international committees among MOST China, NRF Korea and JST Japan, respectively. The goal of triple lateral strategic project was to improve the PSHA methodology for the next generation maps. The approaches were planned to review data and methodologies adopted in the current PSHA maps, to establish ground motion attenuation relationships for the maps; to combine PSHA and the deterministic approach for potential large earthquake; and to prepare one example map for each country.

To achieve the goals, we have carried on meetings and discussions in many ways. First annual meeting of the strategic project was hosted in Harbin, China on Nov 26-28, 2011. Not only the researches from China, Korea and Japan, we also have invited guests from other countries such as Taiwan, USA, Russia, Italia and Canada. Over 27 presentations have been presented from the field of PSHA, Seismic observation, Strong ground motion attenuation, Scenario earthquake simulation, Earthquake Early Warning, Geological structures, Earthquake damage, Site amplification, Smartphone application, and other related topics. Second annual meeting was hosted in Jeju Korea on Oct 29-31, 2012, where in parallel with the East-Asia Earthquake Seminar 2012. Participants in our meeting included 13 researchers from Japan, 8 from China, 15 from Korea and two invited guests from Taiwan and one from Italia. Over 26 presentations presented from the fields of Input for Seismic Hazard, Attenuation on Seismic Hazard, PSHA, Active fault and Site amplification on Seismic hazard. On panel discussions, methodologies of simulation-based PSHA and deterministic seismic hazard assessment (DSHA), issues of the low annual frequency of exceedance $10^{-(4\sim5)}$ (very long return-period) of active faults, collaboration between geologist & seismologist on the active fault study, gaps between the scientific fields and engineering requirements, importance of public education and communications were discussed. Third annual meeting will be hosted in Japan on June 2013 (CJK, 2011).

Collaboration with Taiwan

Taiwan and Japan are located along stretch island arcs where four Plates of Pacific, Philippines, Eurasia, and North-American have complex conjunctions of subducting and overriding each other. Both countries have the highest level of seismic activities and suffered the destructive earthquakes recently. The 1999 Chi-Chi, Taiwan, Great Earthquake (*Mw*7.6) caused 2,444 deaths and missing, and over 100,000 buildings were completely or severely damaged. Under the common lessons learnt from destructive earthquakes and the urgency of the unexpected earthquake possibly occur in the future, the committee of Taiwan Earthquake Model and NIED had consensus of cooperative researches to share data, knowledge and information to mitigate the disasters. First workshop of TEM and NIED was hosted in NCU, Taoyuan, Taiwan in June 4-6, 2012. Over 24 speakers have presented from the fields of PSHA, Seismic network observation, Geological structures, Earthquake Early Warning, GMPE, Scenario earthquake simulation, and other related. Second workshop of the TEM and NIED will be hosted in Japan on June 2013 (TEM, 2011).

Collaboration with Global Earthquake Model

Global Earthquake Model (GEM, 2009) is a collaborative effort devised and launched by OECD’s Global Science Forum, aimed at engaging the global community in the transparent design, development and deployment of uniform open standards and tools for earthquake risk assessment worldwide. Combining the strengths, knowledge and needs, more than 25 public and private sectors have joined GEM, 45 countries where users have tested the GEM’s OpenQuake Engine.

Tohoku earthquake brought to light much-complicated questions to Japan as well as world, with the common motivations and missions, NIED as a representative of Japan joined GEM to reinforce the public part of GEM’s partnership from September 2012. We are going to purpose new Global components of Tsunami assessment and numerical simulation assessments except actively join the existed Global components, such as, Global Instrumental Earthquake Catalogue, Global Active Faults and Seismic Source Database, Global Ground Motion Prediction Equations, Global Earthquake History, Global Geodetic Strain Rate Model, Global Earthquake Consequences Database, Global Exposure Database, Inventory Data Capture Tools, Global Vulnerability Estimation Methods and GEM Ontology and Taxonomy.

In the same time, we are continuing to work with China, Korea, Taiwan, and east-Asia regions related, to promote the regional programs.

By the challenge of unexpected mega earthquakes that exist outside the frame of human lifetimes, or even the lifetimes of entire civilizations, we have re-evaluated the National Seismic Hazard Maps for Japan in even long-term and low probabilities. As a representative of Japan in GEM, NIED will continue to work closely with all members of GEM not only for global components, also for regional programs related.

Acknowledgements

This CJK project was supported by MOST http://www.most.gov.cn/eng/index.htm, NRF http://www.nrf.re.kr/html/en/, and JST http://www.jst.go.jp/inter/english/project/country/jck.html.

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GEM, http://www.globalquakemodel.org

Earthquake Risk in the Tokyo Metropolitan area impacted by the 2011 M9.0 Tohoku-oki, Japan, Earthquake

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A series of magnitude (M) 8-class earthquakes including the 1923 Taisyo-Kanto earthquake and the 1703 Genroku-Kanto earthquake occurred in the Tokyo metropolitan region. Also there are several M7 or greater (M7+) earthquakes, some of which have brought serious damages in the greater Tokyo (Fig. 1). The M7+ earthquake in this region at present has high potential to produce devastating loss of life and property with even greater global economic repercussions although it is smaller than the megathrust type M8-class earthquakes. The M7+ earthquake is evaluated to occur with a probability of 70 % in 30 years by the Earthquake Research Committee of Japan. The M7+ earthquakes may occur either on the upper surface or intra slab of Philippine Sea Plate (PSP). Due to the 2011 Tohoku-oki earthquake it is more likely than before that the M7+ event will occur.

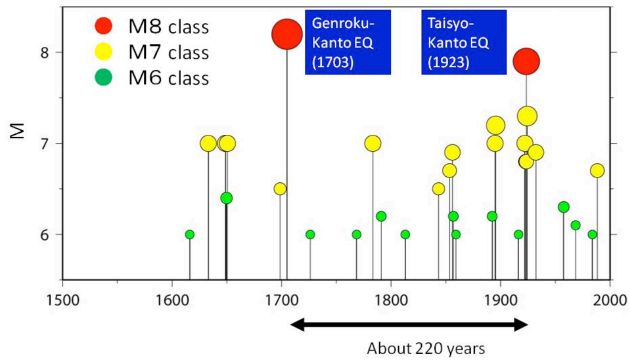

Fig. 1. Large earthquakes in Kanto district.

The greater Tokyo urban region has a population of 33 million and is the center of about 40% of the nation's economic activities. The Central Disaster Management Council of Japan estimates that the next great M7+ earthquake in the Tokyo metropolitan region will cause 11,000 fatalities and 112 trillion yen (1 trillion US$) economic loss at worst case if it occurs beneath northern Tokyo bay with M7.3. However, the estimate is based on a source fault model by conventional studies about the PSP geometry. To evaluate seismic hazard due to the great quake we need to clarify the geometry of PSP and also the Pacific plate (PAP) that subducts beneath PSP. We identify those plates with use of seismic tomography and available deep seismic reflection profiling and

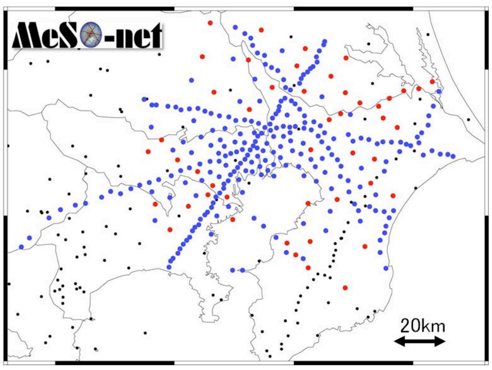

Fig. 2. Metropolitan Seismic Observation network (*MeSO-net*). There are 296 seismic stations are deployed in the greater Tokyo.

borehole data in southern Kanto area.

We deployed about 300 seismic stations (Metropolitan Seismic Observation network: *MeSO-net*) in the greater Tokyo urban region under the Special Project for Earthquake Disaster Mitigation in Tokyo Metropolitan Area (Fig. 2) (Hirata *et al,* 2009). We obtain clear P- and S- wave velocity (Vp and Vs) and Q tomograms which show a clear image of PSP and PAP (Fig. 3). A depth to the top of PSP, 20 to 30 kilometer beneath northern part of Tokyo bay, is about 10 km shallower than previous estimates based on the distribution of seismicity. This shallower plate geometry changes estimations of strong ground motion for seismic hazards analysis within the Tokyo region.

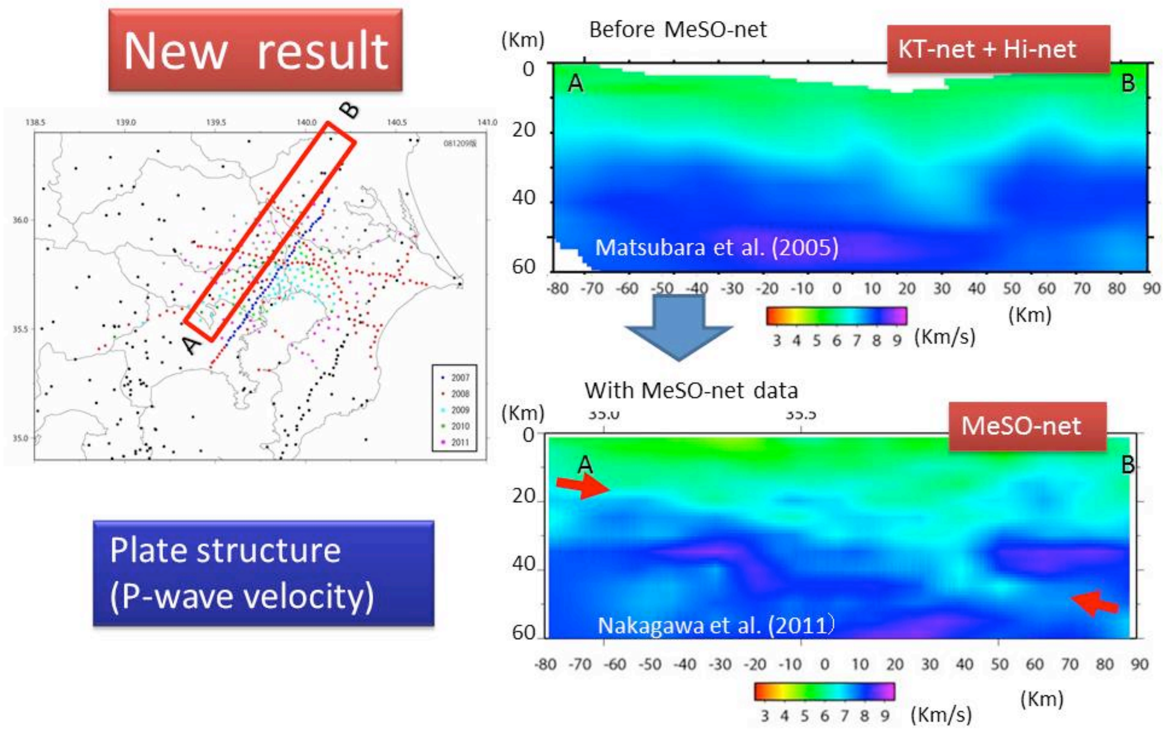

Fig. 3. Comparison of seismic tomogram determined by data before *MeSo-net* deployed and that with *MeSO-net*. A distribution of P-wave velocity is depicted beneath a cross-section from Fujisawa (A) to Tsukuba (B) the greater Tokyo. Red arrowheads indicate the crust of Philippine Sea Plate.

Based on elastic wave velocities of rocks and minerals, we interpreted the tomographic images as petrologic images. Tomographic images revealed the presence of two stepwise velocity increase of the top layer of the subducting PSP slab. Rock velocity data reveals that subducting PSP crust transforms from blueschists to amphibolites at a depth of 30km and amphibolites to eclogites at a depth of 50km, which suggest that dehydration reactions occurs in subducting crust of basaltic compositions during prograde metamorphism and water is released from the subducting PSP crust. Tomograms show evidence for a low-velocity zone (LVZ) beneath the area just north of Tokyo bay. A Q tomogram shows a low Q zone in PSP slab. We interpret the LVZ as a serpentinized region in the forearc mantle of Honshu arc, resulting from hydration by water derived from subducting PSP crust. Because strength of the *serpentinized* preidotite is not large enough for brittle fracture, if the area is smaller than previously estimated, a possible area of the large thrusting fault on the upper surface of PSP can be larger than previously thought. The P- and S-wave velocities within the serpentinized zone represent a degree of serpentinization as high as 10-40% for the LVZ with 20-km-long in noth-south and 90-km-long in east-west just above PSP, which is approximately eastern half or less of the previously estimated *serpentinized* area (Kamiya and Kobayashi, 2000). If the area is smaller than previously estimated, a possible area of the large thrusting fault on the upper surface of PSP can be larger than previously thought indicating more seismic risk.

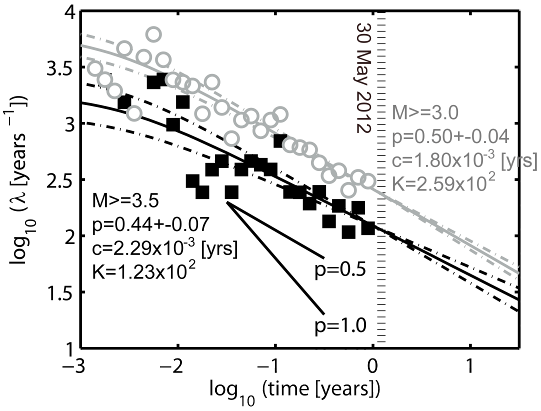

Fig. 4. Annual number λ ($year^{-1}$) of earthquakes with $M \geq 3$ (circle) and $M \geq 3.5$ (square) as a function of t (years). Vertical dotted line indicates 30 May 2012.

We have evaluated a rate of seismicity in the southern Kanto region (Fig. 4) as shown in Fig. 5. We calculate the most probable estimates of future *M*6–7-class events for various periods, all with a starting date of 30 May 2012 (Nanjo *et al.*, in press). The estimates are higher than pre-quake levels if we consider a period of three-year duration or shorter. However, for statistics-based forecasting such as this, errors that arise from parameter estimation must be considered. Taking into account the contribution of these errors to the probability calculations, we conclude that

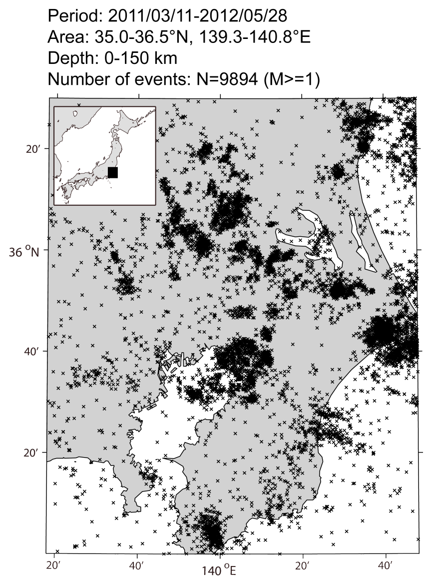

Fig. 5. Spatial map of earthquakes in southern Kanto after the Tohoku earthquake. The zoomed-out inset shows where the study area (black square) lies in Japan. The data is used to evaluate a rate of seismicity in Fig. 4.

any increase in the probability of earthquakes is insignificant (Fig. 6).

