WFEO- JFES- JSCE
JOINT INTERNATIONAL SYMPOSIUM ON DISASTER RISK MANAGEMENT

Under the support of
SCIENCE COUNCIL OF JAPAN

Tohoku University, Sendai
September 11, 2008
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WFEO-JFES-JSCE Joint International Symposium on
Disaster Risk Management

Organizers: World Federation of Engineering Organizations (WFEO), Japan Federation of
Engineering Societies (JFES) and Japan Society of Civil Engineers (JSCE)
Under support of Science Council of Japan (SCJ)

September 11th, 2008  9:00 – 12:00
Venue: Tohoku University, Kawaguchi North Campus
Multimedia Education and Research Complex, Room M601

SYMPOSIUM PROGRAM

Chair: Prof. KAWASHIMA, Kazuhiko, Member of National Committee on WFEO, Science
Council of Japan

Vice-Chair: Dr. NGUYEN, Son Hung, CTI Engineering, Co., Ltd.

Opening Addresses: 9:00 – 9:05 (5 minutes)
Dr. ISHII, Yumio, Elected Representative of Nation Members, WFEO, Chair of IAC-JFES,
Past Immediate President, JSCE

KEYNOTE LECTURE: 9:05 – 9:35 (30 minutes)
World Federation of Engineering Organisations and Engineering Responsibility
Before, During and After Disaster
Eng. Barry GREAR, President, World Federation of Engineering Organizations

PRESENTATION PART I (9:35 – 10:55) 20 min.x 4 presentations (80 minutes)
1. The 2008 Sichuan Great Earthquake Disaster and Technological Restoration and
   Recovery Support Activities of Interdisciplinary Liaison Council led by JSCE
   Prof. Ömer AYDAN, Tokai University

2. Scenario-Based Seismic Risk Assessment and Its Applications
   Dr. Chin-Hsun YEH, National Center for Research on Earthquake Engineering, NARL

3. Seismic Retrofitting of Bridge Columns Using Carbon Fiber Reinforced Plastics in Taiwan
   Prof. Yeou-Fong LI, National Taipei University of Technology

4. Seismic Performance of RC Bridge Columns Based on Full-scale Excitation Tests
   Prof. Kazuhiko KAWASHIMA, Tokyo Institute of Technology
Question and Answer (10:55 – 11:10) (15 minutes)

PRESENTATION PART II (11:10 – 11:50) 20min.x 2 presentations (40 minutes)

5. **Features of Super Cyclone Sidr to Hit Bangladesh in Nov., 07 and Measures for Disaster - from Results of JSCE Investigation**
   Dr. Kazuyoshi HASEGAWA, Foundation of River & Watershed Environment Management

6. **Introduction of SCJ's Proposal on Adaptation to Water-related Disasters Induced by Global Environmental Change**
   Prof. IKEDA, Syunsuke, Tokyo Institute of Technology

Question and Answer (11:50 – 11:58) (8 minutes)

Closing Address (11:58 – 12:00) (2 minutes)
   Prof. IKEDA, Syunsuke, Vice-President of JFES

Discussion: Lunch time
WORD FEDERATION OF ENGINEERING ORGANISATIONS
AND ENGINEERING RESPONSIBILITY BEFORE, DURING AND
AFTER DISASTER

By

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President World Federation of Engineering Organisations
Past National President of the Institution of Engineers, Australia.
Past Chairman, South Australian State Disaster Committee

WFEO Organization and Mission

Engineering is a profession that is truly international. An idea for a structure, project or product may be conceived by an engineer in one country, it may be designed in one or more countries, constructed or produced with components from many countries, operated and maintained where used and disposed of with international support.

In this era of extensive use of the internet the concept of an engineer belonging to a “country” is challenged, and may be considered irrelevant. It is, however, important for all engineering associations (and governments) to have confidence in the abilities, standards and experience of engineers working across international boundaries.

For the above reasons the World Federation of Engineering Organisations has many important roles.

“Its vision is that WFEO be the internationally recognized and chosen leader of the engineering profession and cooperates with national and other international professional institutions in being the lead profession in developing and applying engineering to constructively resolve international and national issues for the benefit of humanity.

And its Mission:
• To represent the engineering profession internationally, providing the collective wisdom and leadership of the profession to assist national agencies choose appropriate policy options that address the most critical issues affecting countries of the world.
• To enhance the practice of engineering.
• To make information on engineering available to the countries of the world and to facilitate communication between its member nations of worlds best practice in key engineering activities.
• To foster socio-economic security and sustainable development and poverty alleviation among all countries of the world, through the proper application of technology.
• To serve society and to be recognised by national and international organisations and the public, as a respected and valuable source of advice and guidance on the policies, interests and concerns that relate engineering and technology to the human and natural environment.

The World Federation of Engineering Organisations (WFEO) is the international body representing the worldwide engineering profession. The national organizations that constitute WFEO include about 15 million engineers worldwide in their membership. The objective of WFEO is to use the skills and knowledge of the engineering profession for the wider benefit of humanity.

WFEO is also the obvious body to relate to many non-engineering world bodies such as the United Nations, UNESCO, FIDIC, CAETS, FIDIC and the World Bank and other aid organizations.

It does this through Eight Standing Committees that are each convened with international membership, they are:

The Committee on Engineering and the Environment that is offering advice on the effect of climate change on infrastructure and supporting the considerations of the United Nations Commission on Sustainable Development as a contribution to the achievement of the Millennium Development Goals particularly in leadership of the “Science, Technology and Innovation Task Force”.

The Committee on Information and Communication that is considering the way that engineers in the world can have appropriate use of Information Technology and advise the developing world on the introduction and development of Information Technology and Communication techniques to assist their development. The Committee is aware of the challenge of the information divide and is working on techniques to reduce that divide.

The Committee on Education and Training is assisting in setting international standards that will allow the easy mobility of graduate and experienced engineers. The profession of engineering is a dynamic one with changes in the academic, practice and discipline criteria. We must expect that the graduate attributes will be changing all the time because of the changing of the knowledge in society. This Committee advises on this issue.
The Committee on Technology has been working on a wide range of projects related to “appropriate technologies”, international building code development and advising on urban infrastructure development in developing countries.

The Committee on Capacity Building has been assisting communities in sub-Saharan Africa and Latin America and the Caribbean. It is also developing a model for ensuring the transfer of technology when development projects are undertaken.

The Committee on Energy has been developing reports on the feasibility conditions of different energy technologies currently being considered for implementation around the world. It has completed and published documents on wind energy and nuclear power energy and is currently preparing documents on solar energy and bio energy.

The Committee on Anti-Corruption acts as a focal point to advise WFEO members and to link with all other like minded organizations such as UNESCO, the World Bank and Transparency International to develop programs that will minimize corruption to limit waste which will reduce the effectiveness of programs for developing countries.

The Committee on Women in Engineering which is developing a program to empower women in engineering and technology by networking and developing leadership skills.
It will both utilize the experience of long established women’s groups and assist in strengthening new ones.

All nations wish their citizens to be able to live with a reasonable level of economic prosperity, to enjoy educational, health and social services that enable them to live their lives in dignity and without hardship, and to do so in a manner that ensures that negative impacts of human activity on the environment are acceptable, and increasingly minimized.

Economic efficiency requires a country to rapidly deploy new technologies from elsewhere, and to attract capital to purchase those technologies. Many developing countries do not have sufficient capital of their own and therefore need to attract foreign direct investment (FDI). This in turn requires adherence to intellectual property laws, but also low levels of corruption and fair taxation and or tariffs. Political instability and access to finance are important factors but electricity supply and adequate roads are also rated as a significant obstacle by the World Development Bank.

Worldwide, Engineering qualifications have become highly regarded by employers because of their emphasis on risk management, ethical practice and sustainable outcomes. In this way, graduates from engineering courses have become a new source of managers and leaders for many organisations and professions.
Thus, whenever capital is made available it is vital that the nation has the technical capability to make good technology decisions. The world has many examples of unsuitable technology being foisted on developing countries because there was not wise buyer capability.

The WFEO has been able to vigorously represent the engineering profession in the global policy settings especially with regard to issues of sustainable development and human welfare. This means interacting visibly and effectively with the United Nations and its specialised agencies as well as the international and regional development banks and financing agencies. With the whole-hearted endorsement and support of WFEO Members there has been significant achievement.

The most important focus of the UN in development in the coming decade is the Millennium Development Goals. WFEO has led the “Science, Technology and Innovation (STI) Task Force.

Sadly there are still too many people who have never turned on a light switch, never walked on a made roadway let alone ridden on one.

This leads on to the final point, the poor condition of infrastructure world wide.

Currently there is minimal involvement of engineers in the political process. An ever-increasing global population that continues to shift to urban areas requires widespread adoption of sustainability. Demands for energy, drinking water, clean air, safe waste disposal, and transportation will drive environmental protection and infrastructure development. Society will face increased threats from natural events, accidents, and perhaps other causes such as terrorism.

The public is becoming increasingly aware that development need not come at the price of a compromised and depleted environment for them and their children. The public has begun to see sustainability, not as an unattainable ideal, but as a practical goal. To answer that call, engineers associated with WFEO increasingly transform themselves from designers and builders to life-cycle project “sustainers.”

On the demographic front, the world is well on its way to a population exceeding 10 billion people in 2050. Today, people occupy more space on the planet than they did 30 years ago, and they are straining the earth’s environment, particularly the needs for energy, fresh water, clean air, and safe waste disposal. Over the past 30 years, gradual global warming has profoundly impacted the more than half of the world’s population that lives within 50 miles of coastal areas. These areas have become much harsher places to live because of sea level rise, increased storm activity, and greater susceptibility to flooding. Growing population, shrinking resources, and climate change have put us on the path to
sustainability and have put sustainability at the forefront of issues requiring global attention.

Emergency Management Planning and Disaster Management

The development of Emergency Management arrangements around the world supports a concept that disaster events can be managed in four phases which will always occur in relation to a particular event or group of events.

These phases are:
Prevention – Those measures which can be taken to prevent or minimise the effects of the impact of an event. In recent times there is a greater attention to Risk Assessment Principles and subsequent attention to Mitigation measures to make considered decisions about the best prevention methods.
Preparedness – the arrangements that ensure full and effective utilisation of all resources and services for disaster response and recovery.
Response – those actions taken to minimise the effects of an impending or actual disaster
Recovery – those actions that assist the community to successfully adapt to the effects of disaster after its impact is over.

This paper asserts that **PREVENTION and RECOVERY** are the phases where a greater involvement and intervention by engineers will reduce the loss of life in a disaster situation.

PREVENTION
Natural hazards to which many cities are commonly vulnerable include tropical cyclones, floods, earthquakes, landslides, volcanic eruptions and tsunami.

In recent years, however, the increase in technological disasters seems to be increasing. These include chemical spills and leaks, radiation leaks and the collapse of bridges, buildings, dams, communication systems, etc.

In recent years there have been many disasters that have resulted in a devastating loss of life in cities and heavily populated areas. However, despite the list below, there appears to be little commitment to ensuring that mitigation methods and the possibility of shifting cities or limiting future growth in the high-risk disaster areas to reduce the future impacts on life and property are considered and undertaken.

The cost of these disasters is very high. In Australia, a relatively low density and low risk country it is about $US1 Billion per year.
Substantial advances in reducing this figure will not be achieved until those concerned about the health; welfare and environment issues generate more public debate.

**SOME MAJOR DISASTERS OF THE WORLD**

- **79** Volcanic Explosion
  - **Pompeii**
  - **10 000**
- **1339-51** Plague
  - **Asia/Africa/Europe**
  - **75 000 000**
- **1556** Earthquake
  - **China/Shensi**
  - **830 000**
- **1737** Cyclone
  - **India/Calcutta**
  - **300 000**
- **1883** Volcano/Tsunami
  - **Indonesia/Karakatoa**
  - **36 000**
- **1887** Flood
  - **China/Honan**
  - **900 000**
- **1908** Earthquake
  - **Italy/Mt Messina**
  - **83 000**
- **1918** Spanish Influenza
  - **Worldwide**
  - **21 640 000**
- **1920** Landslide
  - **China**
  - **200 000**
- **1923** Earthquake
  - **Japan/Tokyo**
  - **143 000**
- **1931** Flood
  - **China**
  - **3 700 000**
- **1949** Flood
  - **Guatemala**
  - **40 000**
- **1960** Earthquake
  - **Morocco/Agadir**
  - **17 000**
- **1965** Cyclone/Storm
  - **Bangladesh**
  - **500 000**
- **1973** Drought
  - **Africa/Sahel**
  - **100 000**
- **1985** Volcanic Eruption/Mudslide
  - **Colombia**
  - **20 000**
- **1994** Civil war
  - **Africa/Rwanda**
  - **1 000 000**
- **2004** Tsunami
  - **Indian Ocean**
  - **300 000**
- **2005** Cyclone
  - **New Orleans**
  - **300**
- **2005** Earthquake
  - **Pakistan**
  - **80 000**

Policy makers and governments need to seek the help of the engineering profession, and interdisciplinary teams; to have risk assessment analyses applied to the infrastructure of all of our cities. These analyses are becoming known as “lifeline” projects.

There needs to be a new approach to the way we manage the development and redevelopment processes applicable to any densely populated area.

**RECOVERY**

The dynamics at work in a community when the people become aware of an impending disaster, immediately a disaster occurs and when recovering from a disaster are very complex.
Engineers need to be aware that they will face issues, which are unique to each situation, and that they often have to make decisions in very short timeframes compared to the normal activities in which they are involved.

Often in smaller or remote communities the engineers and their families may be personally affected. The priority for their immediate family has to be balanced with the needs of the community that they serve.

While it is accepted that not all engineers can give the priority for extensive training in disaster management it is appropriate that all are aware of the principles of emergency management and have a checklist of key people who have had experience and where information can be made available.

For the engineer on the front line there will be competing demands and conflicts which will have to be resolved.

Human behavior must be expected to be different than that which occurs in a normally operating community.

There will be demands for instant information and an expectation that answers can be given in areas outside normal responsibilities. Information is of course vital for everyone, it will need monitoring.

Financial estimates will be demanded for both immediate and long-term requirements.

As soon as possible a program of work needs to be documented. However, programming needs to be flexible. It will have to take account of new information which will be gathered on a daily basis.

It will be difficult to do this with the normal precision. The estimates must cover, cleanup, disposal of waste, assistance with the provision of temporary infrastructure, the rehabilitation of existing infrastructure and the building of new infrastructure and a variety of miscellaneous tasks.

In clean up, priority will have to be given to, safety of the community, health of the community, establishment of communications and restoration of access.

COMMUNITY
Understanding the community is very important. Issues such as its history, locality, dependencies, common interests and time are important to consider. Be prepared to listen to older people.

Having assessed the situation and the amount of recovery work needed it is important for the community to be told.
If, of course, there has been an exodus of population and there is only a low likelihood of them returning, then the recovery program will be quite different to the situation where the community has stayed and is demanding full restoration of services immediately.

ROLE OF THE ENGINEER
The community will depend on the engineer to assess the physical damage and then take significant control of restoration and reconstruction.

There will be excessive demands on the engineering team.

Legal considerations may become immediate and critical. What is my duty of care and legal liability? Undertaking a wide variety of tasks with time pressures that do not always allow due consideration of all aspects. Professional judgment in decisions regarding the protection of persons and property will become more focused than normal. Make sure that you record every decision made and the basis for making it.

The organisational arrangements may have to be changed. What is my authority? This may be an important question, which needs answering.

How am I coping, behaving and reacting? These are questions that need to be asked of a mentor.

Will there be conflicts with my professional ethics? There will be pressures to exceed the limits of approved funding and possibly change previously agreed priorities.

Another challenge is that community leaders and politicians may not understand operational priorities and can often make inappropriate and competing demands for the use of available resources. Keep thinking, keep revising and keep reporting.

VOLUNTEERS
The use of volunteers in recovery is essential for prompt attention to the many tasks required to be carried out, but control may be difficult. You will have varying numbers and their attendance will be irregular. They will have other commitments. There must not be a lack of appropriate tasks or their motivation and effectiveness will be diminished. Send them away with a time and place to return if there are no current tasks.
Be aware that untrained volunteers may make incorrect judgments if authorised persons do not vet decisions. Try to not have the volunteers briefing their replacements.

Be aware as well that there may be conflict between volunteers if contractors get paid for work initially done by volunteers.

MEDIA
Politicians and the media work together on a daily basis. It is worth all engineers understanding the relationships. My belief is that during a disaster event that linkage should be used and the engineer should use the media advisor to make all arrangements to give information and to give radio or television interviews where necessary.

The engineer should not express opinions but provide hard, factual information. Develop a reputation for giving accurate, well-informed and useful information that the community requires.

FINANCIAL MANAGEMENT
No matter what freedoms are available during a disaster event there is one important matter, which must not be forgotten. “The auditors will come”.

It is often the case that when the busy phase of a disaster is over, many things will be in disarray, including the organisation, the office and daily personal interests. Your colleagues may be dispirited and exhausted and now the clean up and rebuilding process may be estimated to be years.

Apart from having good documentation there are now some new issues. Is the funding for the work guaranteed or only promised. What are the sources of new funds? Are there different controls on the spending? Are the accounting requirements different from the normal requirements in my own organisation?

INSURANCE
Insurance companies have a major influence on disaster recovery. The assessment of the insurable portions, the release of funding, and the leaning towards litigation. Will governments make up any shortfalls?

THE ENGINEERING TASK
Clean up can be a major task. I have mentioned priorities earlier, but it is timely to comment that this is a matter which needs careful consideration during the planning phase as dump sites are not always readily available and the road
system may not have been designed for the new traffic demand because or weight or volume.

The separation of the different types of waste is critical. Remember where the waste was put. Photographs are very useful.

Can I utilise private property is an issue.
Is special equipment required?
Toxic chemicals, dead animals and insects may present special problems.
Waste food, oil, sewage, and noxious weeds

Do I have to help in food deliveries, e.g. refrigeration?
Security and communication.

CONCLUSION
Despite all of what I have said, which may sound daunting, my experience and study has demonstrated two things.

The actual efforts of the Engineering team will exceed their own expectations.

There will always be things to be learnt from each incident.
ABSTRACT

The earthquake of the 2008 Great Sichuan Earthquake occurred in Wenchuan County of Sichuan Province of China and caused extensive damage to buildings, infrastructures and it caused the failure of natural slopes as well as cut-slopes. More than 85000 people lost their lives besides the heavy structural damage. A liaison council was established under the leadership of Japan Society of Civil Engineers including 7 academic societies of Japan for supporting the counterparts in China for the restoration and re-construction in the earthquake affected area. This article presents a brief overview of the earthquake, and structural and geotechnical damage, and the support activities of the council.

1 INTRODUCTION

An earthquake with an estimated magnitude of 7.9 (Ms 8.0) struck Sichuan Province of China at 14:28 local time (06:28 UTC) on May 12, 2008. The quake was felt throughout much of China, as well as parts of Taiwan, Thailand, and Vietnam. The confirmed casualties are more than 70000 and it is expected to exceed 85000. The earthquake caused widespread damage to buildings, transportation facilities, industrial plants and large-scale slope failures in the earthquake-affected area.

The earthquake occurred at the well-known and well-studied Longmen Shan Fault Zone by thrust faulting with dextral component. Preliminary analyses indicated that the rupture process activated a 300km long fault section. The strong motion records are not available to the scientific world yet. However, the preliminary estimations indicate that the ground motions are high in epicentral area. The maximum ground acceleration and velocity are expected to exceed 1G and 100 kine. A huge number of reinforced concrete buildings collapsed in the epicentral area. The preliminary reports indicate that 5 million people are homeless. The collapse of structures was mainly associated with high ground motions together with their low earthquake resistance. Furthermore, permanent ground deformation induced by landslides as well as relative motion of the earthquake fault also played a major role in the widespread damage.

A liaison council is established under the leadership of Japan Society of Civil Engineers in relation to technological support for the reconstruction and restoration of the earthquake affected areas in Sichuan Province of China. The liaison council consists of the Japanese Society of Civil Engineers (JSCE) Architectural Institute of Japan (AIJ), Japan Geotechnical Society (JGS), Japan Seismological Society (JSS), Japan Association of Earthquake Engineering (JAEE), Japan Geographical Society, Japan City Planning Society.

This article presents an overview of the characteristics of the Wenchuan earthquake and explains the causes of damage to buildings, infrastructures and natural and cut-slopes, and the goal and support activities of the liaison council for this earthquake.
2 CHARACTERISTICS OF THE GREAT SICHUAN EARTHQUAKE

2.1 Tectonics and Seismicity

The geology of the Longmen Shan region, which is the epicentral area, is divided into four distinct tectonostratigraphic packages (i.e. Şengör et al. 1993; Burchfiel et al. 1995). From oldest to youngest, these include (1) crystalline basement rocks of the Yangtze craton, (2) Neoproterozoic-Permian passive margin sediments, (3) Triassic flysch of the Songpan-Garze terrane, and (4) Mesozoic-Cenozoic terrestrial sediments in the Sichuan Basin. These packages are juxtaposed across a series of structures, collectively termed the Longmen Shan Thrust Belt.

There are many quaternary and Holocene-aged strike-slip faults in the Longmen Shan region, the boundary between the eastern Tibetan plateau and the Sichuan basin in west-central China (Figure 1). Active faults within the mountainous region include the N to NNE-trending Min Jiang and Huya faults and the ENE-trending Maowen -Wenchuan, Beichuan and Pengguan faults (Densmore et al. 2007). The latter are exposed for hundreds of kilometers within the Longmen Shan proper. Less well-known but probably equally significant is the NNE-trending Dayi fault, which lies at and partly defines the edge of the Chengdu basin, the western sub-basin of the Sichuan Basin. The Huya Valley fault marks the eastern boundary of the N-S trending Min Shan, and is generally mapped as a west-dipping thrust. Observations and inspection of aerial photographs over a distance of ~30 km reveals a prominent N to NNW trending fault that offsets a channel sinistrally by ~100m. The Beichuan fault, near Beichuan, comprises three distinct ENE-trending en echelon segments. Channel and ridge offsets show clear evidence for sinistral displacement. The fault is well expressed across the youngest terrace ~4m above the modern river and likely of Holocene age. A minor thrust component is visible along part of the fault, but the overall expression is predominantly strike-slip.

Figure 1. Historical and modern seismicity of the earthquake affected region and major faults.
Figure 1 also shows the seismicity of the region using the USGS database together with major historical events reported. The historical seismicity data is compiled from various sources (Lu et al. 2004; Yang et al. 2005; China Earthquake Administration 2008). As noted from Figure 1, the seismicity between 1973 and 2008 before the main shock occurred along the well-known faults in the domain bounded by Latitudes 30-33 and Longitudes 102-106. However, there is no earthquake with magnitude greater than 7 in the Longmenshan fault zone. The focal plane solutions of the earthquakes in Longmenshan fault zone indicate that earthquakes are due to either thrust faulting with dextral component or pure dextral slip.

2.2 Faulting Mechanism and Its Parameters

The fundamental parameters of the May 12, 2008 earthquake estimated by various institutes worldwide and they are listed in Table 1. Although there are some differences among the parameters of the earthquake estimated by various institutes, the all solutions indicate thrust faulting with a slight lateral component. As two fault planes are obtained from these solutions, the causative fault should be inferred from additional observations and seismic data. In view of the regional tectonics, after-shock activity, the fault plane dipping to NW should be the causative fault. If NW dipping fault is taken as the causative fault, then lateral strike-slip component of the faulting implies dextral motion of the fault.

### Table 1: Parameters of the earthquake estimated by different institutes

<table>
<thead>
<tr>
<th>Institute</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Depth (km)</th>
<th>Magnitude</th>
<th>Strike</th>
<th>Dip</th>
<th>Rake</th>
</tr>
</thead>
<tbody>
<tr>
<td>HARVARD</td>
<td>31.49</td>
<td>104.11</td>
<td>12</td>
<td>Mw=7.9</td>
<td>NP1 229°</td>
<td>33°</td>
<td>141°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NP2 352°</td>
<td>70°</td>
<td>63°</td>
</tr>
<tr>
<td>USGS</td>
<td>31.969</td>
<td>103.186</td>
<td>16</td>
<td>Mw=7.9</td>
<td>NP1 239°</td>
<td>59°</td>
<td>128°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NP2 2°</td>
<td>47°</td>
<td>45°</td>
</tr>
<tr>
<td>IGP-CEA</td>
<td>31.021</td>
<td>103.367</td>
<td>10</td>
<td>Ms=8.0</td>
<td>NP1 229°</td>
<td>43°</td>
<td>123°</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NP2 7°</td>
<td>55°</td>
<td>63°</td>
</tr>
<tr>
<td>Nishimura-Yagi</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>Mw=7.9</td>
<td>NP1 229°</td>
<td>33°</td>
<td>146°</td>
</tr>
<tr>
<td>Yamanaka-NGY</td>
<td>-</td>
<td>-</td>
<td>11</td>
<td>Mw=7.8</td>
<td>NP1 230°</td>
<td>30°</td>
<td>120°</td>
</tr>
</tbody>
</table>

Nishimura-Yagi (2008) and Yamanaka (2008) pointed out that a 120km fault ruptured with a dominant thrust mode first, and it was followed by almost strike-slip faulting by a 10 second delay. Although the overall rupture length seems to be about 300km long, the earthquake is a results of two fault segments successively. Furthermore, it was pointed out that there is a 50-100km long gap between two ruptured fault segments.

Along the Yingxiu-Beichuan segment, rupture structures included road arching, mole tracks, push ridges and tensional fractures, which indicate eastward thrusting of the Yingxiu-Beichuan fault with vertical displacements of 2.5-3m, accompanied by a dextral strike-slip component. The co-seismic vertical displacements measured at Yingxiu Township and the seat of Beichuan County showed the same order of amplitude at several locations indicating that the upward movement of the fault ranges between 2.5 and 3 m.

2.3 Strong Motions

There are several strong motions networks operated by different institutes in China. However, the digital data from strong motion networks are not available to the international earthquake engineering community yet. The China Earthquake Data Center reported the maximum ground acceleration near Shifang, which is 106km from the earthquake epicenter, as 632 gals. However, the maximum ground acceleration is expected to be more than 1G in the close vicinity of earthquake epicenter. The maximum acceleration was 2000 gal at the crest of Zipingpu dam. However, it should be that the maximum ground acceleration at the dam crest contains the amplification factor due to the dam body. As noted from Figure 2, the attenuation...
relations for intraplate earthquakes are far below the reported measurements. The estimations by the attenuation relation proposed by Aydan and Ohta (2006) for interplate earthquakes somewhat closer to the reported measurements (Figure 2(a)). Figure 2(b) shows the contours of maximum ground acceleration and velocity using the epicenter estimated by HARVARD.

(a) Attenuation of maximum acceleration (b) Estimated maximum acceleration contours

Figure 2. Attenuation and contours of maximum ground acceleration

3 SUPPORT ACTIVITIES OF INTERDISCIPLINARY LIAISON COUNCIL LED BY JSCE FOR TECHNOLOGICAL RESTORATION AND RECOVERY

Japan Society of Civil Engineers established Sichuan Emergency Desk soon after the earthquake under the leadership of Prof. M. Hamada. Through the inter-communication of JSCE with other earthquake involved societies, it was decided to establish an interdisciplinary liaison council consisting of Japan Society of Civil Engineers, Japan Geotechnical Society, Japan Seismological Society, Japan Architectural Institute and Japan Association for Earthquake Engineering for technological support for restoration and recovery of the earthquake area. The motivation of the liaison council was to provide technological support for restoration and recovery of the earthquake affected areas through appropriate counterparts and conveying the knowledge and know-how gathered from past earthquake disasters in Japan. It was also pointed out that the support activities are of long-term and it may involve different stages depending upon circumstances.

The first informal meeting of the liaison council was held on May 19 at the headquarters of JSCE and it was decided to dispatch the first team to the earthquake affected region with the close collaboration of Jiatong University in Chengdu between May 28 and June 1. The first team consisted of 10 representative members from each society under the leadership of Prof. Hamada. The support team first visited the earthquake epicentral area to gather some information and assess the situation on the damage to buildings, infra-structures such as bridges, viaducts, roadways, lifelines and geotechnical damage. The team visited Yingxi, Dujianyang, Shifang, Mianzhu. The team members had discussion with the people in charge for each topic on site. At the final day, a joint meeting was organized and the outcomes of investigations by Chinese authorities are presented and discussed.

Based on the outcomes and information from the first team, it was decided to dispatch the second team on the meeting on June 13, 2008 from June 20 till June 25. The second team was also lead by Prof. M. Hamada and it consisted of two sub-teams:

**Group A: Building Group (diagnosis and proposal for restoration)**

*Members:* Prof. Nakano, Prof. Maeda, Dr. Sakuda, Dr. Sakashita, Dr. Wu (translation and coordination)

*Sites:* Dujianyang, Mianzhu, Hangwan, Beichuan

**Group B: Infra-structure group (tunnels, bridges, viaducts, slopes, embankments: diagnosis**
and restoration)

Members: Prof. Kawashima, Prof. Aydan, Dr. Ito, Mr. Okubo, Mr. Honma, Dr. Wu (translation and coordination)

Sites: Zipingpu dam and its vicinity, Longxi Tunnel, Jiujiaya Tunnel, Qichuan County.

These teams investigated the earthquake area and damaged structures for two days and presented their findings to the engineers and people in charge of restoration and recovery and discussed with them what were the problems and how to implement restoration and recovery measures. Figure 3 shows the cities, towns and routes of the investigation by the dispatched teams. Figure 4 shows some views from the seminars held in Jiatong University in Chengdu.

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Figure 3. Routes of investigation and major cities along the routes

Figure 4. Views of the seminar with local engineers at Jiatong University

The teams reported their investigations results and support activities on a gathering on July 17, 2008 at JSCE Headquarters. The contents of the presentations are as follows:
1) Opening Speech by President of JSCE
2) An overview of activities of support teams by Prof. Hamada
3) Report on faulting, earthquake and strong motions by Prof. Koketsu
4) Report on damage to bridges and viaducts and support activities by Prof. Kawashima and Mr. Honma
5) Report on damage to tunnels and support activities by Dr. Ito and Mr. Ohkubo
6) Report on slope failures and support activities by Prof. Aydan
7) Report on damage to buildings and support activities by Prof. Nakano
8) Report by Dr. Wu about the impressions and effects of the seminars on Chinese side
9) Questions and discussions with participants
10) Closure speech by Prof. Hamada

On July 17, some members of the second team made further reports at the meeting of Earthquake Engineering Committee of JSCE. The reports specifically are
1. Report on damage to bridges and viaducts and their causes by Prof. Kawashima
2. Report on slope failures and their mechanism by Prof. Aydan
3. Report on damage to buildings by Prof. Aydan
4. Report on damage to tunnels and some comparisons with Japanese examples by Dr. Ito

The following subsections describe the damage situation, their causes and possible measures for quick recovery and permanent measures suggested by the teams of the liaison council.

3.1 Damage to Buildings

Buildings may be defined as masonry buildings, wooden framed buildings with brick infill walls and reinforced concrete (RC) buildings. Reinforced concrete buildings may be also sub-divided into pre-cast reinforced concrete buildings and cast-in-place reinforced concrete buildings. Masonry buildings are generally common in rural areas and villages. Adobe type masonry buildings were generally observed in Qingchuan County. These simple buildings failed in out-of-plane mode. Furthermore, they have series damage at corners. Wooden framed buildings were also observed in Qingchuan County. The wooden houses generally performed well during the earthquake. The damage to wooden building generally occurred at the foundations and infill walls.

Brick masonry buildings are common in the epicentral area, particularly in Dujiangyan, Hanwang, Hongbai, Deyang, Jianyou etc. Most of single or two story buildings constructed as brick masonry. Although the bricks are generally solid, the recent constructions utilize hollowed bricks. Most of brick houses have reinforced concrete slabs at each floor level. The damage to these buildings was mainly due to out-of-plane failure. Furthermore, the damage was heavy at corners where walls interact with each other. These locations are prone to failure during high ground motions. Some four/five story bricks buildings built in the same way also exist. Figure 4(a) shows an example of such buildings damaged by the earthquake. It is also noted that some walls failed due to toppling while other walls were sheared.

The reinforced concrete structures are the most commonly found buildings with four to six stories. The ground floor of this building are generally used as shops, offices and storage rooms. They are framed structures with integrated or non-integrated in-fill walls. The reinforcing bars are generally smooth and infill walls are built with red-burned solid or hollow clay bricks using mortar. The floor height in the region is about 3 m. The reinforced buildings in the epicentral area were designed according to the lateral seismic coefficient of 0.1 to 0.2g. The reinforced concrete buildings were built as either cast-in-place reinforced concrete buildings or pre-cast reinforced concrete buildings. The inspections of the reinforced concrete buildings indicated that they were mainly failed in the pancake mode. The concrete buildings having 3 or less stories were either slightly damaged or non-damaged. Although the earthquake mostly damaged cast-in-place reinforced concrete buildings, they performed much
better than the pre-cast reinforced concrete buildings. They were more ductile. The collapse of these buildings occurred at ground floor due to soft-floor problem.

![Multi-story brick masonry buildings](image1)

![Cast in place reinforced concrete building](image2)

Figure 4. Views of damaged masonry and cast-in place reinforced concrete buildings

Most of casualties occurred due to the total collapse of the pre-cast reinforced concrete buildings constructed as residential buildings and school buildings (Figure 5). These buildings collapsed due to insufficient lateral resistance against the strong ground motions. The lateral beams with insufficient resistance failed at the column-beam connections. The lack of sufficient reinforcing bars and structural rigidity, these buildings dilapidated like LEGO houses. The all stories of the buildings were piled up in a pan-cake fashion. It is an urgent issue for China how to deal this problem and their retrofitting elsewhere must be priority in order not to face the high casualties in future as experienced in this earthquake.

![Dujiangyan](image3)

![Ronghua-Shifang](image4)

Figure 5. Collapsed pre-cast reinforced concrete buildings at various places

The building group selected a building in Dujiangyan as a sample case and proposed some procedures and techniques how to rehabilitate the selected building (Figure 6). The building had 6 stories. The ground floor had only columns while the floors above the ground floor had brick masonry infill walls. The column-beam connections were partially broken and steel bars were ruptured. The upper floors were drifted horizontally. The team documented the damaged situation and performed some computations for the structural design parameters for damaged state. Then several procedures were considered and the increase of the seismic resistance parameters of the building for each retrofitting procedure was computed. Finally, the actual implementation of retrofitting procedures was explained to local engineers and active discussions were undertaken to know the opinions of the local engineers about the proposed procedures.
3.2 Damage to Bridges and Viaducts

There are four bridge types in the epicentral area. Old bridges are stone masonry arch bridges. The second bridge type includes simply supported or cast-in reinforced concrete arch bridges. The third type bridges or high viaducts are with simply supported pre-cast reinforced concrete bridges. The fourth type bridges are suspension bridges. Although old stone masonry arch bridges generally performed well during earthquakes, they collapsed when there were permanent movements at abutments, piers or the both.