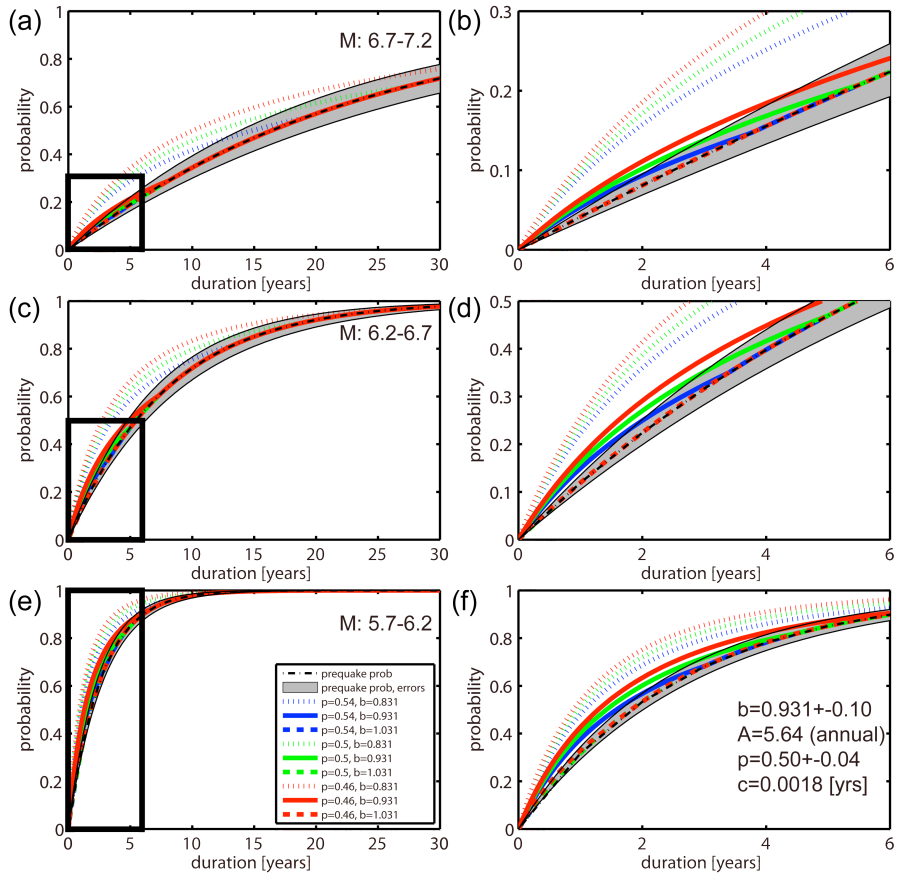

Fig. 6. Probability P as a function of evaluation duration T-S (years) for (a,b) $M7$ class, (c,d) $M6.5$ class, and (e,f) $M6$ class. S = 30 May 2012 (Nanjo *et al., in press*). The area surrounded by the rectangle in (a,c,e) is the same as (b,d,f), respectively. To see variation in P, arisen from uncertainties in b and p, we show the curves based on 9 different combinations of 3 b-values (best-fit of 0.931 and upper and lower bounds of 1.031 and 0.831) and 3 p-values (best-fit of 0.50 and upper and lower bounds of 0.54 and 0.46). Pre-quake probability and its uncertainty are shown by black curve and grey area, respectively.

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Possibility of High Performance Computing for Earthquake Disaster Assessment

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High performance computing (HPC) is a new tool which is accelerating various research activities of numerical computation. Parallel computing is a widely used technique of HPC, and so-called supercomputers which use parallel computing are being developed.

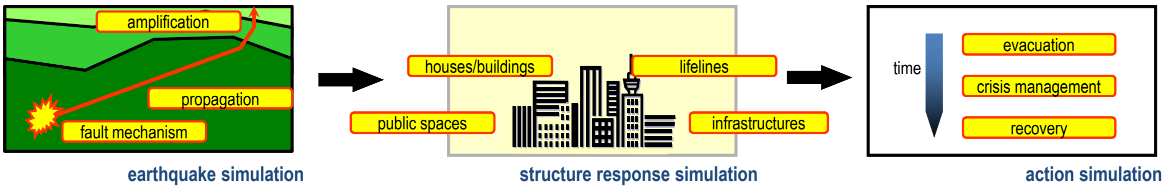

Fig. 1. Overview of IES.

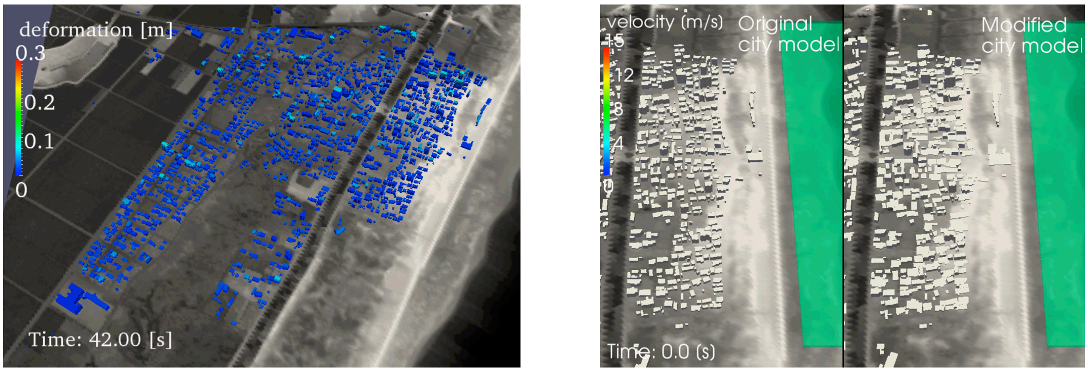

Fig. 2. Examples of IES simulation of tsunami.

A possibility of applying HPC is the earthquake engineering field is to improve earthquake disaster assessment; it is the base of making an earthquake hazard map for an urban area in which buildings are densely located. The current method of this assessment is the use of empirical relations. While advanced simulation is used in designing buildings, it is not feasible to use such simulation to analyze seismic responses of all existing buildings. A new system, called Integrate Earthquake Simulation (IES) is now being developed, so that the seismic response of all existing buildings is numerically simulated by taking advantage of HPC; see Fig. 1 for the overview of IES..

IES is regarded as a computer platform, into which various numerical analysis methods are plugged. The current version of IES employs ground motion simulation in surface ground layers, non-linear seismic response analysis of reinforced concrete buildings, and mass evacuation analysis which uses multi agent simulation. Tsunami inundation simulation and chemical simulation for deterioration and aging is being implemented; see Fig. 2 for the coupling of structure damage simulation and tsunami inundation simulation.

A possibility of HPC to earthquake disaster assessment is not restricted to an urban area earthquake simulation. It provides a more powerful tool for the seismic response analysis of an important structure, such as a high-rise building, bridges, or tunnels. Analysis of a numerical model of high fidelity is made for such structures, to clarify their local or overall failure processes which are caused by ground motion; see Fig. 3.

It is surely possible to extend IES. The first target is to link earth science simulation to earthquake engineering simulation. Crust-wise earthquake wave propagation simulation will play an important role in the earthquake disaster assessment. Also, although it is not simulation, data assimilation of seismograph network will be important, in order to carry out urgent or real-time earthquake disaster assessment at the occurrence of a large earthquake.

In order to realize HPC possibility of the earthquake disaster assessment, collaborative research among computer-science oriented researchers is an essential factor. It is also important to bring up next generation of earthquake engineering researchers.

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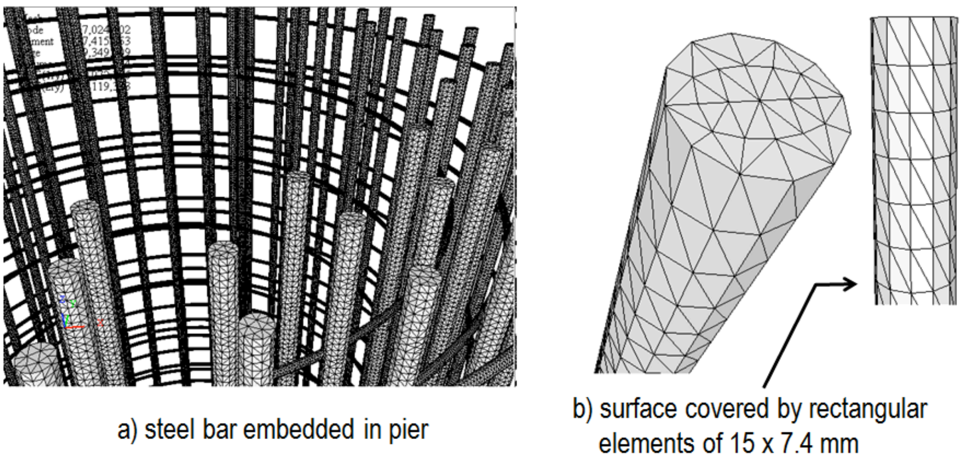

Fig. 3. Example of model of high fidelity for reinforced concrete strucutre.

Earthquake and Tsunami Risk Assessment for the Chinese Coast

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China has 18,000 km continental coastline and 14,000 km island coastline. Many big cities lie in the coastline area, such as Shanghai, Tianjin, Dalian, Qingdao, Hangzhou, Ningbo, Wenzhou, Fuzhou, Xiamen, Guanzhou, Shenzhen, Hang Kong, Macao and Haikou, Sanya, and also most of nuclear power plants and other important engineerings are located in the coastline areas. Figure 1 shows the historical earthquakes with mignitude M≥7.0 in China. The less big earthquakes occured in the coastline areas except Taiwan area than the west area of China, but it also indicates the strong seismicity in the coastline areas. In recent years, earthquake and tsunami disasters had been paid more attentions in Chinese coastal areas, especially after 2004 Sumatra tsunami.

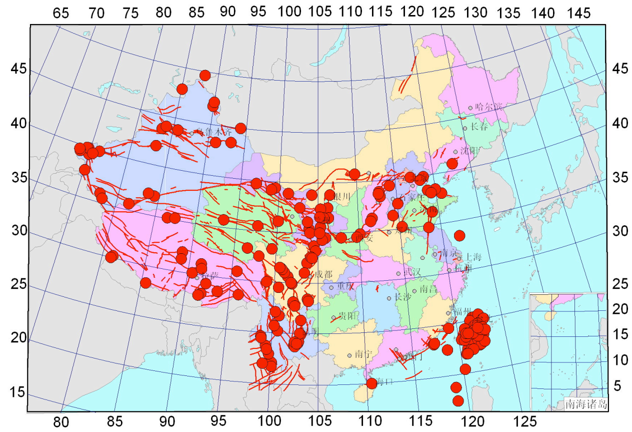

Fig. 1. Distribution of the historical earthquakes with magnitude M≥7.0 in China.

About 100 tsunami events were recorded in the past 2000 years, but 25 events were confirmed for earthquake tsunami and only 8 ~ 9 times for destructive tsunami (Wang et al., 2005). The destructive tsunami earthquakes include M7.0 Taiwan earthquake of May

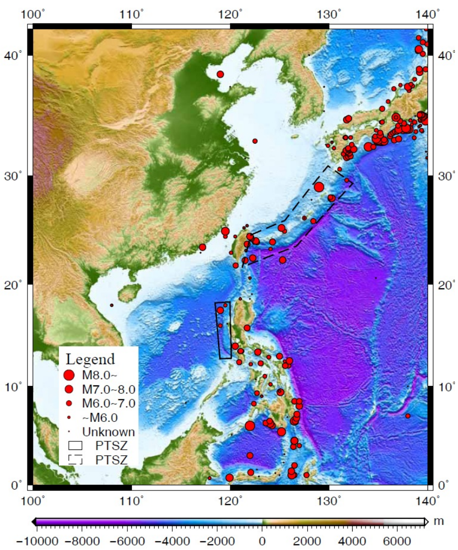

Fig. 2. The bathymetry and tsunamigenic related earthquakes around China (Source: NOAA Website).

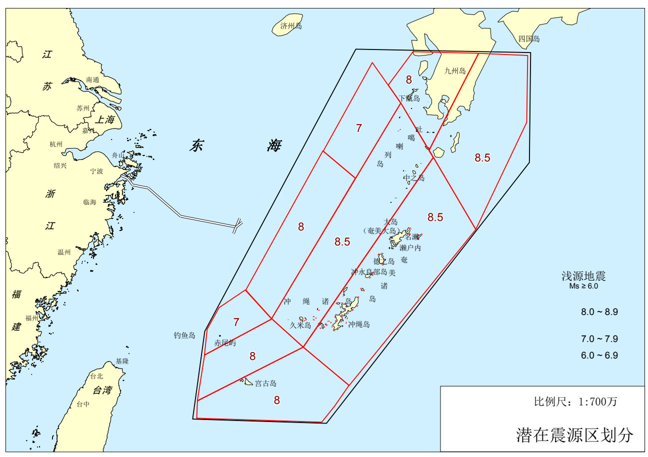

Fig. 3. The historical earthquakes and potential seismic sources in the Ryukyu Trench and adjacent area.

1781, M7.0 Taiwan earthquake of Dec. 1867, M7.5 Qiangshan (in Hainan) earthquake of July 1605 as shown in figure 1. Most of the big offshore earthquakes in China did not cause tsunami disaster (Wang et al., 2005, Shi et al., 2012), such as M7.5 Quanzhu earthquake of Dec. 1604, M7.0 Nanao earthquake of Sept. 1600, M7.3 Nanao earthquake of Feb. 1918, M7.4 Bohai Sea earthquake of July 1969 as shown in Figure 1.

Some studies (Ren et al., 2007, Liu et al., 2007, Wen et al., 2012, Shi et al., 2012) have revealed that the potential tsunami hazard is considerably lower in Bohai Bay, and higher from the Yellow Sea to Hainan Island and in three areas near the deltas of the Yangtze, Qiantang and Pearl river than in other coastal areas. The main potential tsunami risk for the coastal areas of China will be from the future earthquakes in the Ryukyu Trench area and Manila Trench area as shown in Figure 2 and Figure 3.

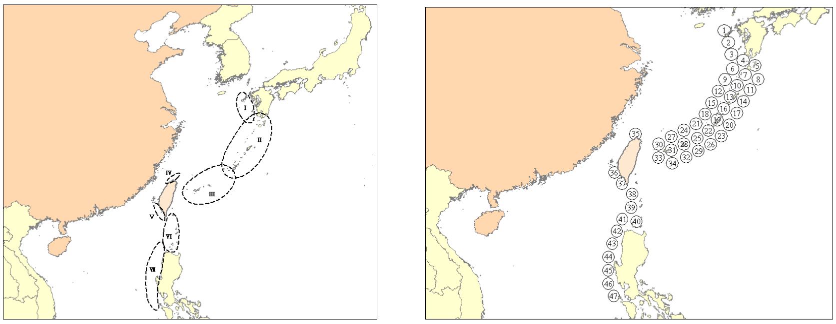

Fig. 4. Distribution of potential seismic sources and scenario earthquakes (Ren, 2007)

Figure 4 and Figure 3 show the potential seismic sources and scenario earthquakes for the tsunami risk assessment for the Chinese Coast, and deterministic analysis method of the tsunami hazard in China was used for the tsunami simulation analysis (Ren et al, 2007). Figure 5 and 6 demonstrate the simulation results of the tsunami risk assessment

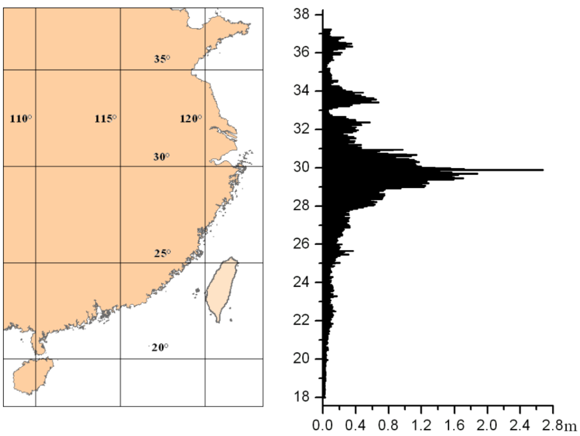

Fig. 5. The simulation results for 18th scenario earthquake

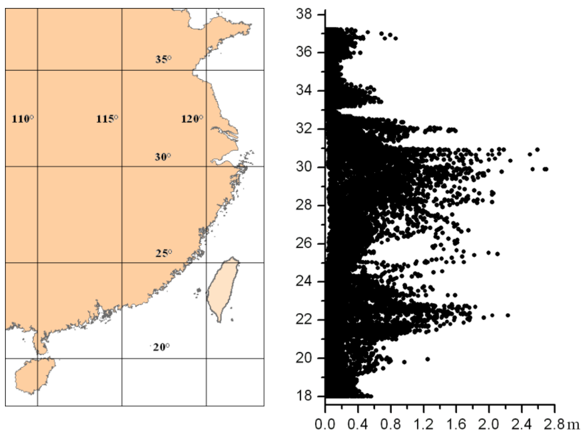

Fig. 6. Max wave height for 47 scenario earthquakes

for the Chinese Coast. From the simulation results, we found that from the yellow sea coast to the southernmost tip of hainan island, tsunami risk distribution is that highest one is in the areas of Yangtze river estuary, the Qiantang river estuary, the pearl river estuary, relative higher along the east China sea, next the south China sea, and lowest

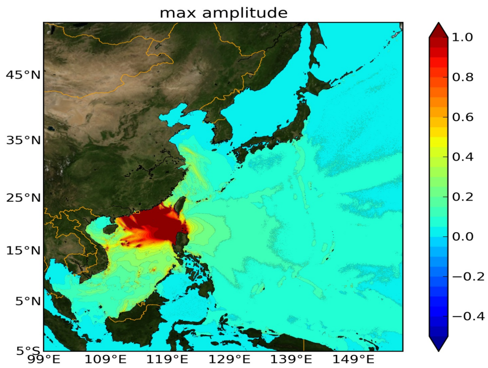

Fig. 7. Simulation of tsunami impact from a M8.8 scenario earthquake in Manila Trench (State Oceanic Administration, 2011)

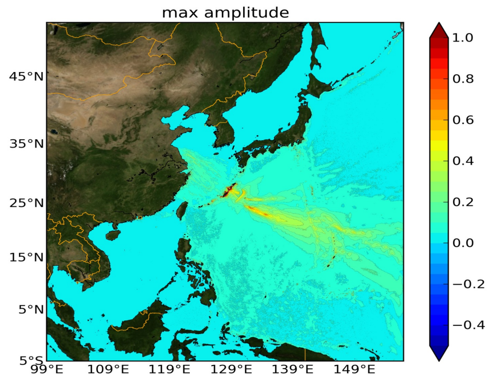

Fig. 8. Simulation of tsunami impact from a M8.5 scenario earthquake in Ryukyu Trench (State Oceanic Administration, 2011)

along yellow sea. The tsunami risk for the engineering site of nuclear power plants also was analyzed, and Figure 7 and 8 show the analyzed results.