The second bridge type includes simply supported or arch cast-in reinforced concrete bridges. The simply supported cast-in place bridges performed very well during the earthquake. Except the settlement of embankment at abutments, the damage to such bridges was almost none or slight. However, some of these bridges become obstructed by rock slope failures at several locations. Furthermore, such bridges collapsed due to permanent movement of the abutment due to thrust faulting.

Reinforced concrete arch bridges with short or long span are quite common in the epicentral area. These bridges generally performed well during the earthquake. However, there were some damage to the arch section of these bridges. The cracks run parallel to the perpendicular to the longitudinal axis of the bridge are thought to be due to movements at the abutments. One of such bridges was about 230km away from the epicenter and it was 6km away from the earthquake fault. In the vicinity of this small bridge, the stone masonry wall of a house was toppled and the inferred ground motion is expected to be more than 0.2g. It is expected that cracks observed should not be of great concern to its structural function. The heaviest damage occurred at the four span reinforced concrete Hsiaoyudong arch bridge in Longmenshan town, from which the Longmenshan fault zone was named. Besides high ground motions in the vicinity of the bridge, the shearing of arched section in the longitudinal axis of the bridge implies permanent ground movements, which may result from thrust faulting and ground liquefaction beneath the riverbed. One section of the highway named as Baihwa(Baihua) Bridge between Wenchuan and Dujiangyan, is a 500m long viaduct with a 30m height. The three-span convex part of the bridge with ground cracks collapsed during the earthquake. The girders were fallen towards the slope side while the columns were broken and fallen towards the river side.

Miaziping (Miaotzuping) bridge passes over Zipingpu dam reservoir. The bridge is 1436m long with a height of 100m (Figure 7). The main bridge has a long span box girder with 19 approaches with T-girders. The construction of the bridge was completed at the time of the earthquake. However, it was not open to traffic yet. The earthquake caused the shifting of bridge girders in longitudinally and laterally. One of the T-type girder approaches fell down.
The surveying indicated that the distance between piers was increased by more than 50cm and there were all-around fractures, spalling and bending cracks in the pier just above its foundation. While there were stoppers for lateral movements, there were no stopper longitudinally. Furthermore, the sliders (pedestals) were 40cm by 40cm.

The bridge and viaducts group discussed with local engineers about the possible restoration procedures for Miaoziping Bridges and associated viaducts, and Shoujiang Bridge. Since local engineers did not present the technical drawings of the chosen structures, it was difficult to make quantitative evaluations and possible procedures for the restoration of bridges and viaducts. Nevertheless, the causes of damaged situation of the bridge and possible restoration techniques were proposed. Furthermore, it was pointed out for the implementation of longitudinal restrainers for the bridge decks.

3.3 Damage to Tunnels

There are many roadway and railway tunnels in the epicentral area. Some of them are under construction. It is well known that the underground structures are earthquake-resistant compared to surface structures when ground shaking is concerned. The damage to tunnels was generally limited to portals, which were mainly caused by slope failures and rockfalls. Similar damage to portals of railway tunnels was also observed. Nevertheless, such damage was light in scale and did not cause any major structural stability problems so far. The authors had the chance to visit five tunnels, three of which were under construction and suffered heavy damage during the earthquake. The tunnel nearby Zipingpu dam (N31.04888, E103.56463) was a two lane tunnel with a length of about 1000m. The lining was damaged at several locations perpendicular to its longitudinal axis, which is aligned NW-SE direction. Longxi tunnel is a part of Wenchuan-Dujiangyan expressway. Two double-laned tunnels are excavated with a 3D wide pillar. The concrete lining was ruptured and the crown concrete was fallen down (Figure 8(a)). However, the overall rupture trace dips NW. The floor of the tunnel is also ruptured and uplifted by buckling. The tunnel collapsed at the location where the overburden is about 70m. The fundamental cause of the damage to this tunnel is probably the permanent ground deformations along the fault zones as well as high ground shaking.

Jiujiaya Tunnel is a 2282m long double lane tunnel and the coordinate of its south portal is N32.41288 and E105.12046. The tunnel is 226.6km away from the earthquake epicenter and
it is about 3-5km away from the earthquake fault of the Wenchuan earthquake. The tunnel face was 983m from the south portal at the time of the earthquake. The concrete lining follows the tunnel face at a distance of approximately 30m. The rock consists of phyllite with intercalations of dolomite. The bedding planes have the orientation of NW50/64, which is roughly similar to that of the Longmenshan fault zone. The geological investigation indicated that the tunnel pass through several fracture zones. 30 workers were working at the tunnel face and one worker was killed by the flying pieces of rockbolts, shotcrete and bearing plates caused by intense deformation of the tunnel face during the earthquake. The concrete lining was ruptured and fallen down at several section (Figure 8(b); Figure 9). However, the unreinforced lining rupturing was quite large and intense in the vicinity of the tunnel face. The rupturing of the concrete lining generally occurred at the crown sections although there was rupturing along the shoulders of the tunnel at several places. Furthermore, the invert was uplifted due to buckling at the middle sections. Sometimes, the whole invert was pushed upward. The tunnel heading was offset in a dextral sense with an upward movement with respect to the rest of the tunnel. The lateral and vertical offset displacements were approximately 100mm. This sense of deformation is very similar to that of the Longmenshan fault zone, which probably cuts through the tunnel with an acute angle of 50-60°. Besides the high ground shaking, the permanent ground deformations definitely played an important role on the damage observed in Jiujiaya Tunnel.

(a) Longxi Tunnel   (b) Jiujiuya Tunnel
Figure 8. Views of damage at Jiujiaya Tunnel

Figure 9. Classification of damage to tunnel linings

The local engineers did not present any technical drawing regarding the design of tunnels. Although the technical data was not available, the possible restoration techniques for the damaged part of the tunnels were proposed and discussed with local engineers involved with the design and construction of tunnels. Furthermore, the possible grouting problems in water bearing and weak fault zones were pointed out and possible procedures to improve the grouting techniques were proposed.

The local engineers for Jiujiaya tunnel also pointed out some problems associated methan gas
emission from coal layers below. The team suggested possible procedures to deal with methane emission.

3.4 Geotechnical Damage

One of the most distinct characteristics of 2008 Wenchuan earthquake is the widespread slope failures all over the epicentral area (Figure 10). The term of slope failure is preferred herein and the landslide is considered to be a special form of slope failures involving slippage on a curved or planar failure surface. Slope failures may be classified into three categories as soil slope failures, surficial slides of weathered rock slopes and rock slope failures. The specific failure modes are rotational or combined sliding and shearing failure, planar sliding failure, wedge sliding failure and flexural or block toppling failure. In addition to these failures, some passive forms of sliding and toppling failures were observed. The passive mode is defined when the vertical component of the movement of the unstable body of the slope is upward. To initiate passive modes of sliding and toppling failures, it should be noted that very high ground accelerations are necessary.

Figure 10. Examples of slope failures (landslides)

The 2008 Wenchuan earthquake caused the formation of 34 quake lakes. Among 34 quake-lakes, three quake-lakes formed in Anxian, Qingchuan and Beichuan counties, were of great scale and were caused by mainly the planar sliding failure of mountains. Among all, the biggest quake-lake was the Tangjiashan "quake lake", which was formed by the collapse of a section of Tangjiashan Mountain. Tangjiashan lake was 2 km from Beichuan and it was 803m long, 612m wide and 70-124m high. The volume of water of the Tangjiashan quake-lake was estimated as 250M m³. Although several spillways were constructed, the drainage through constructed spillways was not successful and several leakages occurred. At the final stage, explosives were used to create channels. However, these measures were not sufficient and missiles were used to control the drainage and erosion of the flow path during the breaching on June 10, 2008.

Figure 11. Tangjiashan quake lake and construction of spillways
The heavy structural damage in towns of Yingxiu and Beichuan were caused by permanent ground deformations due to faulting, slope failures (including so-called landslides) and lateral spreading resulting from strong ground shaking as well as ground liquefaction. The traces of liquefaction and associated geomorphological changes such as sandboils, lateral ground movements, settlements can be easily detected from high resolution pictures and site investigations along the routes. The sandy ground is observed along riverbanks (Figure 12).

Figure 12. Ground liquefaction and lateral spreading in the vicinity of Yingxiu town

The geotechnical group explained the causes of huge slope failures and rockfalls. The group proposed possible techniques to how to clear the collapsed debris along roadways and measures for the quick and permanent restoration procedures (Figure 13). Furthermore, the slope failures were analyzed together with some computational results from previous studies. The results are shown in Figure 14 and this figure may be a guideline for local engineers what should be the slope-cutting angle in actual restoration of the failed slopes.

Figure 13. Proposed quick recovery and permanent measures for the restoration of failed slopes
3.5 Long-term support activities

Following the first stage activities for quick recovery and restorations, the liaison team has been now expanded to include Japan Geographical Society and Japan City Planning Society. As a second stage of support activities, the education of people for earthquake disaster mitigation is chosen. The education activities will take place at Jiatong University as a special course for graduate students as well as the people in-charge with restoration and recovery as well as mitigation activities. This course is planned to start in September, 2008 and lecturers from Japan will be dispatched on chosen topics.

4 CONCLUSIONS

A liaison council was established under the leadership of Japan Society of Civil Engineers in relation to technological support for the reconstruction and restoration of the earthquake affected areas in Sichuan Province of China. The liaison council consists of the Japanese Society of Civil Engineers (JSCE) Architectural Institute of Japan (AIJ), Japan Geotechnical Society (JGS), Japan Seismological Society (JSS), Japan Association of Earthquake Engineering (JAEE), Japan Geographical Society, and Japan City Planning Society.

The liaison council before its expansion to 7 societies dispatched several investigation and support teams to the earthquake affected area. The team members, based on investigations of the damage situation of buildings, infrastructures and natural and cut-slopes, introduced several quick recovery and permanent restoration techniques to local engineers and discussed their possible implementation with them. Following the first stage support activities, the liaison council is now preparing the action and support plans for the second stage. The second stage support activities are planned to be concerned with earthquake disaster mitigation education of local engineers of Sichuan province as well as the graduate student of Jiatong University. Although the third phase activities are not discussed yet, they may involve the collaboration and cooperation of the liaison council with China’s prominent institutes disaster mitigation measures to extend the outcomes of the support activities of the liaison council.
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Abstract: This paper introduces various kinds of applications of the scenario-based seismic risk assessment. Seismic scenario simulation (SSS) is a GIS-based technique to assess distribution of ground shaking intensity, soil liquefaction probability, building damages and associated casualties, interruption of lifeline systems, economic losses, etc. given source parameters of an earthquake. The SSS may integrate with rapid earthquake information release system to obtain valuable information and to assist in decision-making processes to dispatch rescue and medical resources efficiently. The SSS may also integrate with probabilistic seismic hazard analysis to evaluate various kinds of risk estimates, such as average annual loss and probable maximum loss in one event, in a probabilistic sense and to help proposing feasible countermeasures.

Key words: seismic scenario simulation, hazard analysis, risk assessment

1 INTRODUCTION

National Science Council of Taiwan started HAZ-Taiwan project in 1998 to promote seismic scenario simulation technology. Due to lack of experience and database at that time, the original version of data classification schemes, analysis models and associated parameters used in HAZ-Taiwan software are very similar to those of HAZUS 97, which was developed by Federal Emergency Management Administration (FEMA) of USA. Afterwards, in order to fully utilize the local inventory data and associated data classification schemes, to adopt the localized analysis models and associated parameters, and to make up for the shortcomings in the software of HAZ-Taiwan, National Center for Research on Earthquake Engineering (NCREE) develops a new generation of earthquake loss estimation system, named "Taiwan Earthquake Loss Estimation System (TELES)".

There are many new features of TELES, such as running multiple instances at the same time, providing a multiple document interface, displaying multiple map windows in the same project, allowing customizable data classification schemes, and so on. These features are not seen either in the software of HAZUS or HAZ-Taiwan. Integrating inventory data, seismic hazard/damage/loss assessment models and GIS-based technologies, TELES is capable of estimating possible consequences of strong earthquakes around Taiwan. The earthquake loss estimation methodology and software intends to provide standardized scenario-based assessments for proposing seismic disaster reduction plans in normal times, and also helps to provide useful data for decision-making personnel soon after occurrence of strong earthquakes (Yeh, 2004).

Since there are large uncertainties in the earthquake occurrences and the associated consequences, seismic risk assessment is often carried out through a probabilistic approach. Since the extents of possible damages, casualties and losses are not simple one-to-one functions of ground motion parameters, the results of seismic hazard analysis in terms of hazard curves at a specific site or hazard maps of ground motion parameters can not fully represent the seismic risk of a study region, which may include very huge areas. In other words, we need a systematic approach to estimate risk instead of hazard of a wide region instead of a specific site.

This paper intends to briefly demonstrate the analysis modules and application framework of TELES. For example, TELES has developed Early Seismic Loss Estimation (ESLE) module, which is integrated with Taiwan Rapid Earthquake Information Release System (TREIRS) of Central Weather Bureau (CWB) in Taiwan. It takes only a few minutes after earthquakes to obtain valuable information about probable scale and distribution of disasters caused by the earthquake. Such kinds of information may help in the decision-making processes to dispatch the limited rescue and medical resources properly and efficiently. There are quite a few examples that have applied the seismic scenario simulation technology of TELES and integrate with probabilistic seismic hazard analysis to obtain various kinds of risk estimates in a probabilistic sense. The analysis results of quantitative seismic risk assessment have been applied in several fields in Taiwan as will be explained in the following sections.

2 DETERMINISTIC SEISMIC DISASTER SIMULATION TECHNOLOGY

The first step in seismic disaster simulation is to define source parameters of a scenario earthquake. The source parameters may include earthquake magnitude, epicenter location, focal depth, fault rupture length, width and dip angle, etc. Depending on the information of the input
source parameters, the energy release mechanism of an earthquake may be modeled as a point-source, a line-source or a plane-source. As shown in Figure 1, based on the source parameters of a scenario earthquake, the distribution of ground motion intensity (in terms of peak values and response spectra) and ground failure extent (in terms of permanent ground displacement) can be estimated through empirical attenuation laws, site-modification factors and soil liquefaction assessment models. All of the localized seismic hazard analysis have been studied and updated accordingly. The associated parameter values have also been calibrated by using many observed strong-motion records and engineering borehole data that were collected in Taiwan (Yeh et al, 2001; Yeh et al, 2002).

![Diagram](image)

**Figure 1.** Analysis modules and framework of Taiwan Earthquake Loss Estimation System

Depending on the site-dependent ground shaking intensity and ground failure extent, the damage-state probabilities of various kinds of civil infra-structures, such as buildings, bridges and buried pipelines, can also be estimated (Yeh et al, 2000; Loh et al, 2003; Yeh et al, 2004).

For example, in order to obtain more rigorous estimates about damages and losses of general building stocks (GBS), the inventory database of GBS is derived from building tax data, which is maintained and updated yearly by Ministry of Finance. Various kinds of attributes such as structural type, building occupancy class, built year, floor area, number of stories, etc. may be found in the building tax data; therefore they can be incorporated in the analysis without too many subjective adjustments. Furthermore, phenomena of material hysteresis and structural system degradation have been taken into consideration in the damage assessment of buildings. The casualty estimates due to building damages have considered the population migration patterns during different time slots in a day and also applied different casualty rates for different model building types.

All the parameter values used in this study, such as attenuation laws, site modification factors, capacity/fragility curves of model building types, casualty rates for each model building type under different damage states, etc, have been carefully studied and calibrated by using investigation data of the Chi-Chi Taiwan earthquake in 1999.

### 3 SEISMIC SCENARIO BUILDER AND DATABASE

In order to extend the applicability of SSS in early seismic loss estimation and probabilistic seismic risk assessment, it is often necessary to establish database which contains a complete set of simulation results due to many scenario earthquakes. The software architecture of TELES has been upgraded in its SSS and probabilistic seismic risk assessment models. All of the localized seismic hazard analysis have been calibrated by using many observed strong-motion records and engineering borehole data that were collected in Taiwan (Yeh et al, 2001; Yeh et al, 2002).

To be more useful in applications, the set of scenario earthquakes should represent all possible cases that may occur in the future around the study region. All of the simulation results should be systematically stored in subfolders of the project and could be retrieved easily, if required by the users. Depending on the application purpose, some pieces of data in each scenario, such as the number of damage buildings, the number of human casualties and the quantity of economic losses, can be summarized in a separate table and referred to as a scenario earthquake database (SSD). It is noted that the computation time to establish a SSD is much longer than that to run seismic hazard analysis and risk assessment. Therefore, it is desirable to reuse the SSD in the following steps of risk assessment.

Generally speaking, two types of seismic sources are included in establishing the Taiwan seismic scenario database. The first type belongs to active faults that have known geographic properties such as the surface fault trace and the dip angle of fault plane. The fault geometry, characteristic and ultimate earthquake magnitude, average annual slip rate, etc. of each active fault in Taiwan have been investigated by the Central Geological Survey Bureau (CGSB), Taiwan. There are 42 active faults in total which were published by CGSB; among them, only 13 class-1 active faults are shown in Figure 2. The discrete scenario earthquakes are modeled as plane-sources so that effects of hanging-wall versus foot-wall sides will be observed in the simulation results.

The second type of seismic sources is referred to an area source that has unknown fault trace and rupture direction. In order to cover all the possible earthquake events, the rectangular region around Taiwan (see Figure 2: longitude: from 119 to 123 degree and latitude: from 21 to 26 degree) is divided into 500 grids with 0.2 degree increments along longitudinal and latitudinal directions, as shown in Figure 2. Six focal depths, which are 10, 20, 30, 50, 70 and 90 km, are chosen to represent possible future earthquakes. In each grid and at each focal depth, earthquake magnitudes from 5.1 to 7.5 with 0.2 increments are simulated in the SSD.

Since a fault-rupture model (Der Kiureghian and Ang, 1977) is normally preferred to a point-source model in assessing damage distribution and disaster scale, all the scenario earthquakes in Taiwan SSD are associated with fault ruptures. The length of fault rupture and the number
of rupture directions to be simulated in the SSD are functions of earthquake magnitude. For example, four rupture directions are simulated when earthquake magnitude is greater than 7. There are 99,000 scenario earthquakes that belong to area sources in the SSD.

![Figure 2. Boundary map of counties and cities in Taiwan, 13 class-1 active faults classified by CGSB, and the grid system of seismic area sources around Taiwan](image)

4 APPLICATION ON EARLY SEISMIC LOSS ESTIMATION

Some of the essential facilities, such as communication and electric power systems, which are essential to collect and transmit disaster data, are vulnerable in strong earthquakes. Moreover, the response time may be further delayed because of highway damages after the strong earthquakes. Estimated distribution and amount of damages/casualties soon after strong earthquakes provide valuable information for decision-making to properly dispatch rescue forces and medical resources to the right places. Therefore, an Early Seismic Loss Estimation (ESLE) module in TELES was developed (Yeh et al, 2003).

The ESLE module is automatically triggered after receiving earthquake alert mails from the Central Weather Bureau (CWB) of Taiwan. The estimated damages and casualties are automatically output in the form of raster maps and ready-to-use tables to reduce man-works. In the first version of ESLE module, even though the analysis precision has been reduced and township instead of village has been chosen as the geographical unit, the required time to complete the hazard analysis and damage assessment still need 10 to 15 minutes depending on the earthquake magnitude, epicenter location and focal depth. Furthermore, since the seismic source information contained in the earthquake alerts from CWB is limited, a point-source model is applied in the first version of ESLE module. Using the point-source model is likely to underestimate the disaster scale.

The Taiwan SSD described in the previous section contains simulation results, such as ground motion intensity, soil liquefaction potential, amount of building damages, induced casualties/losses, etc. in each village, when scenario earthquakes with different magnitude, epicenter location and focal depth occur around Taiwan. If the SSD is integrated in the ESLE module, when any earthquake occurs, the only task that ESLE module remains to do is to search for the analysis results that coincide with the observed source parameters and the measured peak ground accelerations at the real-time stations. In this way, the SSD can be used to shorten the emergency response time and to increase the precision of analysis results at the same time.

Normally, the estimated results can be obtained within a few minutes after receiving the earthquake alert from CWB. TELES will automatically dispatch the summary information using simple message service through mobile phone and email through internet to emergency response personnel. The summary contains descriptive information such as the earthquake magnitude, the town name nearest to the epicenter, the amount of estimated casualties and the number of villages with PGA greater than 0.16g, which is considered to be the threshold of damaging intensity to the buildings in Taiwan.

Other rescue and medical resources, such as the required number of rescue teams and equipments, the fire-fighting teams and water demands, the required number of medical doctors, nurses and ambulances, the induced amount of debris, and the other livelihood, may be calculated from the analysis results of building damages, casualties, shelter needs and post-quake fires. The various kinds of estimation results have been applied in the disaster reduction and prevention information system in Central Emergency Operation Center (CEOC) of Taiwan.

5 PROBABILISTIC SEISMIC HAZARD ANALYSIS

In general, probabilistic seismic hazard analysis (PSHA) involves four steps. The first step is to identify and characterize seismic sources in the neighborhood of the study region including probability distribution of location and direction of fault rupture. The second step is to characterize the temporal distribution of earthquake recurrence with respect to different magnitudes and to determine the probable ultimate magnitude in each seismic
source. The third step is to select an appropriate ground-motion prediction model. The last step is the summation of individual effect due to different seismic sources. The uncertainties in earthquake location, fault rupture direction and ground-motion prediction model should be taken into consideration to obtain the probability that the ground motion parameter will be exceeded during a particular time period.

The seismic source model in PSHA is simply a description of the spatial and temporary distribution of earthquakes with various magnitudes and focal depths. Referring to the fault-rupture model proposed by Der Kiureghian et al. (1977), the known active faults, such as those identified by CGSB (shown in Figure 2), were classiﬁed as Type 1 sources. The rest of seismic sources with unknown fault location were classiﬁed as either Type 2 or Type 3 depending on whether the rupture direction is known or not. In practice, it is rather difﬁculty to distinguish between Type 2 and Type 3 sources. These sources are referred to as area sources in this study; and the probability distribution of fault rupture direction is not uniform for Type 2 sources.

The quality of historical earthquake catalog may signiﬁcantly inﬂuence the results of PSHA. Therefore, the completeness of earthquake events during different time period, the deﬁnition consistency of magnitude scale, and the measurement accuracy of epicenter and focal depth should be checked and calibrated carefully in the historical earthquake catalog. The seismic source zoning schemes (shown in Figure 3) and the historical earthquake catalog used in this study were the same as those used in Loh et al. (2004). The magnitude scale used in this study is Richter scale, which may saturate at about 7.5, to consist with the magnitude scale used in ground motion prediction model.

The ultimate magnitude \( m_u \) in each source zone can be estimated graphically based on the assumption of constant energy accumulation and release (Makropoulos et al., 1983). The estimated \( m_u \) may increase 2 to 5 percents to consider the uncertainty. The famous Gutenberg-Richter (G-R) magnitude recurrence relationship is often used in PSHA, especially when the earthquake occurrences are modeled as stationary Poisson processes. The parameters in G-R relationship include the annual occurrence rate \( n_0 \) of earthquakes with \( m \geq m_u \) and the relative frequency of various magnitude \( (\beta) \). However, \( n_0 \) and \( \beta \) may be obtained by different regression models, such as two-stage least square method (Loh et al., 2004; denoted by LST) or maximum likelihood estimation (Weichert, 1980; denoted by MLE). Depending on the regression methods, the parameters in G-R relationship have slightly different values, as shown in Table 1, which can be seen as imperfection or uncertainty of the model. Although results were not shown in this paper, the parameters \( m_u, n_0 \) and \( \beta \) may be obtained using different zoning schemes. It is interesting and important to compare the analysis results from different zoning schemes.

![Figure 3](attachment:image.png)

Figure 3. Example of seismic source zoning scheme for (a) shallow earthquakes and (b) deep earthquakes of area sources around Taiwan

The seismic source zones are further divided into smaller grids in calculation of hazard curves or risk estimates. The annual occurrence rate of earthquakes in each grid can be assumed to be uniform within each source zone or proportional to the number of historical earthquakes occurred within the grid. In view of the uncertainty in future earthquakes and the tendency of occurrence in particular regions, it is most likely that the true annual
occurrence rate of earthquakes in each grid lies within the previous bounds. As an example, using the maximum likelihood estimation and assuming the average of two bounds to be the occurrence rate of earthquakes in each grid, Figure 4 shows the annual occurrence rate of earthquakes with \( m \geq 5 \) in each grid of seismic source zones. The annual occurrence rate of each scenario earthquake in the SSD may be calculated by reasonably distributing the occurrence rate in each grid to different focal depths and rupture directions.

Paleoseismicity and fault slip data along major faults in southern California have been studied by Wesnousky (1994) and concluded that the characteristic earthquake model is more suitable than Gutenberg-Richter earthquake recurrence model in seismic hazard analysis and for engineering design purposes. Thus, it is one of the objectives to combine the two earthquake recurrence models in this study. The fault geometry, characteristic magnitude and recurrence rate of 13 class-1 faults are assumed and listed in Table 2. It is noted that, unlike area sources, the characteristic earthquake magnitude of an active fault, bounded by \( m_0 \) and \( m_u \), is determined by fault length or historical earthquakes; and the associated recurrence rate \( V_{T_{avg \_et}} \) is determined from field investigation or monitoring of fault slip rates. To prevent double count of the seismic hazard, the recurrence rate \( V_{T_{avg \_et}} \) has been reduced by certain amount \( \nu \), which was half of the occurrence rate of earthquakes from area source within 20 km and with magnitude in the range between \( m_0 \) and \( m_u \).

Based on the attributes listed in Tables 1 and 2 for area sources and active faults, respectively, the probabilistic seismic hazard analysis can be carried out for different sites. As an example, Figure 5 compares the seismic hazard curves of PGA at six places in Taiwan. The intensity maps of PGA or response spectra corresponding to different hazard levels may also be obtained easily by using TELES.

### Table 2. List of attributes of active faults considered in this study.

<table>
<thead>
<tr>
<th>Fault Name</th>
<th>Dip Angle (degree)</th>
<th>( d_v ) (km)</th>
<th>( m_0 )</th>
<th>( m_u )</th>
<th>( V_{T_{avg _et}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chelongpu</td>
<td>40</td>
<td>20.0</td>
<td>6.91</td>
<td>7.31</td>
<td>0.0025</td>
</tr>
<tr>
<td>Chukou</td>
<td>40</td>
<td>15.0</td>
<td>6.76</td>
<td>7.16</td>
<td>0.0040</td>
</tr>
<tr>
<td>Yuli</td>
<td>50</td>
<td>30.0</td>
<td>6.63</td>
<td>7.03</td>
<td>0.0070</td>
</tr>
<tr>
<td>Chishang</td>
<td>50</td>
<td>30.0</td>
<td>6.63</td>
<td>7.03</td>
<td>0.0100</td>
</tr>
<tr>
<td>Meilun</td>
<td>50</td>
<td>30.0</td>
<td>6.80</td>
<td>7.20</td>
<td>0.0100</td>
</tr>
<tr>
<td>Qimei</td>
<td>50</td>
<td>30.0</td>
<td>6.58</td>
<td>6.98</td>
<td>0.0025</td>
</tr>
<tr>
<td>Dajianshan</td>
<td>40</td>
<td>20.0</td>
<td>6.51</td>
<td>6.91</td>
<td>0.0040</td>
</tr>
<tr>
<td>Xincheng</td>
<td>45</td>
<td>12.0</td>
<td>6.47</td>
<td>6.87</td>
<td>0.0025</td>
</tr>
<tr>
<td>Tunzijiao</td>
<td>90</td>
<td>15.0</td>
<td>6.70</td>
<td>7.10</td>
<td>0.0040</td>
</tr>
<tr>
<td>Meishan</td>
<td>90</td>
<td>15.0</td>
<td>6.70</td>
<td>7.10</td>
<td>0.0100</td>
</tr>
<tr>
<td>Shitian</td>
<td>-75</td>
<td>12.0</td>
<td>6.70</td>
<td>7.10</td>
<td>0.0040</td>
</tr>
<tr>
<td>Shenzhuoshan</td>
<td>60</td>
<td>12.0</td>
<td>6.70</td>
<td>7.10</td>
<td>0.0040</td>
</tr>
<tr>
<td>Xinhua</td>
<td>90</td>
<td>15.0</td>
<td>5.90</td>
<td>6.30</td>
<td>0.0100</td>
</tr>
</tbody>
</table>

### Figure 4. Map of annual occurrence rate of earthquakes with \( m \geq 5 \) in each grid around Taiwan. The coefficients in the Gutenberg-Richter relationship are calculated by maximum likelihood estimation.

### Figure 5. Hazard curves of peak ground acceleration at the selected sites of Taiwan.

### 6 PROBABILISTIC SEISMIC RISK ASSESSMENT

The PSHA is often applied in estimating seismic hazard at different sites or for critical facilities (e.g., nuclear power
plants, dams, etc.). The seismic hazard curves are often in terms of exceeding probability of ground motion parameters during a particular time period. Other risk quantities, such as damage-state probabilities of civil infra-structures, human casualties, economic losses, etc. are then derived indirectly from the hazard curves of ground motion parameters. However, there are many factors which may influence the analysis results of damage/casualty/loss quantities. In other words, these damage/casualty/loss quantities can not be expressed as one-to-one functions of ground motion parameters. Thus, the accuracy of risk estimates obtained indirectly from hazard curves and empirical regression formula is questionable. To overcome the shortage in the previous approach and increase the accuracy of the risk estimates, this study combines the PSHA with seismic scenario simulations to obtain various kinds of seismic risk estimates.

The expected consequences \( (L_k) \) of each scenario earthquake \( k \) in SSD can be obtained through seismic scenario simulation, while the annual occurrence rate \( (v_i) \) for each scenario earthquake can also be determined from PSHA once the zoning scheme and the various kinds of fault attributes have been assumed as in section 5. The annual occurrence rate, expected consequence and associated uncertainty for each scenario earthquake are summarized in a table (see Table 3), which is named seismic event loss table and is very useful in risk assessment. In general, one seismic event loss table could be virtually established for each kind of damage/casualty/loss and for each target (either a study region or a critical facility).

The expected consequences \( (L_k) \) of each scenario earthquake \( k \) in SSD can be obtained through seismic scenario simulation, while the annual occurrence rate \( (v_i) \) for each scenario earthquake can also be determined from PSHA once the zoning scheme and the various kinds of fault attributes have been assumed as in section 5. The annual occurrence rate, expected consequence and associated uncertainty for each scenario earthquake are summarized in a table (see Table 3), which is named seismic event loss table and is very useful in risk assessment. In general, one seismic event loss table could be virtually established for each kind of damage/casualty/loss and for each target (either a study region or a critical facility).

### Table 3. Contents in the seismic event loss table

<table>
<thead>
<tr>
<th>Scenario ID</th>
<th>Annual Occurrence Rate</th>
<th>Expected Loss</th>
<th>Standard Deviation of Loss</th>
<th>Total Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( v_1 )</td>
<td>( L_1 )</td>
<td>( \sigma_1 )</td>
<td>( X_1 )</td>
</tr>
<tr>
<td>2</td>
<td>( v_2 )</td>
<td>( L_2 )</td>
<td>( \sigma_2 )</td>
<td>( X_2 )</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>k</td>
<td>( v_k )</td>
<td>( L_k )</td>
<td>( \sigma_k )</td>
<td>( X_k )</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>J</td>
<td>( v_J )</td>
<td>( L_J )</td>
<td>( \sigma_J )</td>
<td>( X_J )</td>
</tr>
</tbody>
</table>

In practice, given occurrence of a scenario earthquake, the standard deviation and the upper-bound of losses may be estimated by the degree of accuracy of analysis models, experiences and experts’ opinions. The distribution of losses given an earthquake may be modeled as a beta distribution with mean value equal to the expected loss from scenario simulation (Dong, 2001). The beta distribution has four parameters. Two of them control the lower and the upper bounds, while the other two parameters (denoted by \( p \) and \( q \)) define the shape of probability distribution function. According to the experiences from early seismic loss estimation (Yeh, 2004), the upper bound of losses may be assumed to be 3 to 5 times of the mean value. The shape parameters of beta distribution can be assumed to be \( (p = 2, \; q = 4) \) or \( (p = 2, \; q = 8) \) with coefficients of variation about 0.53 and 0.6, respectively.

Once the seismic event loss tables have been obtained, various kinds of risk estimates can be calculated. For example, let \( L_j \) denote the losses due to scenario earthquake \( j \) with annual occurrence rate \( v_j \). The average annual loss and standard deviation of the loss (denoted by \( \mu_L \) and \( \sigma_L \), respectively) can be expressed as:

\[
\mu_L = \sum_{j} L_j \cdot v_j \quad \text{and} \quad \sigma_L = \sqrt{\sum_{j} L_j^2 \cdot v_j} \quad (1)
\]

We can also identify the seismic sources which contribute the most risk to a particular region. Let \( L^j \) denotes the expected annual loss caused by seismic source \( J \). If there are \( m \) disjoint scenario earthquakes in the seismic source \( J \), the expected annual loss caused by the seismic source \( J \) can be calculated as follows:

\[
L^j = \frac{1}{n} \sum_{k=1}^{n} L_k \cdot v_k \quad (2)
\]

Suppose that there are \( N \) disjoint scenario earthquakes which may cause losses in the study region. The \( N \) sets of losses can be sorted in descending order, that is,

\[
L_1 \geq L_2 \geq K \geq L_K \geq K \geq L_N \quad (3)
\]

The corresponding annual occurrence rate of each disjoint scenario earthquake is \( v_1, \; v_2, \cdots, v_k, \cdots, v_N \), respectively. According to the definition, the annual occurrence rate with \( L \geq L_i \) is \( v_i \); the annual occurrence rate with \( L \geq L_1 \) is \( v_1 + v_2 \). In general, the annual occurrence rate with \( L \geq L_K \) is \( v^K \), which can be expressed as

\[
v^K = \sum_{j=1}^{K} v_j \quad (4)
\]

Assuming the earthquake occurrences are stationary Poisson processes, the annual occurrence probability of event \( L \geq L_K \) can be expressed as

\[
P(L \geq L_K) = 1 - \exp(-v^K) \quad (5)
\]

If the uncertainty of losses given occurrence of scenario earthquakes is not considered, the exceeding probability curves of loss estimates can be calculated through Eq. 4 and 5.