After the Tohoku earthquake on March, 11, 2011, the impact of Tsunami on the Chinese coast was simulated as in figure 9, and simulated results were compared with the observed data as in figure 10 and 11 (Wen et al, 2011). The simulation results indicate there is less Tsunami impact of Tohoku earthquake on the Chinese coast.

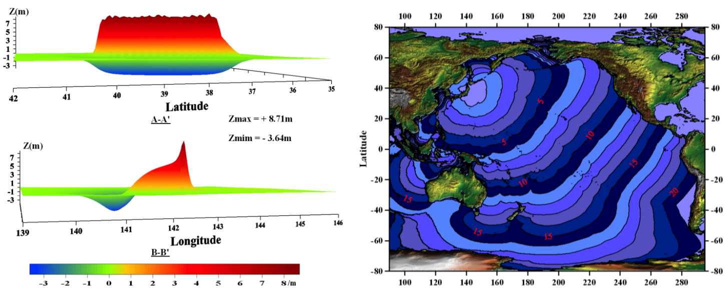

Fig. 9. The tsunami simulation of Tohoku earthquake on the Chinese coast

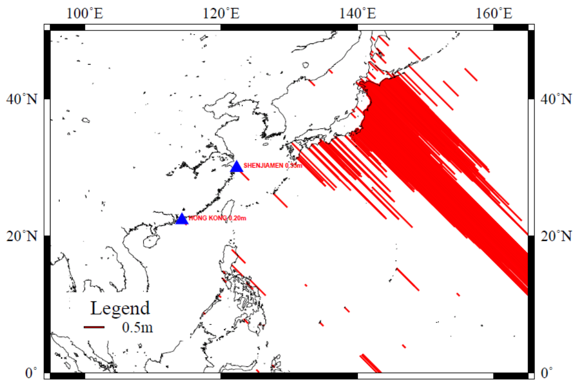

Fig. 10. Observed max wave height around Japan and China (Source: NOAA website).

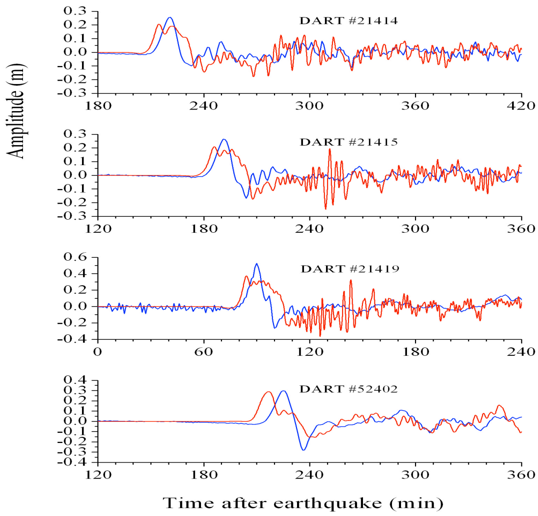

Fig. 11. Comparison between observed (blue line) and simulated tsunami wave (red line).

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Mega-Seismic Risk and Multi-Geological Disasters in Taiwan

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Taiwan has been highlighted by the National Units as one of the highest risk of death in the world (Fig. 1). The reason is obvious not only because Taiwan is located at the place where natural disasters occur very frequent, but also because the population density in Taiwan is also ranking on the top in the world. A variety of natural disasters including earthquakes, typhoons, landslides, flood and debris flows strike Taiwan every year. Some of them had made strong economic and social impact in Taiwan. For example, the 1999 Chi-Chi earthquake (Ms=7.6) killed more than 2,400 residents and the Hsiaolin landside caused 474 casualties when the Typhoon Morakot passed through Taiwan in 2009.

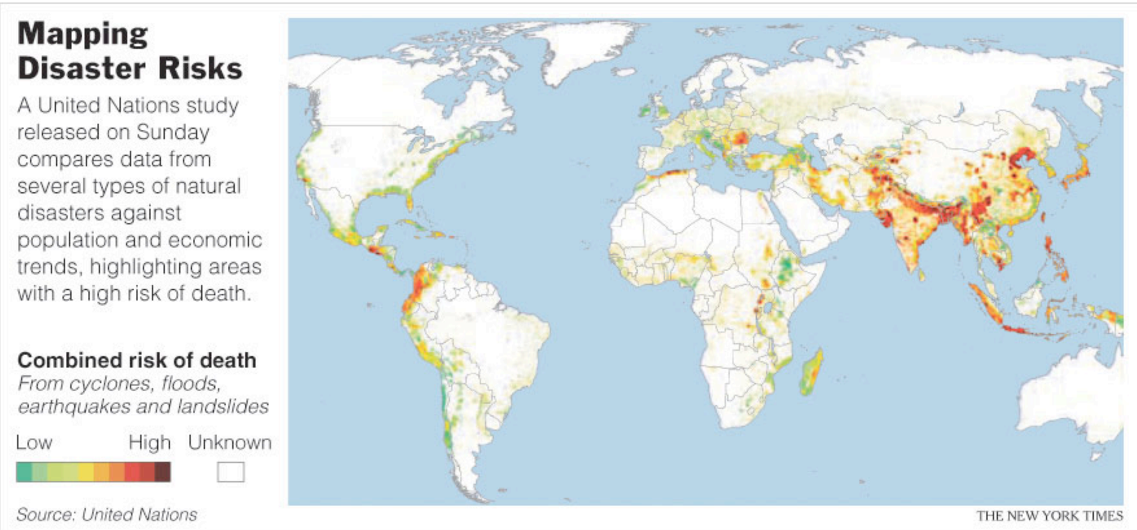

Fig. 1. Natural disaster map in the world.

In addition to those disasters happen in the past, some of potential threaten by tsunamis, volcanoes or even other multiple-geological disasters can't be totally excluded in the future. Since Taiwan is situated along the western part of the circum-Pacific "Ring of Fire", large earthquakes and submarine volcanoes in or around Taiwan might generate significant tsunamis and/or inducing other disasters. Thus, it is without any question that a sequence of multiple-geological disasters might threaten Taiwan in the future. One of the most typical examples maybe similar to the impact by the 311 Japan Earthquake (Ms=9.0) in 2011. A terrible multiple-disasters including earthquakes, tsunamis and nuclear disasters hit Japan badly.

From the seismic hazard point of view, there are two types of potentially catastrophic impacts in Taiwan (Fig. 2). One is the large earthquakes (Ms = ~7) in and around the Taipei basin (Fig. 2a). The most possible case is an earthquake occurring along the Shanchiao fault, which is located at the western margin of the Taipei basin (Fig. 3). If such an earthquake really occurs one day, strong seismic waves could directly destroy many buildings or public structures in that the earthquake is so closed to the metropolitan area. The other catastrophic impact is the mega earthquake (Ms = ~8) taking place in the subduction zone along the Ryukyu trench (Fig. 2b). Although the subduction earthquake might occur at some depths and have distances from the Taipei basin, strong shaking might still be generated due to both basin effect and site amplification.

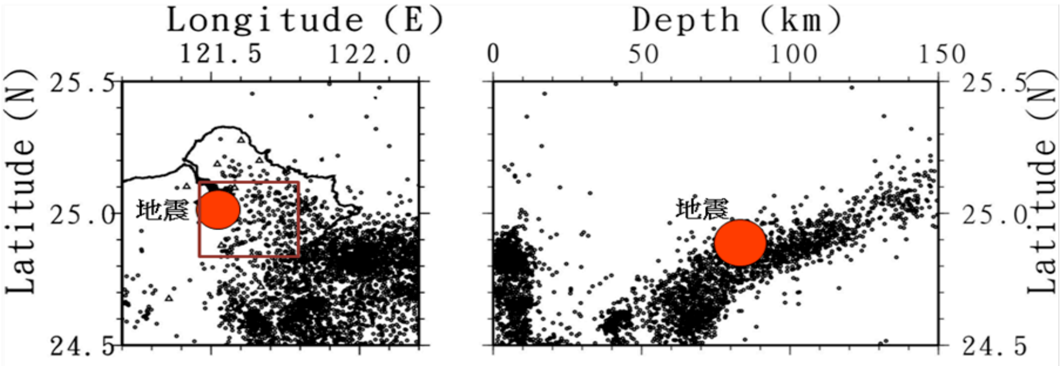

Fig. 2. Two types of mega-seismic risk in northern Taiwan. (a) large earthquakes (red circle) occurr along the Shanchiao fault and (b) mega-earthquakes (red circle) take place in the Ryukyu subduction zone.

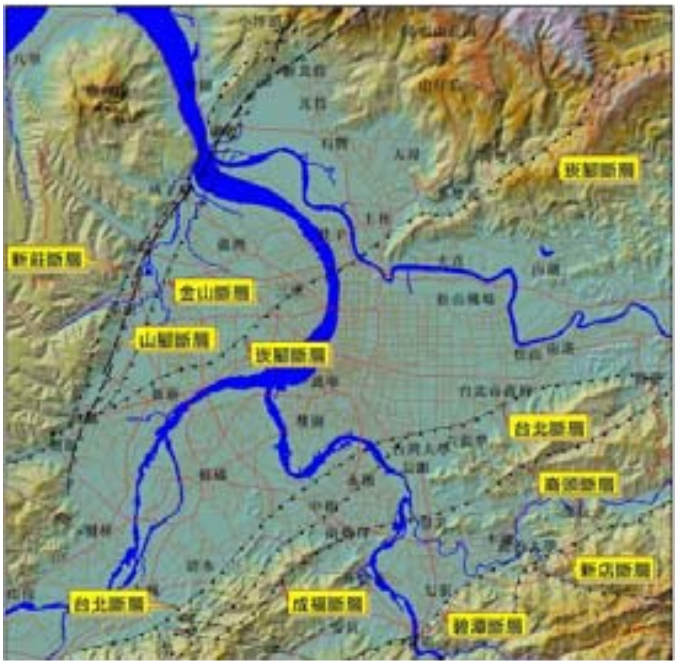

Fig. 3. The Shanchiao fault along the western boundary of the Taipei basin.

To prevent and mitigate potentially natural disasters in the future, we plan to establish different kinds of real-time monitoring system for issuing possible threaten by multiple geological disasters such as earthquakes, tsunamis, landslides and submarine volcanoes. Although it is still very difficult to predict the occurrence of most natural disasters such as earthquakes and landslides, the triggered disasters might be prevented or reduced if the original event (disaster) can be detected in real-time (Fig. 4). For example, early determination of the mega-earthquake parameters might provide useful information to prevent the possible impact by seismic, tsunami or other disasters triggered later. Also, rapid detection of large landslides in the mountain area is useful to issue some warnings for the downstream areas. A possible disaster sequence in Taiwan might start from a typhoon with heavy rainfall, followed by landslides which block rivers in mountainous terrain and eventually cause fatal floods after collapse of landslide dams. Therefore, we will establish some early warning systems for possible seismic impact, tsunamis and downstream debris flow/floods in this project for providing useful information to the government as well as the public.

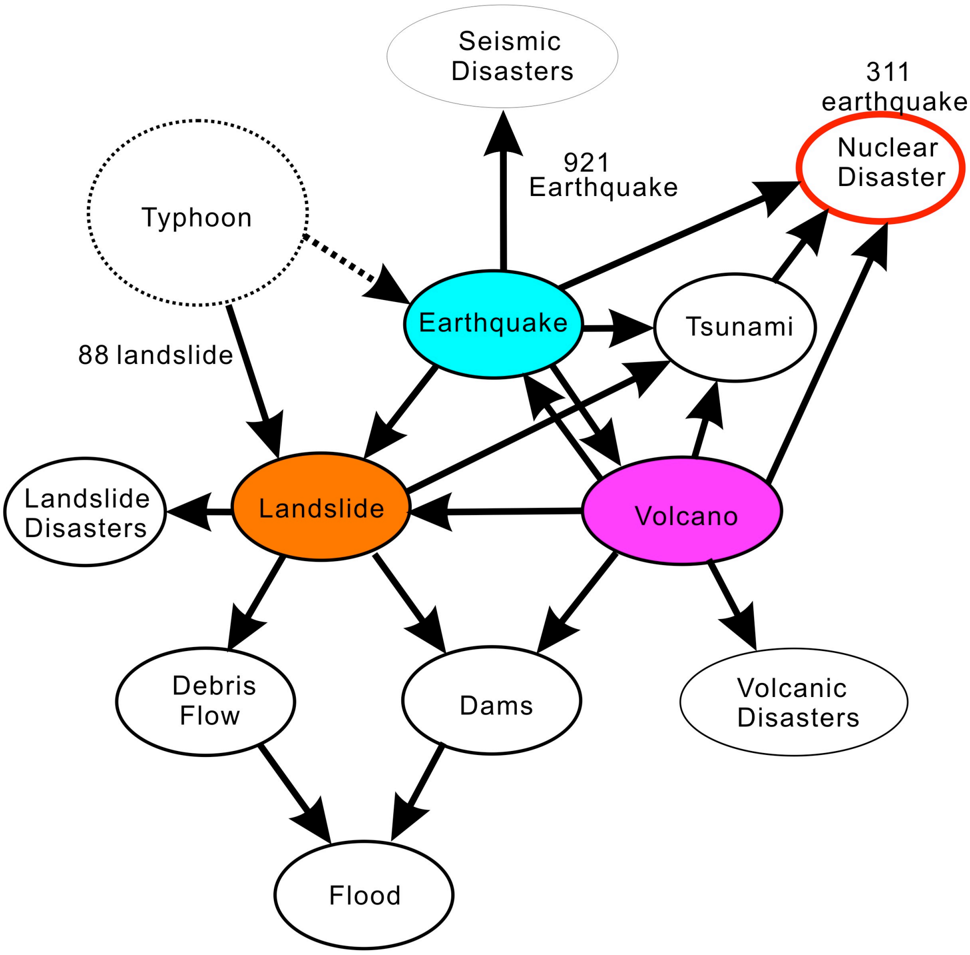

Fig. 4. Potentially geological disasters and multiple interaction among them.

In the meanwhile, we will simulate seismic ground-motions in the metropolitan area as well as possible tsunamis along the coast under the detailed evaluation of the potential mega-earthquake in subduction zones in and around Taiwan. Those results will provide the government as well as the public to evaluate possible seismic risk and other geological impacts in Taiwan, particularly in the metropolitan area such as Taipei.

Present and future of earthquake disaster mitigation and risk assessment in Vietnam

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1. Current situation

Regardless the fact that Vietnam sits outside any of the Pacific plate boundaries, two earthquakes of magnitude 6.7 have occurred during the 20th Century in the northwestern part of the country, while offshore Vietnam, a volcanic earthquake of magnitude 6.1 was recorded in 1923. There is a growing understanding in the country of the active faults in the territory of Vietnam and the adjacent sea area, which indicates that they may generate as large earthquakes as any that occurred during 20th Century. A comprehensive catalog compiled for 1900 onwards shows a high seismic activity in the northern part (inland) and in the central part (offshore) of the country (Fig. 1).

Earthquake has been studied in Vietnam since the last 60's of the 20th Century. Vietnam has established the national seismic network since 1923 with the first station installed in Phu Lien, North Vietnam. However, only after 1975, with synchronic operation of 5 seismograph stations, all earthquakes occurred in Vietnam can really be determined instrumentally. At present, after more than 80 years of development, the national seismic network now consists of 30 stations, capable of recording all events of magnitudes exceeding 3.0 in the North Vietnam and exceeding 4.0 in the whole country. The national network plays important role in providing seismic data for seismic zoning, seismic hazard assessment, seismic risk analysis and loss estimation antiseismic design for many areas throughout the country. However, due to the sparse distribution of strong ground motions and broad band seismic stations, the network needs to be upgraded to detected small, local events in remote areas for urban seismic safety and detail engineering purposes.

The five-decade history of earthquake hazard assessment in Vietnam can be divided into two periods, which reflect two different approaches on methodology used: the deterministic and the probabilistic ones. During the first period (1968-1985), deterministic methods were used for quantitative assessment of seismic hazard, with a widely recognized at that time assumption that, for a certain region, there exists an "average" seismic regime, which is constant during a long, geologic period of time. Results were presented in the form of various maps, showing spatial distribution of parameters of the seismic regime such as seismic activity, seismic shakeability, etc. The most typical maps of this period were seismic zoning maps. The weaknesses of deterministic approach are well understood, and it has become accepted that a probabilistic one should be preferred for seismic hazard assessment in Vietnam. The second period (1985 up to 1999) characterized by a remarkable change, with the use of probabilistic methods in all stages of seismic hazard assessment process. Such statistical methods as Gumbel's extreme-value distributions, maximum likelihood method have been used for estimation of the hazard parameters of source zones. The Cornell-McGuire method has been used for compute probabilistic seismic hazard maps for Vietnam in terms of peak ground acceleration for a given probability level.

From the beginning of the 21st century, a new research direction called neo-deterministic method with return of deterministic approach of SHA appears in Vietnam, characterized by scenario-based assessment method and with the use of advanced technology including GIS. The results of SHA in Vietnam reflect the progress and advantages of the World science and play important role in the National strategy of seismic risk management and hazard mitigation. While Probabilistic SHA can be used appropriately for mid-term to long-term hazard predictions, the neo-deterministic approach gives reasonable results in analyzing risk and loss estimation at urban scales.

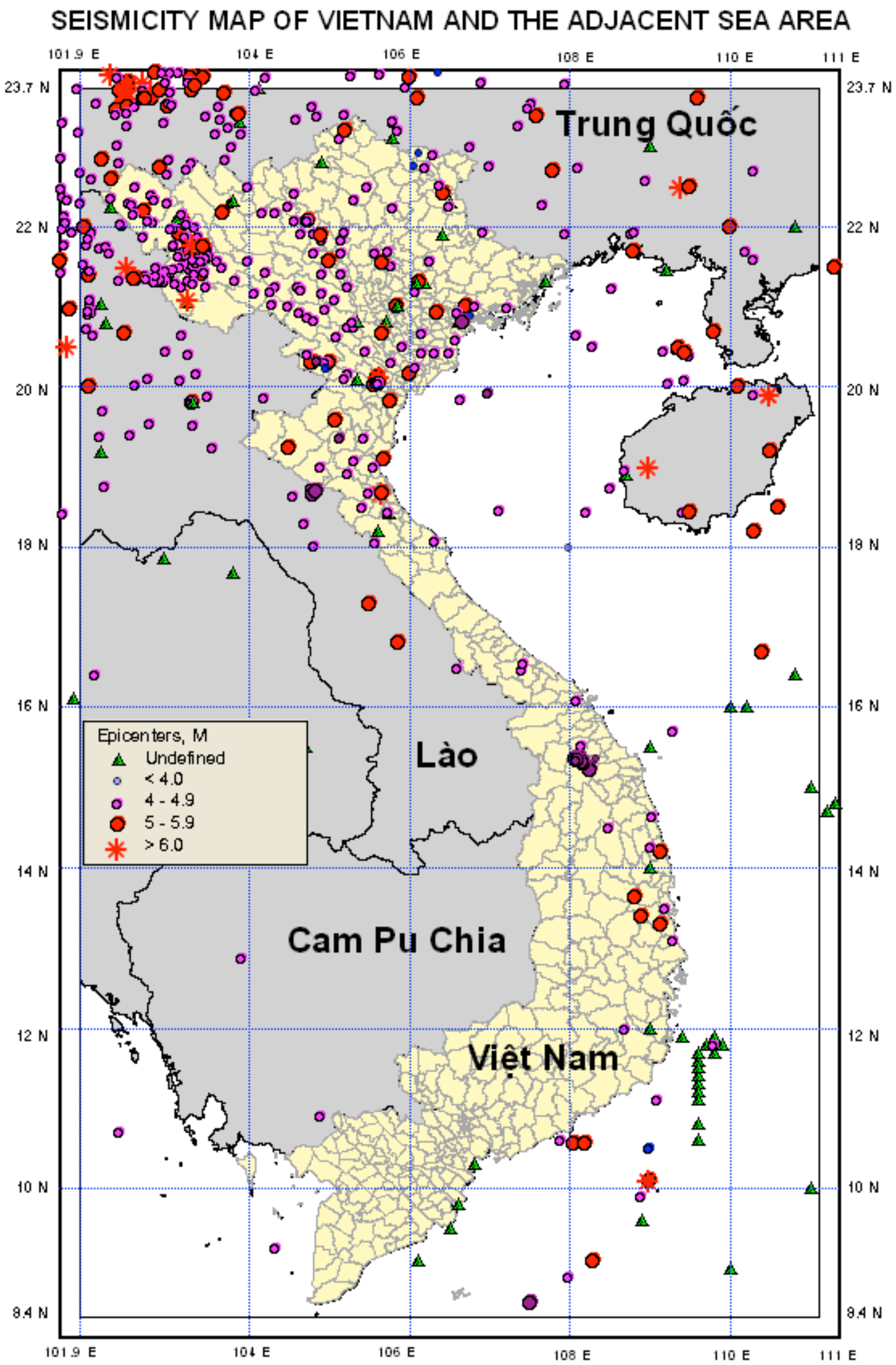

Fig. 1. Seismicity map of Vietnam and adjacent sea area.

2. Existing problems

The explosion of industrial and infrastructure development and other social-economical activities in the country recently have revealed some problems of earthquake disaster mitigation and risk assessment in Vietnam that need to be addressed. Among the existing problems, the most principal are:

- Un-uniform and sparse distribution of seismic stations of the national seismic network in Central and Southern parts of the country in many cases leads to the omission of small earthquakes;
- Lacking of experiences and appropriate methodology in such specific cases as evaluation of hazard due to reservoir's induced seismicity or seismic risk assessment for nuclear power plants.

3. Future plans

The following actions are required for Vietnam in the near future:

- *To heighten public awareness of earthquake risk:* In order to have readiness both spiritually and materially against the risk, education and training should be carried out at many levels, in different forms. In addition to the community education, convincement of the governmental authorities of earthquake risks and hazards is as well crucial.
- *Enhancement of collaboration among the institutional bodies and organizations who have interests in and/or functional responsibilities for earthquake risks & hazards management:* While in the country, currently related organizations are almost operating within their respective specialized fields and in isolation from each another. There seems to be an incomplete communication and interaction among seismologists, geophysicists, civil engineers and specialists, and the community. It is obvious that the development and implementation of any action plan for risk mitigation and management could not be efficient without close collaboration among the respective organizations.
- *Enhancement of international cooperation with research institutes and related organizations in the Asia-Pacific region on seismic and volcanic disaster prevention* to share information and experiences on seismic and volcanic disaster prevention and to build the international standard for the database, data exchange and disaster risk assessment.
- *Strengthening of the related organizations' capabilities:* This work would include investment to upgrade the facilities, infrastructure, training of specialists, encouragement of the research projects in earthquake hazard assessment and loss estimation, earthquake risk management etc. Efforts and works in strengthening the organizations' capabilities will also aim to continue and complete all the works that have not yet been achieved, such as upgrade and enhancement of the national seismic network.

Current and Planned Earthquake and Volcano Disaster Risk Reduction Initiatives in the Philippines

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The Philippine archipelago is prone to earthquakes, tsunamis and volcanic eruptions due to its geotectonic setting. It has been affected by around 90 damaging earthquakes, 40 tsunami events and around 170 volcanic eruptions in the past 400 years. Some of these events have brought significant loss of lives and impact to properties and the economy. With the increasing exposure and vulnerability of the country due to rapid increase in population and urbanization, it is crucial that disaster risk reduction efforts must be integrated and should involve the whole of society. The Philippines has recently taken a participatory, vulnerability reduction and development approach to disasters, emphasizing the importance of preparedness, prevention and mitigation actions. The end goal is to make communities safer from and resilient to various types of hazards.

In line with the new approach to disaster risk reduction (DRR) in the country, the Philippine Institute of Volcanology and Seismology (PHIVOLCS) has current and planned volcano, earthquake and tsunami DRR initiatives to achieve outcomes related to accurate prediction and simulation of geologic phenomena, provision of accurate and timely warning and information, development of cost-effective monitoring and warning systems, empowerment of partners to lead in reducing risks from geologic hazards down to village levels, and increased collaboration with scientific and DRR partners and stakeholders. The strategic initiatives cover development and improvement of volcano, earthquake, and tsunami monitoring and warnings systems, hazards and risk assessment, research on eruption and magmatic history of magmatic systems and on earthquake and tsunami generation potential, and the development and application of tools, models and information materials for public awareness, preparedness and disaster mitigation.

PHIVOLCS monitors 8 out of the 23 active volcanoes and efforts are currently focused on improving and developing multi-parameter and integrated real-time volcano monitoring. PHIVOLCS also operates a 69-station seismic network and plans to set up additional 16 seismic stations within the next three years. Community tsunami monitoring and warning systems for local tsunami detection and warning have been established in 3 bays, with additional 7 areas planned to be covered within the next three years. PHIVOLCS plans to set up real-time sea level gauges in key coastal areas in the country to serve as a backbone for its national tsunami monitoring and warning system.

Improvements in the country's volcano, earthquake and tsunami monitoring and warning systems are being done with support from national government and international partners. PHIVOLCS and several research institutions from Japan led by the National Institute for Earth Science and Disaster Prevention are implementing a project "Enhancement of Earthquake and Volcano Monitoring and Effective Utilization of Disaster Mitigation Information in the Philippines" under the Science and Technology

Research Partnership for Sustainable Development (SATREPS) Program of the Japan International Cooperation Agency (JICA) and Japan Science and Technology Agency (JST). The 5 year project from 2009-2014 focuses on 1) improvement of real-time earthquake monitoring through advanced source analyses, intensity observation and rapid information of earthquake parameters and intensity distribution, 3) improvement of tsunami monitoring and warning, 3) evaluation of earthquake generation potential through GPS and active faults studies, 4) development of real-time integrated volcano monitoring for Mayon and Taal volcanoes, and 5) to provide disaster mitigation information and promote its utilization among national organizations, local government units, businesses, communities and the public. Augmentation of multi-parameter observations in Mayon, Taal and Kanlaon volcanoes have been promoted by recent research partnerships with the Earth Observatory of Singapore, partners of the Electromagnetic Studies on Earthquakes and Volcanoes (EMSEV), and partners of the EU project Mitigate and Assess Risk from Volcanic Impact on Terrain and Human Activities (MIA VITA), respectively.

Crucial to the appreciation of the warning and information messages for immediate public response or for collective disaster risk management actions would be the assessment of hazards and risks posed by various natural events. PHIVOLCS has been conducting hazards assessment and mapping activities at various scales for volcano, earthquake and tsunami events. PHIVOLCS and other national government agencies have also been improving multi-hazards maps in many provinces in the Philippines, as supported by other international partners such as Australian Agency for International Development (AusAID) and United Nations Development Programme (UNDP). To date, 27 provinces have been covered and additional areas are being studied. An ongoing effort that seeks to scale up previous hazards mapping activities to risk assessment efforts is the multi-hazards Risk Assessment Project in Greater Metro Manila, which is a partnership with Geoscience Australia. PHIVOLCS has developed a hazard and impact assessment software, the Rapid Earthquake and Damage Assessment System (REDAS), which is being distributed for use by local governments, national agencies and other DRR partners as a tool for hazards and risk evaluation and development of scenarios as inputs to contingency planning and more importantly land use and development planning. Although this was originally intended for modelling hazards from earthquakes and assessing impacts, the software can be used a multi-hazard tool as static maps of various hazards from PHIVOLCS and other mandated organizations can be incorporated. More than 40 provinces and several national organizations and academe partners have so far been trained in the use of the software.

Translation of hazards assessment into risk assessment entails understanding of the recurrence and scale of anticipated events and requires availability of exposure and vulnerability information of communities but these data are not commonly available. Hence, efforts by national agencies, local governments and the academe are needed in acquiring these. PHIVOLCS is actively developing databases on active faults, subsurface geology, landslides, tsunamis and volcanoes. To aid local governments in developing a systematic database of various elements exposed to hazards in their areas and in order to have a similar data base all over the country, PHIVOLCS developed, through partnership with GA, an Exposure Database Module, which has recently been appended as part of the

REDAS software. Training of local governments, national agencies and academic partners on how to acquire exposure data and use the exposure data base module is on-going.

Strategy on Volcanic and Earthquake Hazards Mitigation in Indonesia

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Indonesia lies within the collision of three plate tectonics, Indo-Australia, Eurasia and Pasific. As the result, despite the country is enriched with abundant of mineral resources, prosperous land and also decorated with beautiful natural landscape, it also put Indonesia actually prone to geological hazard such as volcanic eruptions and earthquakes. Millions of Indonesian living nearby active volcanoes and in earthquake hazard zones. It is obvious that the strategy on both volcanic and earthquake hazard mitigation is needed.

Center for Volcanology and Geological Hazard Mitigation (CVGHM) of Geological Agency monitors all active volcanoes in Indonesia. The volcanoes are equipped with at least 1 seismometer installed at their flank. The seismic data are transmitted to observatory and head office in Bandung. Some methods such as geochemistry, geophysics and geology surveys are also carried out to support monitoring system. In order to reduce risk due to volcano eruption CVGHM issues early warning system based on instrumental and visual data. The early warning system is defined into 4 alert levels. Level I, it means the activity of the volcano in normal no indication of increasing activity. Level II, the activity tends to increase, though at some volcanoes eruptions may have occurred but threaten only the area around the crater. Level III, if the trend of increasing unrest still continues and eruption may have occurred. At some volcanoes eruptions have occurred but no threatened to inhabitant area. Level IV, when the initial eruption begins to occur as ash/vapor and potentially lead to main eruption, and threaten people living nearby. Aside from alert level, CVGHM also provides volcanic hazard map as a guidance and socialization to people living nearby the volcano.

As for earthquake hazard mitigation CVGHM provides earthquake hazard maps across the country in province scale. The hazard map is created using PSHA methods and developed on EQRM program. The hazard zone is divided into 4, very low earthquake hazard zone, low, moderate and high, respective.

Japanese Coordinating Committee for the Prediction of Volcanic Eruptions: Its organization, role, and activities during the volcanic crises

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As there is no centralized authority such as INGV of Italy and PHIVOLCS of Philippines, Japanese CCPVE (Coordinating Committee for the Prediction of Volcanic Eruptions) plays a major role in judging the on-going activities and forecasting the possible transit of volcanic activity during the volcanic crises, and advises the Japanese Meteorological Agency (JMA) which is an official agency issuing volcanic information and alert. The CCPVE is not a governmental organ, but a private advisory organ of the Director General of the JMA having an ambiguous responsibility and authority.

The CCPVE consists of the representatives of the university volcano observatories, research institute, experts of different disciplines of volcanology, and representatives of administrative organizations in charge of disaster prevention such as the MEXT and the Cabinet Office.