### 7 DETERMINATION OF PROBABLE MAXIMUM EARTHQUAKES

The probable maximum earthquakes (PME) in this study refer to the strong earthquakes which may result in very severe damages, casualties and losses; and the earthquakes are expected to occur with reasonable probability within a
specified period of time. Determination of PME for counties/cities is an important subject in proposing effective disaster reduction plans, because all the governmental sectors should apply state-of-the-art technologies to estimate the most severe and still possible consequences based on the definitions or source parameters of the selected PME.

Once the source parameters of PME have been determined, the site-dependent ground motion intensity, soil liquefaction probability, damage-state probabilities of various kinds of infrastructures, number of post-earthquake fires and possible burned floor-areas, number of casualties and temporary shelter needs, socio-economic losses, etc. may be obtained through SSS. Based on the simulation results, proper disaster reduction plans and efficient emergency response strategies may be proposed.

Table 4 lists the average annual loss/casualty estimates due to earthquakes around Taiwan by using Eq. 1. As an example, from Table 4, the annual average casualty is about 90 persons for the whole Taiwan and it means that about 4,500 persons will be killed or severely injured due to earthquakes in every 50-year. The disaster scale is about the same as that caused by Chi-Chi Taiwan earthquake in 1999.

It is noted that depending on the simulation results \( L_j \) and the annual occurrence rates of scenario earthquakes \( v_j \), the average annual loss/casualty estimates may have different values. Besides, the simulation results and the occurrence rates depend on the parameter values used in seismic scenario simulations and the assumptions applied on seismic source models. The uncertainty in analysis models and seismic source models should be considered in more sophisticated ways, such as those used in insurance markets; but they are out of scope of the present study.

From Table 4, it is ready to compare the relative risk in each county/city in Taiwan. It is also noted that the sum of average annual loss/casualty in individual county/city is equal to the average annual loss/casualty of the whole Taiwan area. Since different results may be obtained by using different seismic source models and parameter values, it is important to conduct sensitivity study to find reasonable confidence intervals. For example, only the 13 class-1 active faults listed in Table 2 were taken into consideration in evaluating Table 4. If all of the 42 active faults identified by CGSB were considered in the analysis, the average annual loss/casualty will increase significantly due to increase of seismic hazard potential.

Based on the SSD and the results of PSHA without secondary uncertainties, the loss/casualty of general building stocks in each county/city corresponding to 200-year and 50-year return periods are calculated by Eq. 5 and listed in Table 5. If the secondary uncertainties of loss/casualty estimates were considered, they are often modeled as beta probability distributions with proper bounds and shape parameters. The variances and the confidence intervals of EP curves for the loss/casualty estimates can be studied through Monte Carlo simulation (Dong, 2001). Various kinds of EP curves for risk estimates, such as those for occurrence and aggregate annual losses, of each county/city have been obtained, but omitted in this paper because of space constraints. According to the simulation results, the risk estimates may increase about 14% to 20%.

**Table 4. List of average annual losses and casualties in each county and city of Taiwan**

<table>
<thead>
<tr>
<th>District</th>
<th>Loss (million NT)</th>
<th>Casualty (person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taipei County</td>
<td>187</td>
<td>3.3</td>
</tr>
<tr>
<td>Ilan County</td>
<td>131</td>
<td>3.6</td>
</tr>
<tr>
<td>Taoyuan County</td>
<td>145</td>
<td>2.7</td>
</tr>
<tr>
<td>Hsinchu County</td>
<td>84</td>
<td>2.8</td>
</tr>
<tr>
<td>Miaoli County</td>
<td>141</td>
<td>5.7</td>
</tr>
<tr>
<td>Taichung County</td>
<td>385</td>
<td>17.0</td>
</tr>
<tr>
<td>Changhua County</td>
<td>156</td>
<td>3.9</td>
</tr>
<tr>
<td>Nantou County</td>
<td>105</td>
<td>3.1</td>
</tr>
<tr>
<td>Yunlin County</td>
<td>154</td>
<td>5.9</td>
</tr>
<tr>
<td>Chiayi County</td>
<td>154</td>
<td>6.0</td>
</tr>
<tr>
<td>Tainan County</td>
<td>200</td>
<td>6.4</td>
</tr>
<tr>
<td>Kaohsiung County</td>
<td>88</td>
<td>1.5</td>
</tr>
<tr>
<td>Pingtung County</td>
<td>51</td>
<td>1.1</td>
</tr>
<tr>
<td>Taitung County</td>
<td>47</td>
<td>1.6</td>
</tr>
<tr>
<td>Hualien County</td>
<td>247</td>
<td>8.7</td>
</tr>
<tr>
<td>Keelung City</td>
<td>13</td>
<td>0.4</td>
</tr>
<tr>
<td>Hsinchu City</td>
<td>67</td>
<td>1.6</td>
</tr>
<tr>
<td>Taichung City</td>
<td>234</td>
<td>5.8</td>
</tr>
<tr>
<td>Chia City</td>
<td>108</td>
<td>3.5</td>
</tr>
<tr>
<td>Tainan City</td>
<td>86</td>
<td>1.5</td>
</tr>
<tr>
<td>Taipei City</td>
<td>170</td>
<td>2.8</td>
</tr>
<tr>
<td>Kaohsiung City</td>
<td>113</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>Taiwan</strong></td>
<td><strong>3,067</strong></td>
<td><strong>90.2</strong></td>
</tr>
</tbody>
</table>

It is important to know how to interpret the data in Tables 4 and 5. For example, from Table 5, the casualty estimate is about 879 persons corresponding to 50-year return period for the whole Taiwan. Comparing with the information in Table 4, there are about 4,500 persons killed or severely injured in 50 years, but the largest disaster event causes about 879 persons killed or severely injured in every 50-year period.

As a second example, if the protection standard is decided to be 200-year return period, the rescue and medical resources in Taipei City should prepare to manage a disaster with more than 86 persons in danger at the same time. However, it is also noted in Table 5, corresponding to 200-year return period, that the sum of casualties in each
county/city (3,071) is smaller than that of the whole Taiwan (3,569). It means that if every county/city independently prepares its rescue and medical resources, they are not sufficient for the whole Taiwan. Since the finance and economic conditions are quite different in each county/city, it is suggested that a wealthy county/city should allocate more budgets on the preparedness of rescue and medical resources. The insufficient portion of the rescue and medical resources should be prepared by the central government. Secondly, in order to achieve the goal, nearby counties or cities should sign agreement to cooperate and manage disaster together.

Table 5. List of losses and casualties in different return periods

<table>
<thead>
<tr>
<th>District</th>
<th>200 years</th>
<th>50 years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loss</td>
<td>Casualty</td>
</tr>
<tr>
<td></td>
<td>(million NT dollars)</td>
<td></td>
</tr>
<tr>
<td>Taipei County</td>
<td>9,554</td>
<td>100</td>
</tr>
<tr>
<td>Ilan County</td>
<td>4,429</td>
<td>116</td>
</tr>
<tr>
<td>Taoyuan County</td>
<td>7,310</td>
<td>60</td>
</tr>
<tr>
<td>Hsinchu County</td>
<td>4,113</td>
<td>91</td>
</tr>
<tr>
<td>Miaoli County</td>
<td>6,453</td>
<td>254</td>
</tr>
<tr>
<td>Taichung County</td>
<td>15,403</td>
<td>474</td>
</tr>
<tr>
<td>Changhua County</td>
<td>6,804</td>
<td>106</td>
</tr>
<tr>
<td>Nantou County</td>
<td>3,386</td>
<td>80</td>
</tr>
<tr>
<td>Yunlin County</td>
<td>6,750</td>
<td>244</td>
</tr>
<tr>
<td>Chiayi County</td>
<td>6,548</td>
<td>250</td>
</tr>
<tr>
<td>Tainan County</td>
<td>8,112</td>
<td>230</td>
</tr>
<tr>
<td>Kaohsiung Cnty</td>
<td>4,140</td>
<td>46</td>
</tr>
<tr>
<td>Pingtung County</td>
<td>2,321</td>
<td>26</td>
</tr>
<tr>
<td>Taitung County</td>
<td>1,434</td>
<td>66</td>
</tr>
<tr>
<td>Hualien County</td>
<td>6,612</td>
<td>394</td>
</tr>
<tr>
<td>Keelung City</td>
<td>658</td>
<td>4</td>
</tr>
<tr>
<td>Hsinchu City</td>
<td>3,345</td>
<td>57</td>
</tr>
<tr>
<td>Taichung City</td>
<td>10,387</td>
<td>142</td>
</tr>
<tr>
<td>Chia City</td>
<td>4,488</td>
<td>159</td>
</tr>
<tr>
<td>Tainan City</td>
<td>4,235</td>
<td>55</td>
</tr>
<tr>
<td>Taipei City</td>
<td>9,839</td>
<td>86</td>
</tr>
<tr>
<td>Kaohsiung City</td>
<td>6,301</td>
<td>31</td>
</tr>
<tr>
<td>Taiwan</td>
<td>85,337</td>
<td>3,569</td>
</tr>
<tr>
<td>$\sum L_i$</td>
<td>132,622</td>
<td>3,071</td>
</tr>
</tbody>
</table>

It is also noted that the sum of loss/casualty in each county/city becomes larger than that for the whole Taiwan when the return period becomes bigger. For example, corresponding to 200-year return period, the sum of individual losses is about 133 billions, which is larger than 85 billions for the whole Taiwan.

Based on data in Tables 4 and 5, together with the other related information, it is possible to propose PME for each county/city in Taiwan in a probabilistic sense. Traditionally, the PME for a specific county/city may be solely determined by PSHA. Only EP curves of PGA may be taken into consideration. De-aggregation of hazard sources would be used to determine the location and magnitude of PME. In such cases, the quantity and distribution of vulnerable exposures are not properly taken into consideration and would lead to erroneous choice of PME. To emphasize the importance of consequence, it is suggested that once the protection standards have been determined, the PME for each county/city should be selected from the SSD with similar disaster scale, having the largest occurrence rate, or contributing the most of risk sources. Based on the simulation results of the PME, distribution of rescue and medical resources can be arranges to manage the possible disaster patterns.

8 PRIORITIZATION FOR SEISMIC RETROFIT OF HIGHWAY BRIDGES

There are more than 20,000 highway bridges in Taiwan. Some (about 2,500) of them are located on the province highways, which are the main roads connecting counties and cities and hence belong to important bridges. Since many of the province highway bridges were constructed before modern seismic design codes were enforced, they should be examined, evaluated and retrofitted if necessary. In 2005, a project were issued by the Directorate General of Highways, MOTC, to investigate preliminarily the seismic capacity of the existing highway bridges, to estimate approximately the retrofit cost and to prioritize the retrofit sequence based on the results of seismic risk assessment.

Since there are many existing bridges, it is neither necessary nor practical to evaluate seismic capacity and vulnerability of each bridge in detail at the preliminary stage. To assess probable risk of highway bridges, all of the existing highway bridges were roughly classified into eight categories according to the number of spans, continuity of super-structures and type of piers. Each category of highway bridges was further classified into three sub-categories, i.e., traditional design, retrofitted and seismic design. The fragility curves of the prototype for each class and sub-class were calibrated using nonlinear push-over analysis of 148 existing bridges, which were in different bridge categories, at different locations and with various ages. Since different seismic design forces were used in different version of design codes and depended on seismic zoning schemes, the parameters of fragility curves for each individual bridge was modified based on its design year, site condition and seismic zone.
The losses considered in this project include direct losses due to structural damages and indirect losses due to interruption, restoration or reconstruction of bridges. Average daily traffic, detour length, probability of failure, restoration time, etc. had been taken into consideration in estimating the indirect losses.

Using the probabilistic seismic source model stated in section 5 and the risk assessment methodology stated in section 6, it is possible to calculate the average annual loss of each bridge before and after seismic retrofit, denoted by $L_c$ and $L_r$, respectively. In order to prioritize the retrofit sequence of bridges, two indicators have been proposed in this project. The indicators are defined for each bridge and are based primarily on the results of seismic risk assessment. The first one is called risk indicator ($I_r$) and is defined as follows:

$$0 \leq I_r = \frac{L_r \cdot N_c}{C_b} \leq 1$$

(6)

where $N_c$ denotes the expected service period (in years) of the bridge; $C_b$ is the rebuild cost; and the value of $I_r$ is bounded between 0 and 1. The second one is called beneficial indicator ($I_b$) and is defined as follows:

$$0 \leq I_b = \frac{L_c - L_r - (C_r / N_c)}{L_c} \leq 1$$

(7)

where $C_r$ is the estimated retrofit cost; and $N_c$ is the expected service period (in years) of the bridge after retrofit.

The two indicators shown in Eq. 6 and 7 may be combined with other indicators such as importance indicator and used in prioritization of seismic retrofit of bridges.

9 APPLICATION FRAMEWORK OF TELES

This study combines the probabilistic seismic hazard analysis and the seismic disaster simulation technology in single software. The proposed analysis framework and possible applications of TELES are shown in Figure 6 and are summarized as the following steps:

- Collect various kinds of data including historical earthquake catalog, active fault maps and associated attributes, various inventory databases of structures and facilities, and so on.
- Develop seismic disaster simulation technologies to integrate the state-of-the-art analysis models and to calibrate the associated parameters. The simulation outcomes may include excitation intensity, soil liquefaction potential, damage-state probabilities of civil infrastructures, number of casualties and temporary shelter needs, direct/indirect economic losses, etc. when a scenario earthquake occurs.
- Develop seismic scenario builder to run a series of predefined scenario earthquakes in batch mode and to obtain seismic scenario database based on the simulation results. The set of the predefined scenario earthquakes should cover all possible events, which may influence the study region.
- Develop probabilistic seismic hazard analysis module, not only to obtain hazard curves or hazard maps in terms of ground motion parameters, but also to obtain the annual occurrence rate of each scenario earthquake in the seismic scenario database.
- Combine the seismic scenario database and the results of probabilistic seismic hazard analysis to obtain seismic event loss table, which can be used to calculate various kinds of risk estimates within different regions or of specific targets. The risk assessment can be applied in insurance industries or disaster mitigation plans (Dong, 2001).

10 CONCLUDING REMARKS

Taiwan Earthquake Loss Estimation System (TELES) is part of the research accomplishment of HAZ-Taiwan project. Integration of the seismic scenario database and the probabilistic seismic hazard analysis module may have many potential applications. First, it can be used in early seismic loss estimation, because the distribution and scale of disasters may be calculated before earthquake occurrence and thus the response time is significantly reduced. Second, it may be used in seismic risk assessment and catastrophic risk management, especially in defining the probable maximum earthquakes for each county/city in probabilistic sense. The proposed probable maximum earthquakes are useful in proposing seismic disaster mitigation plans to estimate the possible disaster extent and loss distribution in each county/city and to prepare adequate amount of rescue and medical resources. The systematic approach to estimate seismic hazard and risk is also useful in proposing seismic insurance policy of residential buildings, retrofit prioritization of highway bridges and school buildings, etc.
ACKNOWLEDGEMENTS

The author is deeply grateful to Dr. Wen-Yi Jean for his valuable comments and would like to thank the National Science Council for financial support, the Ministry of Finance for providing building tax data, the Central Weather Bureau for providing complete set of historical earthquake catalog and strong-motion records, and all the participants of joint projects which collected various kinds of database, developed analysis models and calibrated values of the analysis parameters.

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SEISMIC RETROFITTING OF BRIDGE COLUMNS USING CARBON FIBER REINFORCED PLASTICS IN TAIWAN

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Abstract: In this paper, reinforced concrete bridge columns designed according to the old design codes in Taiwan and then retrofitted by carbon fiber reinforced plastics (CFRP) are studied experimentally and analytically. An effective constitutive model for concrete confined by CFRP is then introduced and used to determine the thickness of CFRP for retrofitting bridge columns and to analyze the lateral force-displacement relationship of circular-sectioned bridge columns. After testing the scaled-down bridge columns with different failure modes under cyclic loading at the National Center for Research on Earthquake Engineering (NCREE), we discover that the analytical lateral force-lateral displacement relationships of bridge columns using the proposed constitutive model can predict the lateral force-lateral displacement relationships of the experimental result very well. In addition, the performance of retrofitted bridge columns can be greatly improved by using CFRP composite material.

Key words: Seismic retrofit, Bridge Column, Carbon Fiber Reinforced Plastics

1 INTRODUCTION

In the last few decades, several strong earthquakes attacked California in U.S.A., Kobe in Japan, Ji-Ji in Taiwan, and Sichuan in China. These major earthquakes have caused severe bridge damage and collapses. The conventional method of retrofitting bridge columns is steel jacketing, which can enhance the flexural strength, shear strength or compressive strength of bridge columns. Research on the CFRP composite jacketing of RC bridge columns did not start until the beginning of the last decade. The pioneer researchers of CFRP are Priestley et al. (1992, 1995), Mirmiran and Shahawy (1997), Hoshikuma et al. (1997), Saadamanesh et al. (1997), Pantelides et al. (1999), Saiidi et al. (1999), Xiao et al. (1999), and Li et al. (2002, 2004). CFRP composite material has been widely used in the retrofit and rehabilitation of buildings and bridges due to its merits of anti-corrosion, lightweight, easy cutting and construction, as well as high strength-to-weight ratio, high elastic modulus, and high resistance to environmental degradation.