The CCPVE originated when 1st National Plan for the Prediction of Volcanic Eruptions (NPPVR) was formulated in 1974. NPPVR is a 5-year program aiming an establishment of methods to predict the volcanic eruption through detection of magma migration, and has been revised every 5 years until present. Because the monitoring system of the university volcano observatories was not sufficient, the attempt of NPPVR in the early stages was improvement of the monitoring system of the university volcano observatories. Usu Volcano Obsevatory and Izu Oshima Volcano Observatory were established and the facilities of the other observatories have been enhanced by the NPPVR.

The mandate of the CCPVE established by the NPPVR is to:

1) exchange information on the results of studies and works by related institutes and organization; promote research on volcanic eruption prediction; and develop technologies at each institute;
2) during volcanic crises, make comprehensive judgments on the phenomena of eruption and improve the quality of information about the status of volcanic activity, thus contributing to disaster prevention; and
3) comprehensively investigate measures for enhancing system for studying volcanic eruption prediction and monitoring.

During the volcanic unrest or crisis, comprehensive mobile observation team composed of researchers from universities and research institutes, and staff of JMA is to be formed under CCPVE to understand changes in volcanic activity, establish new observation points, and conduct mobile observations. The results of the mobile observations are to be reported to the CCPVE. The expenses of the members of the comprehensive observation team are, however, covered neither by CCPVE nor by JMA, but are covered by the institutes to which the members belong. Before 2004, the staffs of the universities and the research institutes used to be government employees, and the government was responsible for their accident; however, they are not government employees anymore as the national universities and the research institute were reformed to the independent agencies in 2004 and 2001, respectively. Since then, the institute dispatching the team member will be responsible in case of accident. The comprehensive mobile observation team is responsible for monitoring and collecting data, which are indispensable for predicting the progress of volcanic activity during eruptions. Although team members may have to expose themselves to danger, their legal security is not covered by CCPVE but must be covered by the institutes to which they belong. This is because the CCPVE is a private advisory organ of the Director General of the JMA, which has no legal responsibility or authority over the CCPVE, although it serves as a head office for the CCPVE. Luckily, no accident has occurred since the establishment of CCPVE, mainly because only small-scale eruptions have occurred these days.

Unlike earthquake prediction, for which there is a government authority called the Headquarters for Earthquake Research Promotion, there is no government body for volcano research and evaluation of volcanic activities. The CCPVE is the sole organization that evaluates volcanic activity and predicts activity progress on the basis of monitored data. Radical strengthening of disaster prevention organizations is essential as volcanic activity is expected to intensify in the near future. Particularly, CCPVE should be an official organization of the government instead of being a private advisory organ. Also headquarters in charge of promotion of the research on the prediction of volcanic eruption, such as Headquarters for Earthquake Research Promotion, should be immediately established al least. Under such headquarters, the government should be responsible for unifying related ministries and agencies and preventing volcanic disasters. Ideally, a centralized authority such as a Volcano Agency should be created to monitor, assess and, study volcanic activity, and issue volcanic information and alert.

Strategy for evaluating volcanic activity and mitigating hazards

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Predicting volcanic eruptions and mitigating volcanic hazards are important tasks, especially for many countries with volcanoes. This article introduces our scheme to evaluate volcanic activity using observation networks, databases, and numerical-simulation techniques (Fig. 1). Our purpose is to effectively detect abnormal volcanic activity and estimate hazards.

V-net & detection of abnormal signals

NIED operates V-net, a real-time volcano monitoring network used for both academic research and civil service through JMA, which is responsible for monitoring and issuing warnings and alerts. We are installing 4 to 6 observation stations at 11 volcanoes, and each station is equipped primarily with 1Hz seismometers, a tiltmeter in a 100 to 200 m deep borehole, a broadband seismometer, and GPS. For these on-line data, we calculate the ratios between short-term and long-term perturbations for each kind of data at each station. We examine the observation data at each station whether the activity is normal or abnormal, and if the number of abnormal stations exceeds a threshold, we consider the volcanic activity as "unrest." In this process, it is important to determine whether the unrest signal is from a volcanic source or a non-volcanic source. For example, a tiltmeter in a borehole is highly sensitive (10^{-8} radian), therefore, ground deformation due to subsurface water flow after a heavy rainfall is also detected as a unrest signal. The noise can be rejected by accumulating data over a long term and by the majority rule for judgment by multiple data sources and stations.

The next step is to identify the location, size, and geometry of the active source. We apply the most simple inversion technique using a Mogi source (Mogi, 1958) and/or Okada model (1992) to the ground deformation data to obtain the source model. This inversion is updated with respect to the change of unrest data, and we can follow the source movement, which suggests a subsurface magma migration.

Numerical simulation of volcanic phenomena

From the observational point of view, we can detect unrest signals as discussed above, but it is actually difficult to recognize and to predict the forthcoming activity precisely, since we do not have comprehensive and rigid models for investigating volcanic-eruption mechanisms. Volcanic activity is caused by magma dynamics. This is a multi-phase phenomenon combining gas, fluid, and solid phases as important factors in characterizing eruptions, and theoretical models for both micro- and macro-scale phenomena are widely employed (Fig. 2). Numerical simulation is an effective tool for modeling these complicated multi-phase and multi-scale phenomena. The modeling is roughly classified into two categories: (a) subsurface magma dynamics like dike migration and conduit processes, and (b) ground phenomena like lava flow, pyroclastic flow, ash plumes, and lahars. Category (a) is used for predicting volcanic eruptions, and category (b) is applied for evaluating volcanic hazards.

Subsurface magma dynamics (a) is the most significant property for defining thresholds, for example, eruption/failed eruption and explosive/non-explosive. These simulations give us quantitative implications, for example, how the dike intrusion process is controlled by the regional stress field and viscosity. However, the modeling for these magma dynamics is complicated. Recent trials to build a regime map for conduit flow (e.g., Kozono and Koyaguchi, 2012) provide clues for determining how to predict eruptions.

Numerical simulations for surface phenomena (b) directly reproduce the volcanic hazard and yield useful information for risk mitigation. Recently, we can use these numerical simulation tools via the web at VHUB (vhub.org). TITAN2D (Pitman et al, 2003; Patra et al, 2005) is a standard tool for evaluating granular flows like pyroclastic flows and is utilized for preparing hazard maps at some volcanoes. Beside these tools, scientific simulation code to reproduce the detailed dynamics of lava flows, ash falls, etc. have also been studied and proposed.

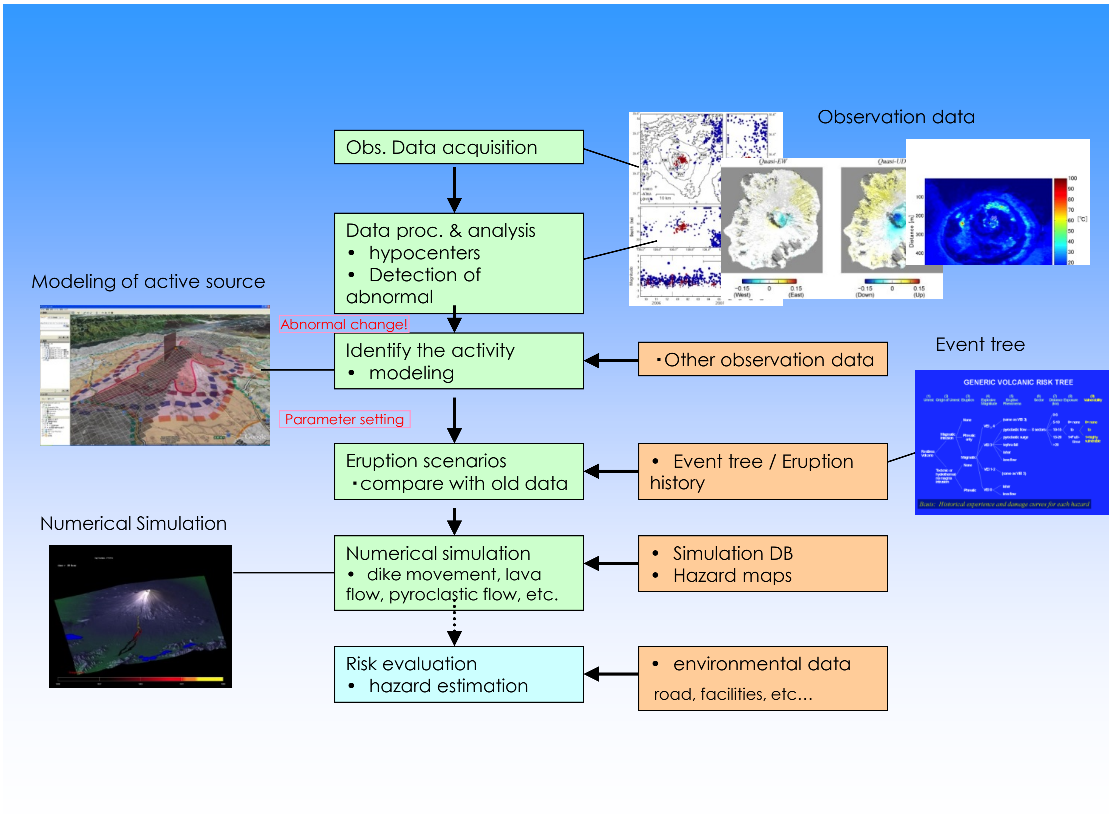

Fig. 1. Flowchart from volcanic data observation to disaster and risk evaluation

Integrating observations, databases, and numerical simulations into an event tree for volcanic hazard evaluation

For both risk and crisis management of volcanic disasters, the event tree (Newhall and Hoblitt, 2002) is used to evaluate and predict volcanic activity from many possibilities. At each node of this event tree, experts and authorities discuss the possibility of each branch and decide measures, sometimes including a probabilistic approach (e.g., Garcia-Aristizabal et al., 2012). However, we do not have enough experience to make decisions at each node of the event tree. Therefore, the database should be consolidated to give us much contribution. The observation data and numerical simulation discussed above can also be included in this scheme, and we would achieve a new volcanic risk and crisis management capability.

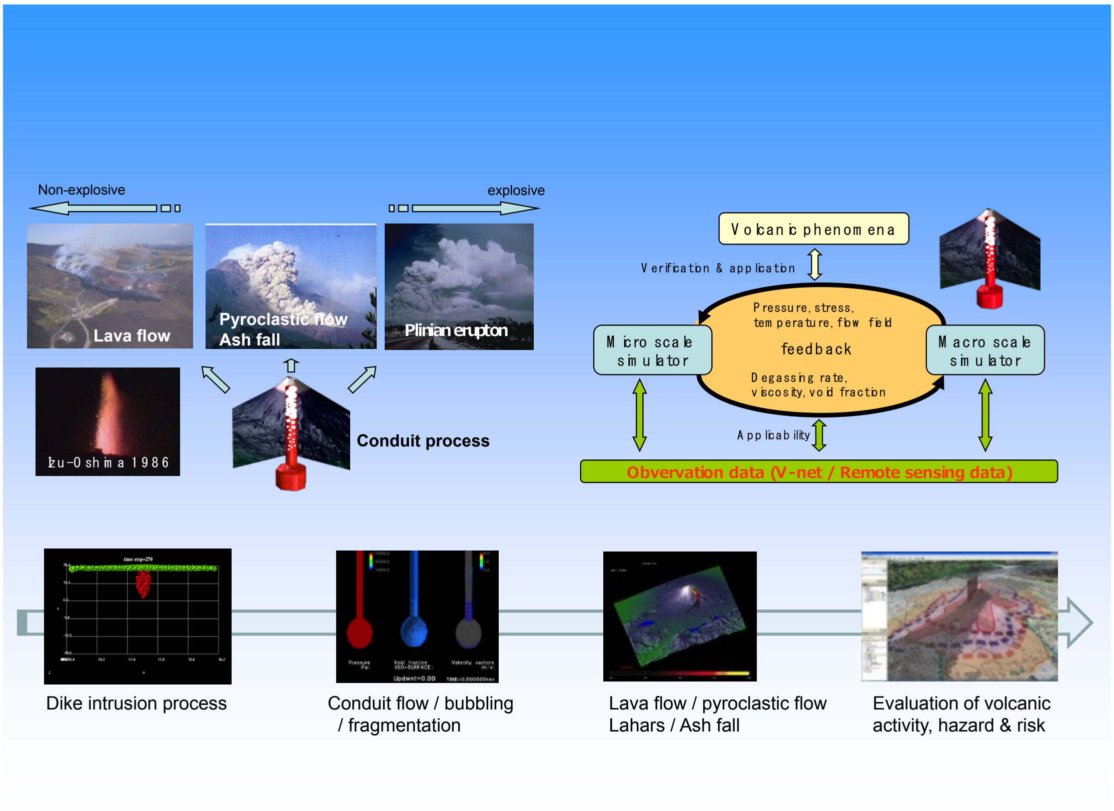

Fig. 2. Application of numerical simulation to volcanic phenomena

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Numerical simulations of volcanic eruptions: multiplicity, instability and predictability

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Volcanic eruptions of high-silica gas-saturated magmas occur in a wide range of regimes from slow extrusion of lava domes to highly energetic Plinian eruptions. Transition between these regimes can occur suddenly with minor precursors and lead to enormous variation in magma discharge rate.

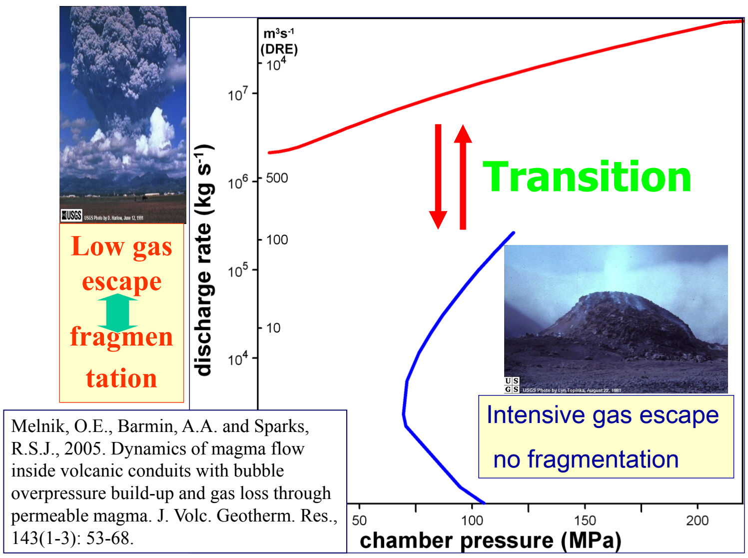

Fig. 1. Transition between explosive and extrusive eruptions.

Starting from Slezin (1984), Barmin and Melnik (1993) and Woods and Koyaguchi (1994) it was found that for the same parameters of magma in a magma chamber there can be up to three steady-state regimes of eruptions with different intensities. High intensity regime corresponds to en explosive eruption whereas in low intensity regime magma ascends without fragmentation leading to extrusion of lava domes. Main mechanism responsible for the presence of multiple regimes is gas separation from the magma during ascent. When magma ascends slowly gas can escape through it or into the host rocks and no fragmentation occurs (Fig. 1).

In Melnik and Sparks (2002) a transient evolution of explosive eruption generated by a lava dome collapse was studied. It was found that depending of the intensity of diffusive volatile mass transfer between growing bubbles and the magma total erupted volume can vary within an order of magnitude or more. The controlling parameter here is a number density of bubbles. This parameter is very difficult to estimate or measure during an eruption. Thus, accurate forecast of eruption intensity evolution during the eruption seems to be intractable problem.

Melnik and Sparks (1999, 2005), Costa et al. (2007), Melnik and Costa (2013) showed that multiple steady-state regimes are also present during extrusive eruptions leading to magma discharge rate variations within several orders of magnitude. These variations are caused by non-equilibrium degassing induced crystallization that leads to rheological stiffening of the magma at high crystal content. Periods of discharge rate variations are of order of weeks to decades (Fig. 2) depending on the architecture of magmatic system of a particular volcano. During periods of high extrusion rate a transition to explosive eruption can occur.

Shown above examples demonstrate that volcanic system is highly non-linear and has many attractors in multiparametric parameter space. Its evolution can result in complex patterns of behavior. When the system is near cusps points small variation in the governing parameters can lead to large variation in magma discharge rate and, thus, in eruption hazard.

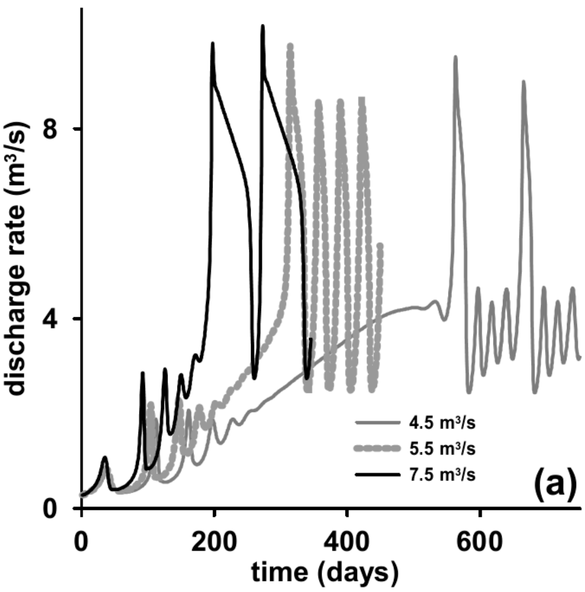

Fig. 2. Variation in discharge rate during extrusive eruption

With large uncertainties in our knowledge of governing parameters of volcanic systems ensemble type of modeling is the only way to produce probabilistic forecast of volcanic hazard evolution during an eruption. This method is widely used in weather forecasting but in comparison with atmospheric processes volcanic systems are less studied and provide mostly indirect information on subsurface processes. There are no well-calibrated models for particular volcanoes nowadays. Models that can correctly reproduce all multiparametric observations such as ground deformation, seismicity, gas and gravity measurements, extrusion rate and others are still remain an unreachable goal for volcano modeling community. A lot of research must be done before we are able to forecast volcanic weather with an accuracy of forecasting atmospheric processes.

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Can we evaluate a potentiality of caldera-forming eruption?

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Some volcanoes cause a caldera-forming eruption after a long low activity stage accumulating magma. The frequency of such an eruption is very low. However, a caldera-forming eruption, erupted volume~ 10-1000 km^3, causes huge global damages including climate change as well as direct ones. Indonesia was suffered unfortunately from a caldera-forming eruption twice for the last 200 years, and three times within 1000 years (Fig.1). We learned various experience and geological examples for caldera-forming eruptions in Indonesia. Can we evaluate a potentiality of future caldera-forming eruption using this knowledge?

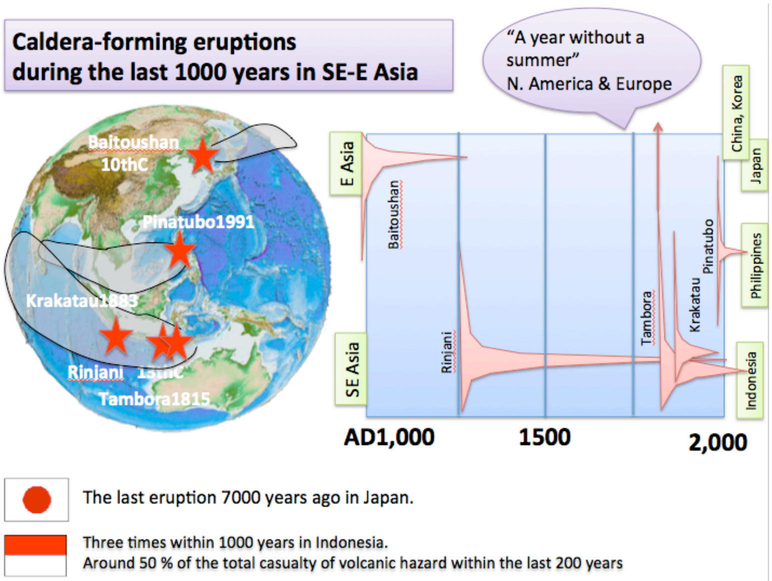

Fig. 1. Caldera-forming eruptions during the last 1000 years in SE-E Aisa.

We have a cooperation project of GSJ and CVGHM to study the eruptive histories of caldera volcanoes, such as Tambora (Takada et al., 2000; Yamamoto et al., 2000; Matsumoto et al., 2000), and Rinjani (Takada et al., 2003; Nasution et al., 2003; Furukawa et al., 2004), Batur and Bratan voclcanoes (Furukawa et al., 2012), volcanoes in Bali and Tengger area, East Java (Toshida et al., 2012) (Fig. 2). Some volcanoes caused a caldera-forming eruption multiply. There are three stages evolving into the first caldera-forming eruption (Fig.3). (1) Shield or stratocone stage (green in color in Fig. 3): Volcanoes built a large shield or stratovolcano with a high eruption rate before a caldera forming eruption. It takes more than 100,000 years generally to complete the shield or stratocone. (2) Dormant low activity stage (yellow in color in Fig. 3): During the last 50,00-10,000 years before caldera formation, the eruption rate decreased; eruption style changed to more explosive; chemical composition changed (Fig. 4). (3) Precursory stage to caldera-forming eruption (orange in color in Fig. 3): There occurred unusual wide-range hydrothermal activity with small explosions and an increase in earthquakes during the last a few months, according to Krakatau 1883 eruption and Pinatubo 1991 eruption, which are compiled by Takada (2010).

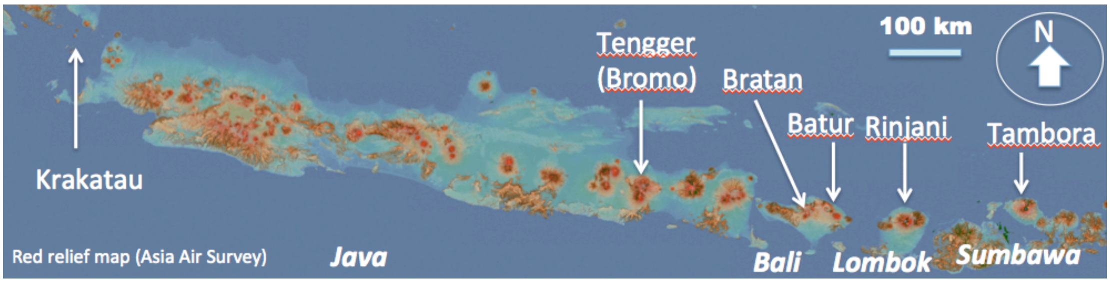

Fig. 2. Location of the studied volcanoes with caldera.

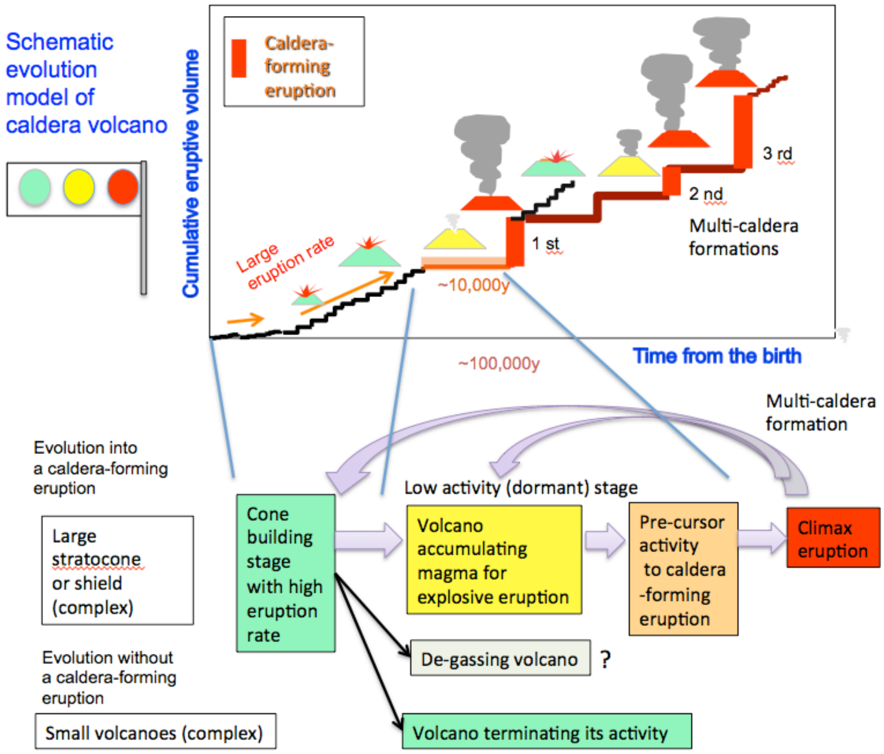

Fig. 3. Schematic evolution of a volcano into caldera formation (upper), and typical stages (lower).

We try to pick up possible volcanoes evolving into a caldera-forming eruption using the characteristics of stages (1) and (2). The candidates are dormant volcanoes after large stratocone building. The historical documents suggest that the activity of Krakatau volcano became dormant except one eruption during 300 years before 1883 eruption (Simkim and Fiske, 1983). The geological evidences of Tambora volcano (Takada et al, 2000) and Rinjani volcano (Nasution et al., 2003; Takada et al., 2003) indicate that a low activity stage with a few explosive eruptions preceded the climax eruptions. There are some possibilities that the geological information near the summit vent area including the deposits of small eruptions disappeared owing to the caldera collapse. However, the information near the summit just before the caldera formation of Rinjani volcano has remained on the outside edifice, because the volcano developed a stratocone outside of the caldera region before the caldera formation (Fig. 4).

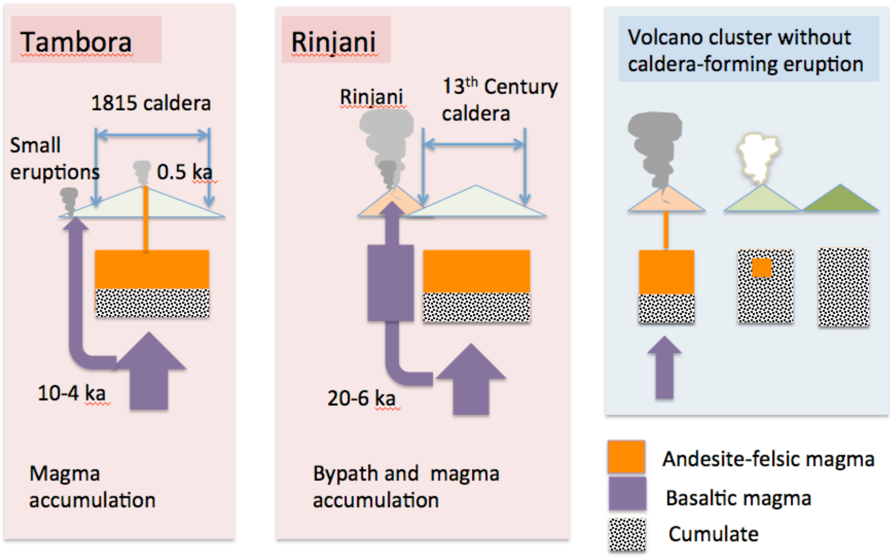

Fig. 4. Examples of low activity stage during the last 5,000-10,000 years, comparing with volcano cluster without caldera-forming eruption.

When we pick up several volcanoes satisfying the condition above, we must, however, distinguish target volcanoes accumulating magma from those terminating its activity (Fig. 3). Moreover, some volcanoes are decreasing in potentiality of eruption by continuous degassing (Fig. 3). The degassed magma is accumulating in the magma reservoir (Kazahaya et al., 1994). After pick up, geophysical exploration beneath the volcanoes must be needed with long-term monitoring. The next stage is a social problem how to explain and mitigate huge hazard with an extreme low frequency like a caldera-forming eruption.

Present Situation and Issues about International Cooperation Projects of Japan for Earthquake Disaster Risk Reduction

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Preface

Author has been engaged in the international cooperation projects of Japan for earthquake disaster risk reduction of developing countries in the frame of ODA (Official Development Assistant) more than 10 years. The most of ODA projects are managed by JICA (Japan International Cooperation Agency), and the private consulting companies are operating the actual works under the contract with JICA. Author has been engaged in the projects as the staff member of the consulting company. In this symposium, I report the present situation of the actual ODA projects from the view point of the staff member in the field. The contents of this report are not reflecting the policy or intention of Japanese Government and JICA, and the opinions are responsible to the author.

ODA for Earthquake Disaster Risk Reduction

The ODA of Japan is constituted by loan aid, grant aid, technical cooperation, etc. The earthquake disaster risk reduction projects that author is involved are implemented as the technical cooperation. The total expense for technical cooperation by JICA based on the annual report 2012 is 189 billion Yen.

Table 1 shows the studied cities in the earthquake hazard/ damage assessment projects by the author. All the cities suffered large earthquake disaster repeatedly or future big earthquake damages are concerned. Also these cities have the issue relating earthquake disaster risk reduction, for example, the earthquake hazard/ risk maps are not prepared or earthquake risk management plan is not formulated.

Table 1. Studied cities and seismic environment

Year	Country	City	Property	Seismic Environment
1999-2000	Iran	Tehran	Capital	No experience of huge destructive earthquake. Several active faults exist near the city.
2001-2002	Nepal	Kathmandu	Capital	No experience of huge destructive earthquake. Seismic gap is pointed out near the city.
2001-2003	Turkey	Istanbul	Economical Center	1000 people were killed by 1999 Kocaeli Earthquake (M7.4). Large earthquake along North Anatolian Fault, just south of the city, is said to be imminent.

2002-2004	Philippine	Metro Manila	Capital	1990 Luzon Earthquake (M7.8) Large active fault exists in the city.
2005-2007	Algeria	Algiers	Capital	M6.8 earthquake occurred just east of the city in 2003. Many active faults exist along the coast of Mediterranean Sea.
2007-2010	Kazakhstan	Almaty	Economical Center	Experienced some damage by the large earthquakes at North Tien Shan Mountains in 1887(M7.3), 1889(M8.3) and 1911(M8.2).
2010-2012	Armenia	Yerevan	Capital	More than 1000 people were killed by 1679(M7.0) earthquake. 1988 Spitak Earthquake(M7.0)

Purpose and Contents of the Project

The goal of the project is to reduce the disaster due to the large earthquake which has a possibility to attack the target city. For this purpose, the seismic hazard/ damage maps are created and the earthquake risk management plan is established. Also the necessary technology is transferred for revising the maps or plans by themselves or extending to the whole country without the help from abroad.

The component activities of the projects are not same based on the situation of the target city and their needs. The components of the project in Armenia, the recent one, are shown below.

A. Seismic Hazard Assessment
   1) Seismic Analysis (Activity, Active fault trenching survey)
   2) Ground Investigation (Drilling, Geophysical survey)
   3) Geology Map Compilation
   4) Ground Modeling
   5) Scenario Earthquake Setting
   6) Ground Motion, Liquefaction, Slope Stability Assessment

B. Seismic Damage Assessment
   1) Building Survey (Inventory, Structure classification, Damage function)
   2) Bridge Survey (Inventory, Damage function)
   3) Lifeline Survey (Inventory, Damage function)
   4) Damage Estimation (Amount, Losses, Casualties)

C. Establish of the Simplified Seismic Disaster Estimation System

D. Writing of the Consequence Scenario after Earthquake Disaster

E. Earthquake Risk Management Planning

F. Prioritize the Action Plans for Earthquake Disaster Risk Reduction

G. Establish of the Real-time Seismic Intensity Distribution Information System (Strong motion recorder installation)

The counterpart organization of the project is the Disaster Management Division of national government or the city government. The Japanese team members stay in the office of the counterpart organization during the project. The period of the Armenia project was two and half years and the 80 man-months of Japanese engineer were thrown for example.

Issues of the Project

1) The experienced past earthquake damage are not compiled and kept.

The most of the target country/ city experienced severe earthquake disaster in the past. The hazard and damage due to the earthquake is the most important data for the seismic risk analysis, however very little information is available in many cases. Also, the available information is not quantitative or statistical one, eg. precise study sheets of heavily damage individual buildings etc.

2) Map Data is hard to obtain.

The map data is still classified as military secret information and it is sometimes difficult to access by foreigners, though the satellite images are easily accessible in most of the world nowadays. In many cases, map is not truly secret but the old law that regulates the secret information is not revised and diverged from the current of the times.