During the Ji-Ji Earthquake in Taiwan, bridges that collapsed were those designed and built using the seismic design codes published in 1987 (MOTC, 1987). This aroused much concern for the safety of existing bridges. Under the current seismic design code, most of Taiwan’s bridge columns are not strong enough to resist major earthquakes and need to be retrofitted. Therefore, the seismic retrofit of bridge columns became a very important issue in the Taiwan area. Since 1997, a great deal of research on how to retrofit the existing bridge columns has been done. After the Ji-Ji Earthquake in 1999, the research results of retrofitting bridge column have been widely used in the Taiwan area, and more than 200,000 m² CFRP composite material has been used. By using CFRP to retrofit bridge columns, we have found that the compressive strength, shear strength, flexural strength and displacement ductility of bridge columns can be tremendously increased.

In this paper, the constitutive model for concrete confined with CFRP was introduced (Li et al. 2003); the experiments of the bridge columns retrofitted by CFRP were tested at NCREE, and the experimental results were discussed; the theoretical sectional analysis of the circular sectioned bridge columns were analyzed and compared with the experimental results.

2 CONSTITUTIVE MODEL FOR CONFINED CONCRETE

The constitutive model for confined concrete was developed by Li et al. (2003) for concrete confined by both the steel reinforcement and CFRP composite. The illustration figure of steel reinforcement and CFRP confining concrete cylinder is shown in Fig. 1. According to the Mohr-Columb failure envelop of the soil under lateral confined stress (σ₃), the axial stress (σᵢ) can be expressed as follows:

\[ \sigmaᵢ = 2c \tan \left( 45° + \frac{\phi}{2} \right) + \sigma₃ \tan^2 \left( 45° + \frac{\phi}{2} \right) \]  \( (1) \)

In Eq. (1), \( \sigmaᵢ \) is the axial stress, \( c \) is the cohesion of the soil, \( \sigma₃ \) is the lateral confined stress, and \( \phi \) is the angle of internal friction. If the stress relationship of Eq. (1) is the tri-axial stress relationship of confined concrete, \( \sigmaᵢ \) is the
effective confined stress, while $\sigma_i$ is the maximum axial strength. When $\sigma_i=0$, i.e. in the unconfined situation, the unconfined concrete strength can be expressed as $\sigma_i = 2\epsilon \tan (45^\circ + \phi/2) = f'_{cc}$. In the retrofit design of columns using CFRP composite materials, the lateral confinement should consider the confinements of the CFRP and steel reinforcement together. Therefore, the peak strength of the concrete confined by CFRP and steel reinforcement can be expressed as follow:

$$f'_{cc} = f'_{co} + (f'_{lb} + f'_{l2}) \times \tan^2(45^\circ + \phi/2) \quad (2)$$

In the above equation, $f'_{cc}$ is the peak strength of confined concrete, $f'_{co}$ is the strength of unconfined concrete, $f'_{lb}$ is the effective lateral confinement strength due to steel reinforcement (spiral or hoop), and $f'_{l2}$ is the effective lateral confinement strength coming from CFRP, and these two confinement stresses can be expressed as follows:

$$f'_{lb} = \frac{1}{2} k_c \rho_s f'_{ylh} \quad (3)$$

$$f'_{l2} = k_c \frac{2 \times n \times t \times E_{cf} \times \epsilon_{ef}}{D} \quad (4)$$

In Eq. (2), $\phi$ is the angle of the internal friction of concrete and usually ranges from $36^\circ$ to $45^\circ$ for most strengths of concrete. The angle of internal friction is not easily obtained from experimental observation. The failure mode of the uni-axial compression test of the concrete cylinder is shear failure, and this failure angle depends on the concrete strength. Therefore, the angle of internal friction $\phi$ can be expressed as a function of concrete strength, as shown in Eq. (5).

$$\phi = 36^\circ + 10 \left( \frac{f'_{co}}{3.5} \right) \leq 45^\circ \quad (MPa) \quad (5)$$

In Eq. (3), $f'_{ylh}$ is the yield strength of the transverse reinforcement, $\rho_s$ is the transverse steel ratio, and $k_c$ is the effectiveness confinement coefficient (Mander et al., 1988). In Eq. (4), $k_c$ is the coefficient of the section shape, $n$ is the number of the layers of CFRP, $t$ is the thickness of CFRP per layer, $E_{cf}$ is the elastic modulus of CFRP, $\epsilon_{ef}$ is the allowable strain of CFRP, and $D$ is the diameter of the cylinder.

Based on the experimental data of Li et al. (2003) with different concrete strengths, different layers of CFRP and different dimensions, the relationship between $\epsilon'_{cc}$ and $(f'_{l2}/f'_c)$ can be expressed as a linear relation as shown in Eq. (6).

$$\epsilon'_{cc} = \epsilon'_{co} \left[ 1 + 2.24 \tan^2(45^\circ + \phi/2) \right] \frac{f'_{l2}}{f'_c} \quad (6)$$

In Eq. (6), $\epsilon'_{co}$ is the compressive strain at the unconfined ultimate concrete stress. As the strain $\epsilon'_c$ falls between 0 to $\epsilon'_c$, the stress-strain relation can be approximated by using the second-order polynomial equation. The stress-strain relation of confined concrete is shown as follows:

$$f'_c = f'_{cc} \left[ \frac{\epsilon'_c}{\epsilon'_{co}} - \left( \frac{\epsilon'_c}{\epsilon'_{co}} \right)^2 \right], \quad 0 < \epsilon'_c < \epsilon'_c' \quad (7)$$

### 3 EXPERIMENTAL PROGRAM

The experimental test uses a displacement control method to precede the cyclic loading test. The actuators apply both the horizontal load and the vertical load simultaneously. By applying the vertical load, a horizontal beam was used on the column top, as seen in Fig. 2. The vertical actuator was embedded at the bottom of the strong floor at NCREE. The experimental test uses a displacement control method to precede a horizontal cyclic-loading test with constant axial load. The test does not stop until concrete spalling happens, the vertical reinforcement bar breaks, the horizontal reinforcement bar loosens, or the lateral force reduces to 40% compared to the maximum (ultimate) force.

The retrofit design equations (Aschheim et al., 1997) of the flexural-failure and shear-failure bridge columns using CFRP are expressed as Eq. (8), and Eq. (9), respectively.

$$t_f = \frac{D}{22.5} \left\{ f'_{yl} \left[ 0.5 + 1.25 \frac{P}{f'_{c}A_g} \right] + 0.13 \left( \rho_s - 0.01 \right) \right\} \quad (ATC-32, 1996). \quad (8)$$

$$t_f \geq \frac{\pi}{2} f_{jd} D \cot \theta \quad (Priestly et al., 1996) \quad (9)$$

where $t_f$ is the design thickness of the CFRP.
failure bridge columns (named as BMCS, FCS-1, FCS-2). The design details of the two groups bridge columns are shown in Fig. 3 and Fig. 4, respectively.

According to the retrofitted design equations, the columns FC2, and FC3 were retrofitted by using four layers CFRP; and FCs-1 and FCS-2 were retrofitted by using three and two layers CFRP. The detailed discussions were mentioned by Li et al. (2002) and Li and Sung (2004).

4 EXPERIMENTAL RESULTS

In this section, the topics of the ductility and draft ratio of bridge columns, and the energy dissipation of bridge columns will be further discussed.

4.1 Energy Dissipation

The dissipated energy was defined as the area within the lateral force-lateral displacement envelop curve.

- Flexural-failure bridge columns

The comparison of the energy dissipation for columns FC1, FC2 and FC3 are shown in Fig. 5. As seen in Figure 5, the dissipation energies of FC2 and FC3 are much higher than the dissipation energy of FC1.

- Shear-failure bridge columns

The comparison of the energy dissipation for columns BMCS, FCS-1 and FCS-2 are shown in Fig. 6. As seen in Fig. 6, the dissipation energies of FCS-1 and FCS-2 are much higher than the dissipation energy of BMCS.

4.2 Ductility and Drift Ratio

The peak ductility was obtained by calculating the column deflection occurring at 80% of the peak lateral force. The yield deflections were idealized from the measures lateral force-lateral displacement envelopes using an equal area method and the elastic slope passing through first bar yield.

- Flexural-failure bridge columns

The lateral force-displacement relationship of column FC1 is shown in Fig. 7, the ductility of FC1 is 7.9 (drift ratio=4.3), and the maximum lateral force is 260 kN. As seen from Fig. 8 and Fig. 9, the ductilities of columns FC2 and FC3 are 14.6 (drift ratio=6.3) and 14.5 (drift ratio=6.2), while the maximum lateral forces are about 340 kN and 320 kN, respectively. We can see that the strength degradation was delayed in the CFRP retrofit columns, and the seismic retrofit can indeed increase the ductility and ultimate strength of the bridge columns.

- Shear-failure bridge columns

According to Fig. 10 (the lateral force-displacement relationship), the ductility of BMCS is 2.3 (drift ratio=1.5), and the maximum lateral force is 660 kN. As seen from Fig. 11 and Fig. 12, the ductilities of FCS-1 and FCS-2 bridge columns are 9.8 (drift ratio=6.3) and 9.1 (drift ratio=5.4), while the maximum lateral forces are about 981.8 kN and 953.2 kN, respectively. We can see that the strength degradation was delayed in the CFRP retrofit columns, and the seismic retrofit can indeed increase the ductility and ultimate strength of the bridge columns.

5 THEORETICAL ANALYSIS

The analytical calculation of the lateral force-lateral displacement relationships was based on the proposed constitutive model and the sectional analysis of circular bridge columns. The discretized column section is shown in Fig. 13; D is the diameter of the column, \( t \) is the thickness of each slice, and \( y_c \) is the distance between the center of the slice to the top edge of the column.

- Flexural-failure bridge columns

Fig. 14 and Fig. 15 are the comparisons of the analytical and experimental results for columns FC2 and FC3, respectively. As seen from those figures, the analytical results can simulate the experimental results very well.

- Shear-failure bridge columns

Fig. 16 and Fig. 17 are the comparisons of the analytical and experimental results for columns FCS-1 and FCS-2, respectively. As seen from those figures, the analytical results can simulate the experimental results with a good accuracy.

6 CONCLUSIONS

From the analytical and experimental results of this paper, the following conclusions can be addressed:

1. Using the proposed constitutive model and implementing it into the sectional analysis, the results can simulate the experimental results very well.

2. Using CFRP jacketing to retrofit bridge columns, the ultimate lateral force and ductility of bridge columns can be increased for the circular-section columns.

3. The experimental results show that proper repair and rehabilitation can significantly improve the seismic performance of the bridge column in terms of strength and ductility (Column FCS-3).

4. With proper retrofitting, the failure mode of the bridge column changes from shear failure to flexural failure.

5. For shear-failure bridge columns, using CFRP jacketing can tremendously increase the ultimate lateral force and ductility of bridge columns.

ACKNOWLEDGMENT

This work has been financially supported by the National Science Council (NSC) of the Taiwan government with National Taipei University of Technology. The bridge column experimental work was jointly supported by the NSC and the National Center for Research on Earthquake Engineering (NCREE) of Taiwan.

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Fig. 3  The design details of the flexural-failure bridge columns

Fig. 4  The design details of the shear-failure bridge columns

Fig. 5  The energy dissipation of bridge column FC1, FC2 and FC3

Fig. 6  The comparison of the energy dissipation for bridge column BMCS, FCS-1 and FCS-2

Fig. 7  The experimental relationship of hysteretic lateral force-displacement for column FC1
Fig. 8  The experimental relationship of hysteretic lateral force- displacement for column FC2

Fig. 9  The experimental relationship of hysteretic lateral force- displacement for column FC3

Fig. 10  The experimental relationship of hysteretic lateral force- displacement for column BMCS

Fig. 11  The experimental relationship of hysteretic lateral force- displacement for column FCS-1

Fig. 12  The experimental relationship of hysteretic lateral force- displacement for column FCS-2

Fig. 13  The illustration figure of the discretization of circular section
Fig. 14  The comparison of the theoretical and experimental results for column FC2

Fig. 15  The comparison of the theoretical and experimental results for column FC3

Fig. 16 The comparison of the theoretical and experimental results for column FCS-1

Figure 17. The comparison of the theoretical and experimental results for column FCS-2
Constitutive Model for Confined Concrete Using Lateral Steel Reinforcement and CFRP

- M-L-L Model

Spiral (Steel Reinforcement)
SEISMIC PERFORMANCE OF RC BRIDGE COLUMNS BASED ON FULL-SCALE EXCITATION TESTS

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Abstract : This paper presents a large scale shake table experiment on a reinforced concrete bridge column conducted using E-Defense in December 2007. The model was a typical column which was built in 1970s in Japan. Collapse of this type of columns was one of the major causes of the extensive damage during 1995 Kobe, Japan earthquake. Invaluable data on the failure mechanism and response of a RC bridge column was obtained.

Key words : bridges, seismic response, seismic design, ductility, flexure failure, E-Defense

1. INTRODUCTION

E-Defense was built to advance the scientific knowledge in the earthquake engineering as a consequence of the extensive damage of urban infrastructures in the 1995 Kobe, Japan earthquake. “Why did structures suffer such extensive damage during the Kobe earthquake?, what were the mechanism of failure?, and what extent do structures fail under near-field ground motions?” are the basic motivations of constriction of E-Defense [Katayama 2005].

The first large-scale shake table experiment using E-defense on bridge structures was conducted in 2007 on a reinforced concrete column which represented a typical column built in 1970s in Japan. Because collapse of this type of columns was one of the major sources of the extensive damage of bridges during 1995 Kobe, Japan earthquake [Kawashima and Unjoh 1997], it was considered important to clarify its failure mechanism based on the original motivation of E-Defense [Nakashima et al 2008]. The seismic design criteria for bridges before 1980 had various deficiencies. The design essentially stood on a static working stress analysis considering 0.2-0.3 seismic coefficient. It was considered at those days that bridges designed based on the traditional static analysis might be safe for responses higher than 0.2-0.3g because various redundancies were included in design. However, such a design concept only prevented and delayed to introduce new research accomplishments on ground motions, nonlinear structural response and the capacity of structural components. An overestimation of the shear capacity of RC columns, insufficient development of ties, insufficient development of main reinforcements when they were terminated at mid-heights, underestimation of seismic force demands for bearings and girders and lack of the capacity design concept were the major problems included in the design of bridges which suffered extensive damage during the 1995 Kobe earthquake.

This paper introduces the first E-Defense experiment on a RC bridge column which represents typical bridge columns in 1970s. This column model is denoted hereinafter as C1-1 column mode.

2. MODEL

C1-1 is a 7.5 m tall 1.8 m diameter circular reinforced concrete column as shown in Fig. 1. It was designed based on a combination of the static lateral force method and the working stress analysis specified in the 1964 Design Specifications of Steel Road Bridges, Japan Road Association [JRA 1964]. Combination of the lateral seismic coefficient of 0.23 and the vertical seismic coefficient of +/-0.11 (upward and downward seismic force) was assumed in design. It is also assumed that the column is built on the Type II soil (moderate) site. It was nearly a half scale of prototype columns, therefore it was designed assuming that it was a small prototype column without considering the scaling rule. This is because the scaling rule cannot be explicitly implemented to structures in which plastic deformation is predominant.

The column had reinforcements in three layers, i.e., 32, 32 and 16 longitudinal reinforcements were provided at the outer, middle and inner layers as shown in Photos 1 and 2. Longitudinal and tie reinforcements were deformed 29 mm and 13 mm diameter bars, respectively, with the nominal yield strength of 345MPa. Ties were provided at every 300 mm interval, except the outer ties at the top 1.15 m zone and the bottom 0.95 m zone where they were provided at 150 mm interval. Ties were lap spliced. It was the common practice by the mid 1980s because the importance of the lateral confinement was not considered. The longitudinal reinforcement ratio is 2.02% and the tie volumetric...
reinforcement ratio $\rho_s$ is 0.32% except the top 1.15m and bottom 0.95 m zones where $\rho_s$ is 0.42%. The design strength of concrete was 27 MPa.

Table 1 shows an evaluation of the seismic performance of C1-1 in the longitudinal direction based on the current design code [JRA 2002]. The seismic performance of another column which is designed based on the 2002 design code (denoted here as C1-5 column) is also presented here for comparison. C1-5 is a 2m diameter circular column with the longitudinal reinforcement ratio of 2.19% and tie volumetric reinforcement ratio of 0.911%. The E-Defense excitation for C1-5 is scheduled in 2008. Because the moderate soil condition (Type II) is considered, the design response acceleration $S_A$ is 17.15 m/s$^2$ for both C1-1 and C1-5. The yield displacements $u_y$ and ultimate displacement $u_u$ are 0.046m and 0.099m in C1-1 and 0.045m and 0.231m in C1-5. The design displacement $u_d$ is evaluated from $u_u$ and $u_y$ as

$$u_d = u_y + \frac{u_u - u_y}{\alpha u_y}$$

(1)

in which $\alpha$ depends on the type of ground motions (near-field or middle-field) and the importance of the bridge. Because $\alpha$ is 1.5 for a combination of the near-field ground motion category and the important bridges category, the design displacement $u_d$ is 0.081m in C1-1 and 0.169m in C1-5.

Table 1 Evaluation of C1-1 Column in Comparison with C1-5 Column in the Longitudinal Direction

<table>
<thead>
<tr>
<th>Demand &amp; Capacity</th>
<th>Properties</th>
<th>C1-1</th>
<th>C1-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Force</td>
<td>Design response spectrum $S_A$</td>
<td>1.75 x 9.8 = 17.15 m/s$^2$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Force reduction factor</td>
<td>1.58</td>
<td>2.56</td>
</tr>
<tr>
<td></td>
<td>Response acceleration demand</td>
<td>10.83 m/s$^2$</td>
<td>6.70 m/s$^2$</td>
</tr>
<tr>
<td>Demand</td>
<td>Displacement demand of the column</td>
<td>0.328 m</td>
<td>0.168 m</td>
</tr>
<tr>
<td>Capacity</td>
<td>Yield displacement capacity $u_y$</td>
<td>0.046 m</td>
<td>0.045 m</td>
</tr>
<tr>
<td></td>
<td>Ultimate displacement capacity $u_u$</td>
<td>0.099 m</td>
<td>0.231 m</td>
</tr>
<tr>
<td></td>
<td>Design displacement capacity $u_d$</td>
<td>0.081 m</td>
<td>0.169 m</td>
</tr>
</tbody>
</table>

Photo 1 C1-1 under Construction

Photo 2 Reinforcements in Three Layers
On the other hand, because the force reduction factor is 1.58 in C1-1 and 2.56 in C1-5, the displacement demand of the column $u$ is 0.328m in C1-1 and 0.168m in C1-5. Consequently, C1-1 is evaluated to be unsafe while C1-5 is safe. From the evaluation of the shear capacity, both fails in flexure.

3. EXPERIMENTAL SETUP

The C1-1 column was set on E-Defense as shown in Fig. 2 and Photo 3. Two simply supported decks were set on the column and two steel end supports. The decks are a device to fix four mass blocks on the column and they are not designed to idealize the stiffness and strength of real decks. Each deck was supported by a fixed bearing on the column and a movable bearing (friction bearing) on the end supports as shown in Photos 4 and 5. Two side sliders (friction bearings) were provided at the both sides of the fixed and movable bearings for preventing overturning of the decks around its axis.

A 78 t mass block and a 44.6 mass block per deck are fixed to the decks. The mass blocks are of laminated steel plates. Total mass due to 4 mass blocks, 2 decks, 2 fixed bearings, 2 movable bearings, 8 side sliders and 32 load cells is 302 t. Including masses of the column with a 1.8 m thick footing, 2 steel end supports and table protections, the total mass of the model is slightly over 1,000 t.

Fig. 4 shows the response displacements at the top of the column. The combined displacement of two lateral components had a peak of 0.195 m (2.56 % drift) at 6.9 s. Because the ultimate displacement at the top of the column is 0.091 m, the peak response exceeded the ultimate displacement by a factor of 2.1.

Photo 6 shows progress of failure of the column at the plastic hinge on NE and SW surfaces. It should be noted that N-S and E-W correspond to the longitudinal and transverse directions of the model, respectively. At an instance of 6.9 s, the covering concrete started to spall at SW surface due to compression. At SW, covering concrete spalled between the bottom and 0.6 m from the bottom of the column and several outer longitudinal reinforcements locally buckled between the bottom and 0.2 m from the bottom of the column during the excitation.

A ground acceleration recorded at JR Takatori Station during the 1995 Kobe, Japan earthquake (refer to Fig. 3) was used for the table motion. It is well known that the radiational energy dissipation of a model on a shake table is extremely smaller that the real energy dissipation. Taking account of the soil structure interaction effect, a ground motion with 80% the original intensity of JR Takatori record was used as a command to the table in the experiment. This ground motion is called hereinafter as E-Takatori ground motion.

The model was subjected to a 10%, two 20% and six 30% E-Takatori ground motion excitations to check the response and measurement. No visible cracks occurred during those excitations. Main excitation using 100% E-Takatori ground motion was conducted twice. Only the response and failure mode for the first 100% E-Takatori excitation are shown in this paper.

4. SEISMIC PERFORMANCE OF THE C1-1 COLUMN

Fig. 4 shows the response displacements at the top of the column. The combined displacement of two lateral components had a peak of 0.195 m (2.56 % drift) at 6.9 s. Because the ultimate displacement at the top of the column is 0.091 m, the peak response exceeded the ultimate displacement by a factor of 2.1.

Photo 6 shows progress of failure of the column at the plastic hinge on NE and SW surfaces. It should be noted that N-S and E-W correspond to the longitudinal and transverse directions of the model, respectively. At an instance of 6.9 s, the covering concrete started to spall at SW surface due to compression. At SW, covering concrete spalled between the bottom and 0.6 m from the bottom of the column and several outer longitudinal reinforcements locally buckled between the bottom and 0.2 m from the bottom of the column during the excitation.
**Photo 4** Fixed bearing and 2 Side Sliders on the Column

**Photo 5** Movable Bearing and 2 Side Sliders on an End Support

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**Fig. 3** E-JR Takatori Ground Accelerations
Figs. 5 and 6 show strains of the outer longitudinal and tie reinforcements, respectively, at 6.9 s [JSCE 2008]. Strains in the longitudinal reinforcements were over 4000 $\mu$ in tension at SE, E, NE, N and NW while they were over 2000 $\mu$ in compression at W and SW. Strains in the longitudinal reinforcements are extremely large between 0.25 m below and 1.5 m above the surface of the footing. It is interesting to note that extensive yielding of longitudinal reinforcements occurs at the zone higher than the anticipated plastic hinge region. Deformation of the longitudinal reinforcements inside the footing contributes to the lateral response of the model.

Although it is not presented here, interaction of three layered longitudinal reinforcements is complex. Similarly, the lateral confinement among the three layered ties is very complex. The lateral confinement is not uniform around the ties, and it is not the same among the three ties. Mechanism of the lateral confinement by multi-layered ties should be critically investigated.

The strains of the tie reinforcements at an instance of 6.9 s are larger at 0.35 m and 0.65 m above the surface of the footing. The maximum strains at the two locations are nearly 2000 $\mu$, slightly larger than the yield strain. It is important to note that strains of tie reinforcements are larger at SW and W where the section is subjected to compression. Obviously this is resulted from the local buckling of longitudinal reinforcements at SW.

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**Fig. 4** Response Displacement of C1-1 at the Top during the First 100% E-Takatori Ground Acceleration Excitation

**Photo 6** Progress of Failure of C1-1 during the First 100% E-Takatori Ground Acceleration Excitation
Fig 5 Strains of Outer Longitudinal Bars at 6.9 sec during the First 100% E-Takatori Ground Acceleration Excitation

Fig. 6 Strains of Ties at 6.9 sec during the First 100% E-Takatori Ground Acceleration Excitation
5. CONCLUSIONS

C1-1 column which is a typical flexural failure type column in 1970s was excited twice under 3D 100% E-Takatori ground accelerations using E-Defense. It was designed assuming 0.23 lateral seismic coefficient and +/-0.11 vertical seismic coefficient based on the seismic coefficient method in accordance with the JRA 1964 design codes. Preliminary findings from the E-Defense experiment are summarized as follows:

1. C1-1 column suffered extensive damage under a near field ground motion recorded at JR Takatori Station during the 1995 Kobe earthquake.
2. The lateral confinement of three layered ties is very complex. The lateral confinement is not uniform around the ties, and it is not the same among the three ties. Mechanism of the lateral confinement by multi-layered ties should be critically investigated.
3. Although it was anticipated that yielding of the longitudinal and tie reinforcements was less significant at the zone higher than the plastic hinge, extensive yielding occurred up to 83% and 69% the column diameter in the longitudinal and tie reinforcements, respectively. The deformation of both longitudinal and tie reinforcements should be investigated.
4. Deformation of the longitudinal reinforcement inside the footing contributes to the response of the column. The mechanism and its effect should be investigated.
5. Effect of the bilateral excitation should be included in design. The current design still stands on the concept of unilateral excitation.

ACKNOWLEDGEMENTS

The E-Defense bridge project was formulated as a US-Japan cooperative research based on NEES and E-Defense collaboration. The C1-1 experiment was conducted based on the extensive support of over 70 members in the Overview Committee (Chair, Iemura, H., Professor Emeritus, Kyoto University), Executing Committee of Large-scale Bridge Experimental Program (Chair, Kawashima, K., Tokyo Institute of Technology), Analytical Correlation WG (Chair, Unjoh, S., Public Works Research Institute), Measurements WG (Chair, Takahashi, Y., Kyoto University), and Dampers and Bearings WG (Chair, Yabe, M., Chodai). Their strong support is greatly appreciated.

REFERENCES


FEATURES OF SUPER CYCLONE SIDR TO HIT BANGLADESH IN NOV., 07 AND MEASURES FOR DISASTER – FROM RESULTS OF JSCE INVESTIGATION

Kazuyoshi Hasegawa

Foundation of River & Watershed Environment Management, Hokkaido Office, Sapporo, Japan

Abstract: Cyclone SIDR, one of the ten strongest cyclones for past 131 years struck the south-west coastal region in Bangladesh and caused the widespread serious damage. Remarkable feature is that the fatalities due to Cyclone SIDR sharply decreased compared with the cyclones in 1970 and in 1991. One of the factors is measures of Government for early warning and for increase of cyclone shelters. Also, embankments showed significant roles to minimize the damage, although they could not prevent the storm surge with over 6-9m wave height. However, condition of embankments was seen insufficient in the investigation. It was confirmed that vegetation zone along shorelines or riversides contributes to decrease the water depth of storm surge, and is useful to protect the bank from the erosion. The excellent activities of CPP volunteers were known.

Key words: cyclone, storm surge, embankment, shelter, vegetation zone, evacuation

1. GENERAL INFORMATION

Bangladesh is a deltaic lowland country located in South Asia of which territorial area is 147,570 sq. km and population is about 144 million. About one-fifth of the population lives within 19 coastal districts. Since the geographical, natural and social characteristics of this country, people have suffered repeated disasters of floods and storm surges including huge 1970 and 1991 cyclone disasters.

The powerful Cyclone SIDR hit the south-western coast of the country on 15th, November, 2007. According to Disaster Management Center in DMB (reported in December 18, 2007), the cyclone resulted in the severe damages of 3,363 deaths, 871 the missing, 8.9 million affecting people, 2,472,944 acres crops damage and estimated over 3.1 billion US dollars economical loss.

Japan Society of Civil Engineering (JSCE) decided to dispatch an urgent investigation team to Bangladesh in order to investigate and assess the states and mechanisms of disaster from the storm surge.

Field survey in Bangladesh was performed by two parties of Coastal Group (the leader T. Shibayama, Yokohama National University, and other 6 investigators) and River Group (the leader K. Hasegawa, and other 7 investigators) from 26 to 28 in December, 07 and from 19 to 23 in January, 08, respectively.

This paper is described by the author as a representative of the team, based on the investigation report (2008) that the team published after return home.

2. FEATURES OF THE CYCLONE SIDR

Cyclone SIDR was born in Bay of Bengal on 11th, November, 2007 and disappeared on 17th. It landed on around November 15th 18:30 at the almost same point as the cyclone in 1970 landed on as seen in Fig.1. The maximum wind speed of SIDR was 69m/s (250 km/h, average for one minute), and the lowest atmospheric pressure was 944hPa. In past data, the cyclone in 1991, which is known as the strongest cyclone to cause about 140 thousand fatalities, recorded the maximum wind speed 72m/s (260 km/h) and the lowest atmospheric pressure 898hPa on 29th April. Also, the cyclone in 1970, which gave rise to about 500 thousand fatalities, recorded the maximum wind speed 71m/s (205 km/h) and the lowest atmospheric pressure 966hPa on 12th November.

From the comparison of these data, it is understood that if estimated from the lowest atmospheric pressure, the strength of the cyclone in 2007 was stronger than that in 1970 while weaker than that in 1991, and that from the maximum wind speed, the strength of the cyclone in 2007 was almost same as in 1991.

According to the material of BWDB, Cyclone SIDR is one
of the ten strongest cyclones that landed on Bangladesh during 131 years from 1876 to 2007.

3. FEATURES OF THE TOTAL DAMAGE
To compare the damage in 1991 and in 2007, the number of victims, the death toll, the house damage, the arable land damage, and the damage amounts such as educational facilities, the road, bridges, and embankments are shown in Table 1. The damage of typical social infrastructures such as harbors, airport, electric power, communications, and railways were limited to the provincial one in the case of Cyclone SIDR, because the stricken regions corresponded to comparatively small towns and villages. On the other hand, the infrastructures had suffered nationwide damage in the cyclone in 1991, because the stricken regions were typical big city like Chittagong with important port and airport. According to the trial calculation of a Bangladesh government, it is assumed 3.1 billion dollars in 2007 while the damage total was about 7.6 billion dollars in 1991 (It is shown in Emergency Response and Action Plans Interim Report, Dec.2007, MoFDM with 2.3 billion dollars.). The dead, missing, and the injured person of the personal suffering in 2007 were more greatly less than that of 1991. This is an important feature in respect of the damage from Cyclone SIDR. The followings are thought as the factors. (1) The route of SIDR passed the region where the population density and the scale of the city were smaller than those in the case of 1991. (2) Cyclone SIDR attacked in the dry season, while the cyclone in 1991 was in the rainy season.

Table 1 Comparison of the cyclone damage between the case in 1991 and that in 2007

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Damaged zila</td>
<td>14</td>
</tr>
<tr>
<td>Damaged upzila</td>
<td>75</td>
</tr>
<tr>
<td>Damaged union</td>
<td>8</td>
</tr>
<tr>
<td>Number of victims</td>
<td>10,721,707</td>
</tr>
<tr>
<td>Death</td>
<td>138,866</td>
</tr>
<tr>
<td>Disappearance</td>
<td>1,195</td>
</tr>
<tr>
<td>(100,000 people or more in a report.)</td>
<td></td>
</tr>
<tr>
<td>Injured persons</td>
<td>138,849</td>
</tr>
<tr>
<td>Damaged houses</td>
<td></td>
</tr>
<tr>
<td>complete collapse</td>
<td>780,081</td>
</tr>
<tr>
<td>half collapse</td>
<td>850,462</td>
</tr>
<tr>
<td>Arable land damage area</td>
<td></td>
</tr>
<tr>
<td>complete collapse</td>
<td>117,753 acre</td>
</tr>
<tr>
<td>part collapse</td>
<td>791,621 acre</td>
</tr>
<tr>
<td>Domestic animal damages</td>
<td>10,030,656</td>
</tr>
<tr>
<td>Educational facilities damages</td>
<td></td>
</tr>
<tr>
<td>complete collapse</td>
<td>3,749</td>
</tr>
<tr>
<td>half collapse</td>
<td>5,618</td>
</tr>
<tr>
<td>Road damages</td>
<td>764 miles</td>
</tr>
<tr>
<td>Bridge, Culvert damages</td>
<td>496</td>
</tr>
<tr>
<td>complete collapse</td>
<td>112 miles</td>
</tr>
<tr>
<td>half collapse</td>
<td>585 miles</td>
</tr>
<tr>
<td>Bank damages</td>
<td></td>
</tr>
<tr>
<td>complete collapse</td>
<td>1,875 km</td>
</tr>
<tr>
<td>(There is a description of the complete destruction 362.45km and the partial destruction 1,927.55km in the report.)</td>
<td></td>
</tr>
</tbody>
</table>

- 52 -
(3) Structures for disaster prevention such as embankments have been constructed or maintained successively.

(4) Cyclone shelters have been increased.

(5) The disaster prevention education that has been done after 1991, the enlightening activity such as CPP, and maintenance and the enhancement of the system of information transmission have advanced.

(6) Enhancement of weather warning system.

(7) Improvement of residents’ understanding for cyclone disaster.

4. FEATURES OF THE STORM SURGE AND ROLE OF ENBANKMENT

Fig.2 Survey route and measured storm surge height (Coastal Group)

Fig.2 shows the result of survey for storm surge height conducted by Coastal Group. The storm surge caused by SIDR went up over 100 km upstream through the rivers, specifically through the Baleswar River. The surge inundated the riverside districts with bringing a big damage. Royenda Bazar is located in the right hand side near the river mouth of Baleswar River, which is one of the sites where the victims concentrated. Fig.3 is a cross sectional sketch showing the inundation height and depth along a line from the riverbank to the inner land of Royenda (surveyed by Coastal Group). It can be seen that inundation height overtopping the Riverside embankment became near 6 m.

Photo.1 Estimated height of the storm surge at Katachera Village

Also at the opposite riverside of Royenda, Katachera Village in Sapleza Union was most severely damaged, where 49 people died. The fatalities totaled to 78 in whole Sapleza Union. Where, the water depth of storm surge was round 2 m on the crest of embankment (Photo.1) and round 5.2 m on the ground of inner land. It also reached round 1.5 m on the roof of a nearby primary school. So the people to take refuge on the embankment and on the roof of school were floated away up to the far village.

Although Hajipur is located further from the coast (however closer to the river mouth), the inundation height at Hajipur was higher than the one at Alipur. It is essentially important to consider the runup flow not only from the coastal area but also along the river, branches and waterways.