3) Cooperation with organizations other than counterpart is difficult.

As the seismic risk analysis relates many fields, the necessary data should be collected from a lot of relevant organizations; however the cooperation is not always available. It is not unusual to deny offering the data or to require the money even the counterpart and the asked organization are the ministries.

All the results of the projects are basically open to the public through the seminar. The reports are also open in digital but some counterpart organization buries the precise data, e.g. building inventory database.

4) Counterpart personnel can't concentrate to the technology learning.

The counterpart personnel are assigned to each Japanese member in the project and the technology transfer is carried out in OJT style. However, the selected counterpart is not fully engaged in the learning. The technology learning is the additional work to the daily routine in many cases; therefore the sufficient learning is difficult because of the overwork. Even the counterpart personnel are eager to learn, they should prefer to manage the daily work. The systematic training is hard to conduct.

5) Succession of the technology in the counterpart organization is not enough.

The counterpart personnel, who learned the technology, sometimes change the job and move to other agency; especially the talented person frequently moves. The member, who studied the new technology, is expected to become the technical leader in the organization and raise the technical level of the group. But the transferred technology may be lost by their job change.

6) Long-term technical assistance is difficult.

The period of the project of this type is about only two years. To raise the capacity of the city for earthquake disaster risk reduction, much more time and continuous systematic technical cooperation is necessary. The long-term road map is important.

Earthquake Risk Management in the Private Sector –Current Status and Problems–

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1. Introduction

The Great Tohoku Earthquake, which struck in 2011, caused heavy damage throughout the Pacific coast from Tohoku to Kanto. This earthquake was a widespread disaster experienced by modern-day Japan for the first time. As a characteristic, this disaster caused indirect damage in many areas, in addition to direct damage from the earthquake and tsunami. Events, which occurred as spillover effects such as a lack of electricity supply due to the electrical power plant suffering simultaneous damage, and a suspended logistics network due to road damage, influenced the people's daily life and social life not only in disaster-affected areas, but also on a nationwide scale.

Meanwhile, the disaster-prevention activities of corporations have become increasingly important in recent years as a management issue. The objectives of corporate disaster-prevention activities can be broadly categorized into "Ensuring safety" and "Business continuity." Firstly, ensuring the safety of employees and customers ranks the highest among the disaster-prevention activities of corporations. Secondly, continuation of business at the time of disaster and early recovery of business after disaster are acknowledged as a significantly important issue both in terms of rebuilding the lives of disaster-affected employees and in terms of recovering and restoring disaster-affected areas. The government has recommended that corporations design a Business Continuity Plan (BCP) for the said objective of business continuity. According to the BCP guideline[1)] designed by the Cabinet Office, "Earthquakes," also a high concern of corporate management overseas, were recommended as a disaster to be anticipated first by corporations; thus, many corporations designed a BCP for earthquakes and were prepared for earthquake disaster. Even so, in the Great Tohoku Earthquake, BCP did not function in a number of cases, especially in cases of indirect damage as noted above. Therefore, many corporations have been reviewing their disaster-prevention activities since the earthquake disaster and some are restructuring the BCP.

This report introduces the major current status and problems of earthquake risk management in such private-sector corporations. In addition, it introduces ways in which earthquake information is used by corporations, and summarizes the information considered necessary for earthquake risk management in the future.

2. Current status and problems of earthquake risk management in the private sector

As for the disaster-prevention activities of corporations with the objective of ensuring safety, awareness towards the risk of tsunami has sizably changed during the time frame of before and after the earthquake disaster. The two laws below require specific business operators on Table 1 to create a risk management plan that states securement of a smooth evacuation from the tsunami.

- Act on Special Measures for Promotion of Tonankai and Nankai Earthquake Disaster Management
- Act on Special Measures for Promotion of Disaster Management for Trench-type Earthquakes in the Vicinity of the Japan and Kuril Trenches

Therefore, it is thought that these specific business operators had established some sort of plan regarding tsunami evacuation prior to the earthquake disaster. However, many corporations, in addition to these specified business operators, have become aware of the risk of a tsunami since the earthquake disaster, and have started considering tsunami evacuation. Needless to say, evacuation plans are being actively reviewed by these specified business operators as well. When corporations consider this type of issue, tsunami hazard maps disclosed by local governments, etc. are used very effectively. However, the following problems can be found in this regard:

- Tsunami hazard maps are not necessarily disclosed by all local governments.
- When corporations that own many facilities across various prefectures use the maps, they may have to refer to numerous tsunami hazard maps. Confirmation through the use of many hazard maps requires both time and effort.
- When confirming the tsunami risks of many facilities across various prefectures, conditions which cause tsunami and conditions to conduct the tsunami inundation analysis may vary in the respective prefectures; thus, confusion is created in terms of consistency of results.
- Information listed on the tsunami hazard map varies in the respective local governments. In some cases, information necessary for planning evacuation e.g. arrival time of a tsunami, cannot be obtained.
- The government is still in the process of consideration regarding the massive earthquakes which would occur in the Nankai Trough and Sagami Trough; thus, it is necessary to establish evacuation plans before the latest information is disclosed. Furthermore, it has not yet been clarified as to what kinds of tsunamis should be the subject of the hazard maps along the coastal areas of Tohoku and those along the Sea of Japan.

Table 1. Business operators that require tsunami risk management

Business operators that require tsunami risk management
Hospitals, theaters, department stores, hotels/inns, and other facilities which are entered and exited by many unspecified people.
Facilities that produce, store, process, or handle petroleum, gunpowder, high pressure gas, and other components specified by Cabinet Order.
Railway business and other businesses related to general passenger transport.
Important facilities or businesses acknowledged as necessary to take measures for earthquake prevention, other than those mentioned in the preceding three items.

In contrast, as for disaster-prevention activities with the objective of business continuity, corporations are re-acknowledging the necessity and importance of BCP. Tokio Marine & Nichido Risk Consulting has conducted a survey among earthquake-affected corporations to study[2)] the effectiveness of BCP when an earthquake disaster strikes. A summary of research results is provided below:

- Over 90% of corporations that had some sort of damage mentioned earthquake ground motion as the cause of the damage.
- As factors that prolong business recovery, recovery of construction damage and counterparties suffering damage were mentioned.
- The rate of corporations which formulated or had formulated a BCP before the earthquake disaster was 58% among large corporations, around 30% among medium-sized corporations, and around 10% among small-to-medium-sized corporations.
- Effectiveness of BCP was confirmed among many corporations which had formulated a BCP. On the other hand, as BCP did not function in some cases, many items that should be reviewed or considered anew were brought to attention.
- Among many corporations which had not formulated a BCP, it is assumed that they will accelerate their moves to consider BCP in the future.

This research also indicates the key points when corporations review BCP (Fig 1). It is interesting that many corporations mentioned "Damage anticipation" as a key point to review. The following problems exist as a background to this response.

- Subjected earthquakes were inadequate: When corporations formulated BCPs, they anticipated damage to their business by referring to damage anticipation provided by the government and local government. However, as an earthquake that was not anticipated in advance occurred, it is necessary to review damage anticipation anew as to whether the earthquake subjected for damage anticipation is adequate or not.

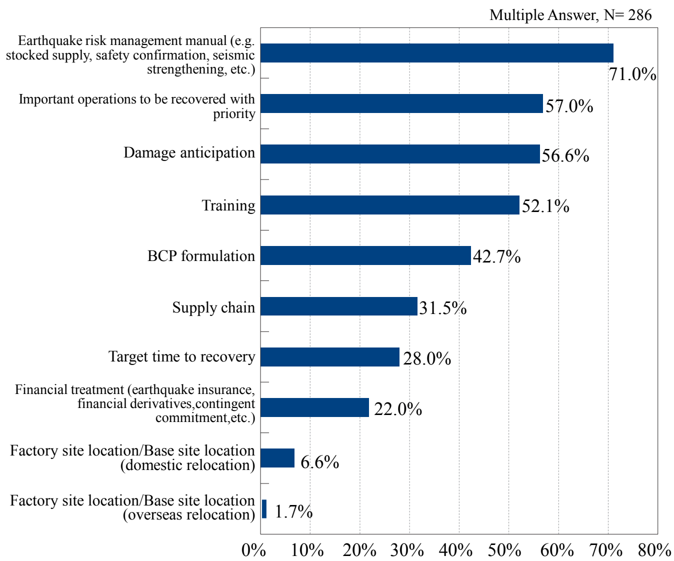

Fig 1. Key points for reviewing BCP

- Items regarding damage anticipation were insufficient: While corporations were aware of direct damage when anticipating damage, they did not anticipate indirect damage as in supply-chain cut-off due to counterparties suffering damage, and business shutdown due to planned power outages. It is necessary to consider the possibilities of such damage anew.

Currently, corporations reconsidering damage anticipation are increasing in light of these problems.

3. Earthquake information in the private sector: How information is used and problems

In the disaster-prevention activities of corporations, earthquake hazard information is used as a basic material to conduct risk management. This section introduces what kind of information is used within corporations for what kind of objectives. A summary of earthquake hazard information frequently used within corporations is shown in Table 2.

Firstly, information on the seismic source which would affect business becomes necessary as basic information for earthquake disaster prevention measures. Corporations seek this information from the Ministry of Education, Culture, Sports, Science and Technology's Headquarter for Earthquake Research Promotion (HERP), the Cabinet Office's disaster prevention sector, the Central Disaster Management Council (CDMC), and public materials disclosed by local governments. Corporations with very high consciousness towards risk management sometimes refer to information such as findings from the latest academic papers. In addition, these types of information are often reviewed by external intellectuals. The problem is that these types of information are likely to be updated on a day-to-day basis, however private corporations may not be aware of the update or may not be able to keep up with the information being updated.

Secondly, for information regarding earthquake ground motion, corporations often refer to the results of disaster anticipation provided by CDMC or local governments. In addition, Japan Seismic Hazard Station (J-SHIS)[3] is often used as a reference for detailed information as in the size of the earthquake

Table 2. Summary of earthquake hazard information used by corporations

Seismic source	Target	Objective
Past earthquakes	Business base and surrounding areas, business areas, supply chain facilities	Ensuring safety, damage anticipation (BCP), training, etc.
Active faults nearby		Ensuring safety, damage anticipation (BCP), training, etc.
Earthquakes that will affect business (seismic source, size, probability)		Data on earthquakes that will affect business (seismic source, size, etc.)
Earthquake ground motion	**Target**	**Objective**
Earthquake ground motion which occurred in the past	Business base, employees' homes, supply chain facilities	Ensuring human-life safety, damage anticipation, consideration of business continuity, training
History of liquefaction in the past		
Earthquake ground motion intensity (seismic intensity, PGV: Peak Ground Velocity)		
Probability of earthquake ground motion (seismic intensity, etc.)		
Earthquake ground motion intensity (PGA: Peak Ground Acceleration)		Damage anticipation, hardware measures (seismic design, etc.)
Possibility of liquefaction		Ensuring human-life safety, damage anticipation, consideration of business continuity, training
Waveform by ground acceleration and time history	Business base	Hardware measures (new design of buildings/facilities, seismic strengthening, etc.)
Tsunami	**Target**	**Objective**
Past tsunamis	Business base, business areas, employees' homes, supply chain facilities	Ensuring human-life safety, damage anticipation, training, etc.
Height of tsunami in neighboring coasts		
Arrival time of tsunami in neighboring coasts		
Form of tsunami in neighboring coasts (leading wave, drawback, etc.)		
Possibility of flooding		
Time regarding flooding (start of flooding, flooding peak, draining water)		
Ground deformation		

ground motion and its probability. However, for this type of damage anticipation for public use, earthquakes that have the most influence on the nation and local government are selected as the earthquake subjected for assessment. Whether or not the same earthquake has the most influence on the corporation's business needs a fresh judgment, however many corporations are not aware of the need towards this judgment. In the case when it is appropriate to select a different earthquake for anticipating damage to corporations, corporations must conduct assessment on their own, and the task is undertaken by external consulting companies.

Currently, as for risk management of a tsunami, corporations are considering the objective of ensuring security with priority, and information that is most needed is the possibility of flooding in business location bases and surrounding areas. If the area is subjected to flooding, they seek detailed information to plan ways to evacuate from the tsunami hazard area, such as flood depth and arrival time of tsunami at locations/areas subject to flooding. In order to obtain this type of information, corporations must conduct a predictive simulation of flooding from a tsunami; however, this is difficult for the private sector due to cost. Therefore, corporations seek the government and local governments to conduct simulations and to disclose detailed information about the simulations. As for tsunamis which would occur in the Nankai Trough, Sagami Trough, and the Japan Trench, the government and local governments are currently going through considerations. Corporate employees responsible for disaster prevention are paying close attention to their activity and hoping for an early disclosure of data.

4. Closing

For the private sector corporations that conduct business in Japan, measures against earthquake disaster is indispensable. When corporations devise measures, they often rely on publicly-disclosed information from the government and local governments for the information they need. However, such information sometimes contains considerable uncertainty depending on the objectives and methods. It is considered important for corporations from now on to grasp the credibility of such information, and to judge whether or not it is appropriate to use that information when making considerations for their corporation. Therefore, physical and engineering findings on earthquakes from experts will become more and more necessary in the future even within corporations.

In particular, the Nankai Trough earthquake whose occurrence is anticipated in the near future has the possibility of causing widespread damage exceeding that of the earthquake off the Pacific coast of Tohoku. As remaining time and cost are limited to secure reliable measures for this earthquake, corporations must determine measures that are more important and effective, and move forward with such measures.

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Comprehensive assessment for seismic risk in industry

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1. Introduction

The Tohoku Earthquake on March 11, 2011, caused tremendous damages to the industries. The industrial damage is caused by direct and indirect effects. In case of the Tohoku Earthquake, direct damage was caused by ground-motion and tsunami in Tohoku and Kanto regions in Japan. Secondary industrial damage was mainly caused by being cut off the industrial supply chains of various products. These secondary damages affected the industries not only on the domestic scale but also on the global scale. After the March 2011 earthquake, production at many automobile factories over the world was affected by a shortage of parts produced in Tohoku and Kanto regions. These seismic secondary damages to the global and domestic industries have also occurred in the case of past other massive earthquakes, such as the Hanshin-Awaji Earthquake and the Niigata Chuetsu earthquake.

Repeated seismic hazards in Japan may result in the removal of Japan from the area for important parts supplier in the future. Thus, Japanese government and the industrial associations should make an effort to draw up the measures for the business continuous plans (BCP) at the company level and even at the industrial level (Industrial Structure Council 2011).

On the other hand, damage anticipation of seismic hazards and measure planning are considered by the Central Disaster Prevention Council of Japan, and the disaster prevention council of local government. These anticipations are analyzed for earthquake loss assessment which mainly considers direct damages in urban areas.

In order to formulate measures for these seismic risks, a research project to develop simultaneous risk assessment simulation tool based on the scheme of disaster risk in 2011 was initiated. Another aim of this project is to control low probability - high consequence disaster which causes huge social and economic damages. The proposed new risk assessment simulation tool includes diverse effects of primary disaster of earthquake or tsunami and secondary damages of industrial plants and atomic power plants or supply chains of various products including function of production and transportation.

2. Framework of Seismic Risk Assessment

The risk assessment simulation tool is composed of the three sub-systems: the primary disaster predictive simulation, the hazard assessment of secondary damages and the risk assessment. In this study, we focus on the industrial damage in Japan including secondary damage to the supply chains which might be caused by the anticipated huge

Earthquake such as Tokai, Tonankai and Nankai Earthquakes. In order to assess the risk to the industries caused by seismic ground motion, a framework for the proposed risk assessment and a computable general equilibrium (CGE) model are developed.

There are some frameworks being discussed under global alliance for seismic risk assessment by forecasting probabilistic seismic shaking, which make possible to assess the risk of earthquake in Turkey, Europe, California and so on (GEM website). However, that can't assess a comprehensive risk including the secondary damage to industry and its supply chains. This study considered not only direct damages to industry but also indirect damages to industry by severed supply chains; therefore, the boundary and procedure of a comprehensive risk assessment was set as below.

- Considering building and factory damages in each company as seismic direct damage
- The direct damage to production loss in each industry in the considered region
- Production loss ratio represents reduction ratio of industrial production index
- The effect of secondary damage in each industry in each region is simulated by using a CGE model

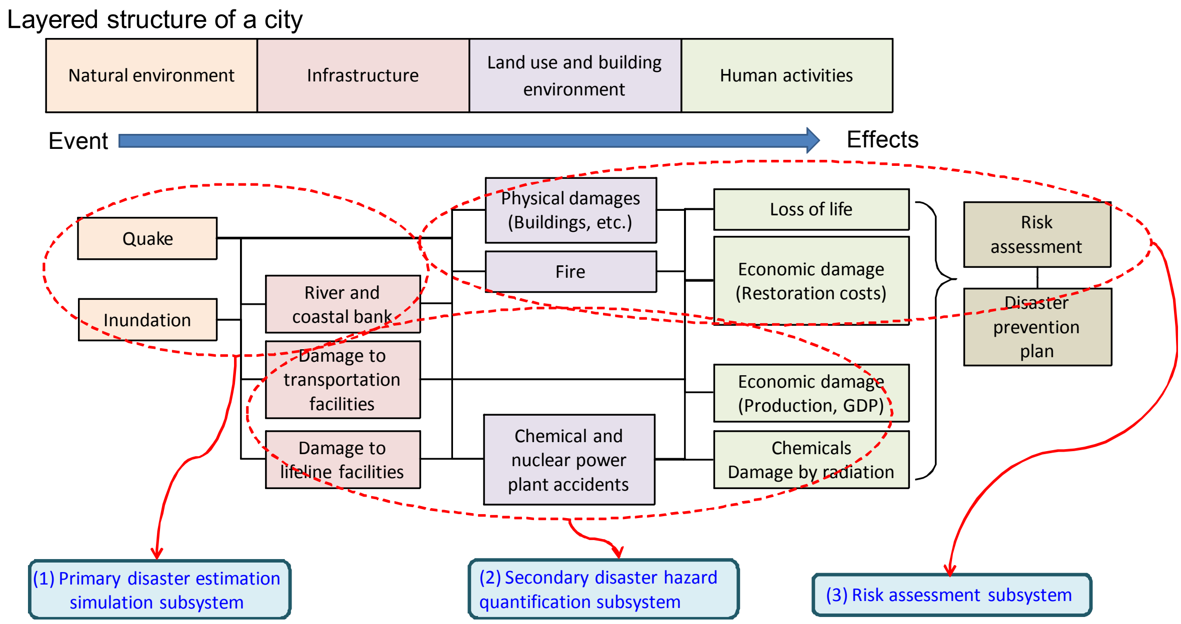

Fig. 1. Framework of the risk assessment simulation system

Based on these procedures, we are now carrying out our research according to the steps below.

- Preparing the fragility curve of each industry
- Mapping the plants of each industry
- Recreating the damages using CGE model, by regions and industries, on information obtained from the experiences of the Tohoku Earthquake

The industry-specific fragility curve was created based on the damage studies (Naraoka et.al. 2012) and questionnaire for the past earthquakes. Reduction of industrial production index was resulted from many causes such as reduction of production, disruption of transportation, power failure, lack of water supply and shortage of employee. At the early stage of this study, we only consider reduction ratio in each industry, which is accumulated from regional statistics, such as a regional industrial statistics, a census of commerce of Japan and so on. Disruption of transportation, power failure, lack of water supply and shortage of employee will be taken into account in our future study.

3. Computable General Equilibrium Model

When considering the effect of supply chain disruption, a computable general equilibrium (CGE) model is a powerful tool to estimate the economic damage of natural disaster. A CGE model is built from general equilibrium theory, which expresses the economy as a set of simultaneous equations, and interregional input-output table, which carries the actual business between industries, and other information. This study employs multi-regional, multi-sector and static CGE model to estimate sectorial impacts of the earthquake. The model divides Japan into 8 regions (i.e., Hokkaido, Tohoku, Kanto, Chubu, Kinki, Chugoku, Shikoku, and Kyushu (including Okinawa)). Kanto, Chubu, and, Kinki include Tokyo, Nagoya, and Osaka respectively.

The model includes a representative household, local government and 40 production sectors in each region. Production sectors trade their products with each other within their regions and across the regions. They can also import intermediate products and export their products to the rest of the world. The representative household and the local government serve as the final consumers. All goods markets are assumed to be perfectly competitive, such that demand equals to supply and zero profits are earned.

The disaster damage to each production sector is modeled as a decrease in productivity of capital and labor input. The productivity is adjusted so as to reproduce actual production decrease in each production sector in Tohoku and Kanto regions in the model. The general equilibrium solution of the model reflects not only the high-order business interruption due to the supply chain disruption but also the economic resilience through input substitution behavior of production sectors and households.

4. Simulation result of industrial damages caused by the Tohoku earthquake

We carried out a simulation to estimate the industrial damage in each region of Japan caused by the Tohoku earthquake. The reduction ratio calculated from decrease in industrial product index was set as the input data of the CGE model. The input data of upstream industries such as chemical and allied products, petroleum, plastic products, iron and steel, electrical industrial apparatus, motor vehicles' parts and accessories, and precision instruments and machinery considered as the reduction ratio in both Kanto and Tohoku regions where suffered serious damage by the Tohoku earthquake. Simulation results in the west region of Japan, such as Kyusyu, Shikoku, and Kinki regions, were compared with the results from statistics, because power failure and disruption of water supply occurred in the east regions of Japan and these damages would affect on the results from statistics.

Results are shown in Fig. 2. Most changes in the reduction ratio of industrial production index calculated from statistics in each region were qualitatively consistent with the simulation results. The reason of quantitative difference can be considered that power failure and disruption of transportation affect on uncertainty of input data and the influence of suspension of important parts supply, which is small in terms of the amount of money, is not taken into accounts.

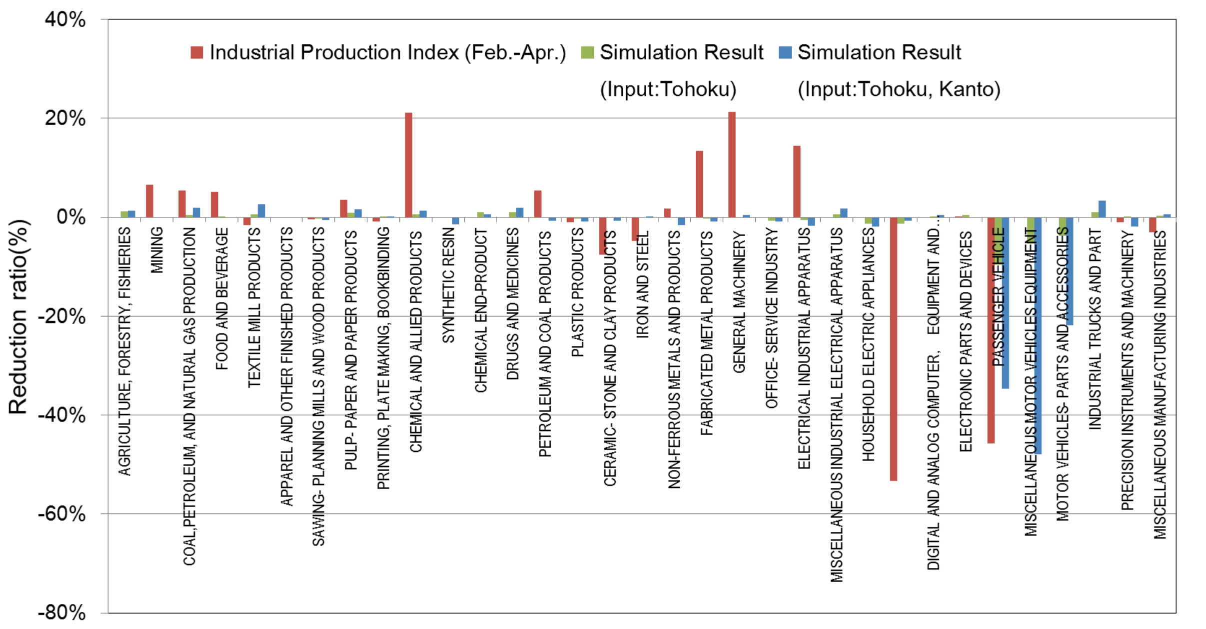

Fig. 2. Comparison of results from statistics and a CGE model (Kyushu region)

In future studies, critical supply chain, which is difficult to find from our simulation results will be identified by comparing results from statistics and simulation.

5. Summary

The risk assessment simulation will enable the national and municipal governments and industries to quantitatively assess the multiplex risks of primary hazards and secondary damages and assist them in making decisions, such as in formulating disaster prevention measures and urban planning by municipal governments, designating industrial areas in strong zones against disasters, and establishing optimum production areas and distribution networks.

The results of the study will enable the scale of secondary damages, which has been desultorily and fragmentary estimated, to be quantitatively and comprehensively simulated and will introduce the concept of quantitative risk assessment and management in the disaster prevention measures of the national and municipal governments and the industries.

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Evaluation of subduction zone earthquake by geological records for mitigation of tsunami disaster

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The Great Off-Tohoku Earthquake (M 9.0) of 2011 turned out to be an unprecedented disaster due to the giant tsunami that invaded the Pacific coast, and it is often said that its magnitude was “unexpected.” However, geological data such as tsunami deposit obtained from the coast facing the Japan Trench suggested that the giant tsunami as large as the 2011 event had repeatedly occurred for several thousand years, including the Jogan Earthquake (greater than M 8.4) of 869. Subduction Zone Paleoearthquake Research Team in GSJ has conducted paleoseismological survey to evaluate the recurrence time, tsunami inundation area and source of the Jogan Earthquake and its predecessors since 2004. Eventually, the inundation area of the tsunami in 2011 was very similar to the estimated tsunami inundation area of the Sendai Plain at the time of the Jogan Earthquake (Sawai et al., 2012) (Fig. 1). What this implies is that if the magnitudes of past earthquakes and tsunamis are elucidated and if histories of occurrence are reconstructed, we will be able to make a rough assumption of the magnitude and imminence of future probable earthquakes and tsunamis.

After the 2011 earthquake, GSJ urgently surveyed to observe the distribution and sedimentological characters of tsunami deposit, which was derived from the 2011 tsunami. This is for improving a reconstruction technique of past tsunami inundation. From the results of this survey, it is recognized that actual tsunami inundation is able to reach 1-2 km further inland than the landward limit of the distribution of tsunami deposit (Fig. 1). This means that reconstructed past tsunami inundation from geological record indicates 62.2-82.9 % of actual inundation area (Shishikura et al., 2012). For more reliable estimation of future tsunami inundation area for mitigating disaster, it is highly important that we not only focus on the distribution of past tsunami sand layer, but also evaluate the scale of tsunami inundation by methods such as chemical component analysis in combinating with tsunami simulations. This instruction should be immediately apply to other coastal areas facing subduction zone which have potential of giant tsunami in near future such as the Nankai Trough. GSJ therefore is conducting field survey along the Pacific coast of

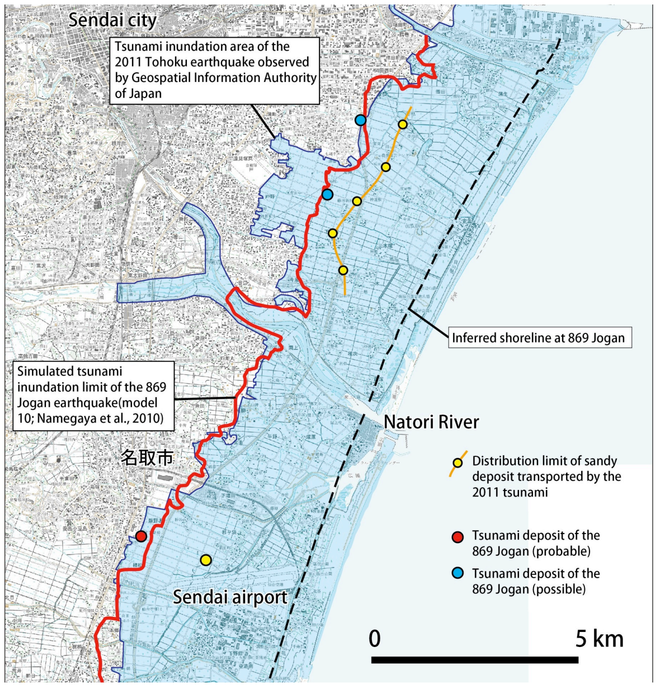

Fig. 1. Comparison of tsunami inundation area between the 2011 Tohoku and the 869 Jogan, and inland limits of tsunami deposits.

Japan.

On the other hand, regardless of paleoseismology, recently the government announced the estimation of disaster for future giant earthquake and tsunami in the largest case simulated from mega-thrust ruptured as much as possible. However the evidence of such largest event has not yet been found in any records not only historically but also geologically. Therefore a role of paleoseismological study was oppositely changed. Before the 2011 event, paleoseismologists suggested the possibility of future giant earthquake from field survey data by inductive approach. But after the 2011 event, paleoseismologists must evaluate by deductive approach whether such the largest event suggested by the government exist or not from the evidence of field survey data.

Fig. 2. Photos of tsunami boulders scattered on wave-cut-bench near the Cape Shionomisaki, which have recorded past giant tsunami produced from mega-thrust along the Nankai Trough.

One of the solutions to evaluate the largest event was identified in the Shionomisaki Cape, where we found tsunami boulders, which were moved at only the timing of giant earthquake generated from the Nankai Trough such as the 1707 Hoei earthquake (M 8.6) (Fig. 2). The boulders are distributed over the range of ca. 200 m from shoreline, but nothing was found on the Holocene terrace of 2-4 m in altitude just behind them. Because the terrace was probably emerged during 6000 years ago, the largest tsunami in the past 6000 years must be not able to transport the boulders over the terrace. Then it can evaluate the actual magnitude of the largest tsunami by calculation of critical velocity.

For more precisely reconstruction of past earthquake and tsunami, we should develop paleoseismological methods and widely find geological evidence of past phenomena (tsunami, crustal movement and strong ground motion), which are not only tsunami deposit but also emerged shoreline topography, biological marker of sea level change, sand dike of liquefaction, mass movement and submarine turbidite. Although each record may be incomplete, it would be able to reveal actual past phenomena by combining them.

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The earthquake catalog in East Asia including historical events

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The earthquake catalogs were published in many countries and the organizations in the world. Japan Meteorological Agency (JMA) issued the seismological bulletins and it included the hypocenters from 1923. Those of ISS from 1918 to 1963, USGS and ISC from 1964, Korea Meteorological Administration (KMA) from 1978, Korea Institute of Geoscience & Mineral Resources (KIGAM) from 1994, and Institute of Geophysics, China Earthquake Administration, from 1978. The historical earthquakes were compiled in many ways by many researchers. Utsu (2002) complied the destructive earthquake catalog in the world. It was the very important result, but there are still some problems. It did not include the undestructive earthquakes and some duplications for the same event were found, because the origin time was not used in only UT for all event. Engdahl and Villasenor (2002) compiled the global earthquake catalog in 20c. Their result was very useful for many researchers, but the parameter of some hypocenters were not suitable. Large differences of the hypocenter locations between JMA and their result were reported by Ishikawa (2002). For example, three events were determined at Hidaka region, Hokkaido. But those of them by JMA were in the Pacific Ocean. Especially the hypocenter of the 1952 Tokachi-Oki earthquakes was inland region by Engdahl and Villasenor (2002). The depth of some events in the Japan Sea must be much deeper.

The many domestic catalogs were rather uniform in the own country, but still included the limitation. For example, the 1700 April 15 Tsushima-Iki M7 earthquake was located between Kyushu and Korea in Japanese catalog, but it was not found in Korean catalogs by Korea Earthquake Research Institute (1984) and Li (2001). The event in the same day was located inside of the Korean peninsula in Korean catalogs. It shows the importance of the international cooperation for the research on the historical earthquakes.

Additionally, the calendar and the time must be uniformed, because the Julian, Gregorian, and lunar calendars were adopted and local time also used in some researches.

Usami (1974) and Mogi (1976) presented that the seismic activity was simultaneously very high in 17 century in NE China, Korea and SW Japan. So, international uniform catalog was very important to research the seismicity in wide region.

The Gregorian calendar and Universal Time were used in this new catalog. The data in China from BC 23c, Korea from AD 2, Japan from AD 715, Vietnam from AD 114 and Philippine from AD 1897 were compiled.

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