The maximum inundation height of the surge was 9.6m (the inundation depth 6.5m) in the coastal area Kuwakata, and

- 53 -
6.5m (5m) in the river area Southkhali. Comparison of the data with the past records shows that the storm surge in this cyclone was in the same scale as in 1970 or in 1991. In the field survey around the coast Kuwakata, failure of coastal embankment, erosion of coast and scouring of sand dune etc. were observed at any place (Photo.2). Bank erosion and bed evolution are continuing near the river mouth. Immediate countermeasure is required to maintain the function of tide embankment.

Many witnesses were obtained near coastal area that storm surge inundated with bore-like waves. At Southkhali, people witnessed that storm surge came up with three waves of 1 minute period and high water stage continued for 15 minutes. On the other hand, other witnesses were obtained in inner land areas that the storm surge gradually rose up with one wave.

Countermeasure against storm surge should be planed to take account of the physical mechanisms on the development of such bore-like waves and their deformations, and also of possible damages due to such waves. Coastal embankments and Polders in Bangladesh are constructed as the crest should be 1.5m higher than the mean sea water level in the annual maximum high tide record. Even for the best coastal embankments, the crest is kept only 5.2m above the mean sea water level. Therefore, it is difficult to prevent a storm surge with over 6-9m wave height as experienced in this time. However, in Kuakata and Somboria, embankment showed significant roles to minimize the damage. Development of riverbanks especially around the river mouth is one of the most essential countermeasures to be carried out in Bangladesh.

5. WEAKNESS OF THE EMBANKMENTS AND MEASURES FOR IMPROVEMENT

Embankment and Polder in Bangladesh seem to have the following weakness.

(1) Embankments and Polders do not provide the enough heights to prevent overtopping of cyclone storm surge. Entire overtopping had occurred in the coastal area and the Baleswar River area in this cyclone.

(2) Accuracy of construction for the side slope and surface of the structures is low. Irregular undulation is seen at any places (Photo.3).

(3) Many trees are planted in the surface layer of embankments and polders. A large number of these trees were blown down by the strong wind to cause the overturning or uprooting and the failure of embankment body (Photo.4).

(4) Maintenance for the structures has scarcely been executed.

(5) Illegal habitation on the structures (Photo.5).

The followings should be considered to strengthen the embankments and polders.

(1) Present coastal embankments are besides effective against cyclone storm surge not only to normal high tide. However, they will involve a risk of failure by overtopping of a surge or a flood.

(2) The action plan to make all embankments reconstruct with higher bank enable to prevent a storm surge seems to have several problems in the present time such that the related infrastructures are not fully provided. When considered the nature of bank materials, the present compaction technique for soil, the accuracy control
technique, the level of maintenance, the agricultural state in polder lands and the quick drainage system for inundation area so on, the plan to make all embankments enlarge would be seen difficult to be executed.

(3) Embankments and polders should be strengthened with geo-textile or local productive materials like jute. Proper compaction and vegetative protection to the bodies will be effective.

(4) Bank protection with stonemason or concrete block would not be reasonable in use in Bangladesh, since the stone and concrete block are rarely produced and need high cost.

(5) It will be worth while constructing secondary embankments parallel to the present embankments, those are expected in flood storage and energy decay of storm surge. The bounded land by two embankments could be used for a farm field.

(6) Shorefront rooms are remained or newly formed in several places of the coastal area (Photo.6). It is effective for prevention and mitigation to a storm surge, to make new coastal vegetation zones at the places together with conserving the present coastal vegetation zones.

(7) Embankment plan should be adjusted to the road construction as local disaster prevention can be developed. Synthetic measures should be planned with considering the relation between embankments, roads, upping of residential land, channel network and culverts so on. A surrounded land by embankments and roads should be appropriated for a retarding basin.

(8) Computer simulation techniques should be used more practically for the land administration to achieve the purpose.

6. EFFECTIVENESS OF THE VEGETATION ZONE

Many trees were damaged in this cyclone with
1) the trunk bending or breakage,
2) the overturning or uprooting,
3) the loss of the substrate and
4) local scour around the trees.
Most of the damaged patterns are related to the mechanisms 1) and 2) in the affected sites. The overturning damage was mostly occurred along the bank of the road, the river bank and the bank of the paddy field. The high trees were overturned but the low height trees or coconut trees were seldom overturned. These damages were caused mainly by the strong wind and partially by the water flows. Due to the local people’s speech at Sapleza, vegetation zone with 150m width made the water depth reduce maximum 0.5m-1m, compared with the frontal water depth at the coastal vegetation.

Tanaka (2008), a member of the investigation team, analyzed the vegetation effect for preventing storm surge by using mathematical models under different conditions of average sea water level, wind velocity, wave period, wave height, and gradient of the land. Figs.3 and 4 show the simulation results for time series of water depth behind vegetation zone in the case of compound wave and long wave, respectively. The decrement of the water depth in the case of compound wave is about 80 cm, while it is 55 cm in the case of long wave. The short waves are found to be affected more than the long waves, and also the vegetation zone contributes more to decrease the water depth of storm surge when the land slope becomes milder.

Coastal vegetation and riverside vegetation are useful to protect the bank from the erosion. Planting of Coco trees or
Guava trees which will be useful for the life of local peoples is recommended since mangrove trees are little preserved. However, afforesting on the embankments must be avoided because overturning of tall trees will weaken embankments.

7. IMPORTANT ROLE OF CYCLONE SHELTERS

Cyclone shelter is particularly important facility to reduce cyclone disaster, especially to save life in Bangladesh. The facilities have been increased gradually by Government, local Government and kinds of Donors since the disaster in 1991. In this cyclone, three million people were evacuated and 1.5 million were accommodated in cyclone shelters. Considerable decrease of fatalities in this cyclone could be realized through early warning, proper evacuation guidance and accommodation to shelters.

However, still remain problems on shelters. Photo.7 is a cyclone shelter at Kadamthala, Royenda Bazar, which was constructed in 1990 with donation by German Red Cross. There is a primary school in the site. Ground elevation of the site is 2.8m and height of the peak flood mark is 3.96m. Questionnaire survey was conducted by the River Group members at the site. According to residents’ witness, the storm started to rise at round 19:00, and passed at round 22:30. After that, storm surge attacked the site from round 23:00. Residents told that as many as about 5000 people had taken refuge to the shelter, although of which accommodation is only 500. Many people were forced to give up getting inside the shelter because of this situation.

Photos.8 and 9 show another cyclone shelter at Royenda Bazar, which is used for an elementary school. It was gathered that the same situation would occur.

The following issues are pointed out regarding to the cyclone shelters.

1. While number of necessary shelters for the population is short, it is not easy to obtain necessary lands for constructing shelters.
2. There are many local residents who claim that shelters are too far from their locations.
3. Not many shelters are provided with good maintenance.
4. Poor people, who do not have lands (illegal residents), were not allowed to enter cyclone shelters.
5. There is no refuge or evacuation place for the livestock.
6. There were local residents who refuse their evacuation for the fear to loss the house, land and livestock.

To solve the problems the following measures are required together with the measure for poverty dissolution.

1. Increase of shelters for multipurpose use (e.g. schools, community centers) with high-story.
2. Well balanced distribution of cyclone shelters according with the locations of villages and establishment of the evacuation plan.
3. Increase in number of Killa that can be the refuge for livelihood.
4. Development of the system where local beneficiaries can take care of maintenance of the shelters.

8. EFFECTIVENESS AND CHALLENGES IN NON-STRUCTURAL MEASURES

Bangladeshi disaster prevention as well as disaster communication systems have dramatically improved in recent years. DRR, under the MoFDM (Ministry of Food and Disaster Management) is playing the central role in this field.

Among the institutions that bear warning communication,
CPP (Cyclone Preparedness Program) seems to be most important. The CPP, inaugurated in 1973, based on
Bangladesh Red Crescent Association, in collaboration with
disaster management sections in GOB, provides overall
activities such as disaster preparedness, disaster information
communication and evacuation guidance in case of
emergencies.

CPP volunteers consist basically of 15 members per each
village (10 men and 5 women). At normal times, volunteers
are engaged in raising public awareness and disaster
education while providing some education materials to the
local people. Their responsibilities during disasters are
categorized into following five activities.

1) Warning
2) Evacuation
3) Rescue
4) First aid
5) Relief

In case of cyclone SIDR, 4 days (96 hours) before the
expected landfall they could issue forecasts and warnings
through radio, TV, local government’s networks and CPP
volunteers’ network. These networks functioned very well
during the cyclone SIDR event.

However, some challenges are still remaining, as follows.

(1) Information on storm surge prediction did not seem to be
incorporated into cyclone warning.

(2) Distinction of Rainy and Dry seasons are so clear that
people usually do not have the daily habit of relying on the
weather forecasts through radios, etc.

(3) People are misunderstanding the relationship between
storm surge caused by cyclones and natural fluctuations of
sea water level (high tides) – the fact that storm surges can
also happen during low tide need to be understood.

(4) Failure of Tsunami early warning reduced credibility of
forecasts in general that are issued by the authority.

(5) People place little trust in warnings sounded by the
authorities concerned. (They place more trust in the men of
influence in their communities.)

Measures in the future to improve evacuation action are
summarized as follows.

(1) The maintenance of evacuation routes should be done in
conjunction with the maintenance of roads. In addition,
people should be given evacuation drills and knowledge for
disaster prevention should be widely spread.

(2) As to the problems of poor maintenance of cyclone
shelters and influential men prevailing over the poor, a
democratic system in which the poor can participate in
should be established in each area, with the characteristics of
the area taken into account.

(3) The present ten-level warning system is designed for the
protection of harbors and ships against disasters. The ten
warning levels do not mean much for the general public. The
education level and literacy rate of the poor who live in the
coastal area and possess no piece of land, in particular, are
low and they hardly understand the concrete meanings of the
ten warning levels. It is necessary, therefore, to develop a
warning system practical for the general public and set forth
guidelines for the general public’s conduct.

(4) Influential men and religious leaders in each community
should contribute effectually toward education for, and
planning of, disaster prevention and improvement of
disaster-preventing capacity of the community.

(5) The disaster-prevention authorities and universities in
Bangladesh should further investigate disaster -preventive
systems in the area hit by the 2007 cyclone and contribute
toward awareness raising through the mass media and
educational institutions.

9. CONCLUSION

Cyclone SIDR which is one of the ten strongest cyclones for
past 131 years struck the south-west coastal region in
Bangladesh and caused the widespread serious damage. It
was a remarkable feature that the fatalities due to Cyclone
SIDR sharply decreased compared with the cyclones in 1970
and in 1991. A geographical condition that SIDR landed on
the rural districts and a seasonal condition that it was dry
season would be factors to reduce the casualties from this
cyclone. Furthermore, successively promoted measures for
early warning and for increase of cyclone shelters could be
effectual to the disaster reduction.

Bangladesh Government approved the Comprehensive
Disaster Management Program (CDMP) in 2003 as a key
strategy, which is designed to optimize the reduction of long
term risk and to strengthen the operational capacities for
responding to emergencies and disaster situations. It is
purposed to achieve a paradigm shift in disaster management
from conventional response and relief to a more
comprehensive risk reduction culture.

The measure for flood disaster is considered as a part of
whole disaster risk managements (floods, cyclones, droughts,
tidal surges, tornados, earthquakes, river erosion, water
logging, water and soil salinity, etc.), and lays stress on
improvement of forecast-prediction-warning technique,
strengthening of community preparedness and
enlightening, increasing of shelters, close rescue and relief for victims, aid for reconstruction, training of professionals to support the system, and NGO cooperation, etc.

When consider the cyclone disaster from a view point of this strategy, we can accept that the measure successfully reduced the fatalities through implementation of early warning, evacuation guidance, increasing of shelters, etc. Also, immediate rescue and reconstruction aids for the casualties were securely managed in spite of many difficulties. Residential people seem to be possibly rebuilding their daily lives.

However, infrastructures to prevent floods and cyclone storm surges such as embankments, polders and shelters etc. are still considerably insufficient in numbers and in quality in Bangladesh, as reported partially in this paper. Therefore, widespread inundation occurred and casualties concentrated in the poor class of landless people at vulnerable areas.

Action plans for infrastructure in Bangladesh seem to be included in a measure of comprehensive risk reduction, that may be a non-structural measure.

Disaster prevention structures should be planned scientifically and technologically as to ascertain priority construction and to adjust to other structures like roads. Synthetic measures should be planned with considering the relation between embankments, roads, upping of residential land, channel network and culverts so on. It would be advisable to make a more close cooperation between the scientific and technological experts and the disaster management administrations.

ACKNOWLEDGMENT

The author would like to appreciate the friendly reception given the investigation team of JSCE from many staffs in many organizations of BUET, MoFDM, BWDB, IWM, CEGIS, BDPC, Embassy of Japan, JICA and JBIC. The team obtained many data and important information, and further valuable discussion about the feature of cyclone, the effective countermeasures and so on by courtesy from them.

Parsons in charge of BWDB, IWM and CEGIS also politely showed and explained the systems of organizations and valuable results of their analyses on the disaster.

Furthermore, many local people friendly gave us the important witness to answer our complicated questions.

APPENDIX

Members of JSCE investigation team are as follows.

Coastal Group is from five investigators recommended by Coastal Engineering Committee in JSCE, and two engineers those were dispatched from EWBJ (Engineers Without Borders, Japan): Tomoya SHIBAYAMA (Professor, Yokohama National University) (Group Leader)

Yoshimitsu TAJIMA (Associate Professor, The University of Tokyo)

Taro KAKINUMA (Associate Professor, Kagoshima University)

Hisamichi NOBUOKA (Lecturer, Ibaraki University)

Tomohiro YASUDA (Assistant Professor, Kyoto University)

Toshiya TSUKAMOTO (Tokyo University of Foreign Studies) (Leader of EWBJ Members)

Kouji HAYASHI (Pacific Consultants Co., Ltd.) (EWBJ Member)

Following investigators from Bangladesh University of Engineering and Technology (BUET) joined and made an important contribution to the investigation of Coastal Group: Raquib AHSAN (Associate Professor, Bangladesh University of Engineering and Technology)

Mizanur RAHMAN (Associate Professor, Bangladesh University of Engineering and Technology)

M. Shariful ISLAM (Assistant Professor, Bangladesh University of Engineering and Technology)

River Group is from six investigators recommended by Committee on Hydroscience and Hydraulic in JSCE, and two Engineers dispatched from MLIT (Ministry of Land, Infrastructure, Transport and Tourism):

Hajime NAKAGAWA (Professor, Disaster Prevention Research Institute, Kyoto University)

Kazutoshi KAN (Professor, Shibaura Institute of Technology)

Norio TANAKA (Professor, Saitama University)

Sadayuki HIRONAKA (NEWJEC Inc.)

Shoji OKADA (Associate Professor, Kochi National College of Technology)

Hamidul HUQ (Research Coordinator, Institute of Water and Flood Management, BUET)

REFERENCES


Flood Simulation of Storm Surge by SIDR (at 23:00 on 15th)
(By courtesy of IWM)

The figure shows a part of the flood simulations at 11:00 PM, 15th, when the water level was the highest. It well reproduces the concentration of the storm surge in the mouth of Baleswar River and flow propagation to the upstream.

Flooded area water estimated from the maximum inundation area and the averaged inundated depth which was to be scattered in the area of distress in southern part of Bangladesh by the huge energy of the cyclone.

Spatial distributions of measured inundation heights around Kuakata district

Minimum Height of Polder Block
(By courtesy of IWM)

Coastal vegetation and riverside vegetation are useful to protect the bank from the erosion. Planting of Coco trees or Guava trees which will be useful for the life of local peoples is recommended. However, afforesting on the embankments must be avoided because overturning of tall trees will weaken embankments.
Proposal

Adaptation to Water-related Disasters Induced by Global Environmental Change

June 26, 2008
Science Council of Japan
Committee on Planet Earth Science and Committee on Civil Engineering and Architecture
Subcommittee on Land, Society and Natural Disasters
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Summary

1. Background

The Committee on Disaster Mitigation under Global Changes of Natural and Social Environments, Science Council of Japan (SCJ), issued on May 30, 2007 a report, “Policies for Creation of a Safe and Secure Society against Increasing Natural Disasters around the World.” The report, which includes an outline of Japan’s past responses to natural disasters of a global scale, provides a comprehensive discussion of a desirable direction for the development of infrastructure and social systems to meet the forthcoming changes in nature and society. Based on the report, the committee reported to the Minister of Land, Infrastructure and Transport, in response to the minister’s former inquiry. The Science Council of Asia (SCA) meeting in Okinawa held in the same year had a session on disasters, and several presentations have been made on the subjects.

This proposal is on countermeasures by adaptation to water related disasters, following the former report and the result of discussions made in the subcommittee.

2. Current status and problems

In Japan, over the past 30 years, the number of days of heavy rain with a daily rainfall of 200 mm or more have increased to about 1.5 times that of the first 30 years of the 20th century. It has been pointed out that this is likely to have been caused by global warming. The Fourth report of the IPCC indicates that even low-end predictions implies an unavoidable temperature rise of about 2°C, and, even if the concentration of greenhouse gases is stabilized, the ongoing warming and sea level rise will continue for several centuries.

In terms of social systems, population and assets are increasingly concentrated in metropolitan areas. At the same time, economic recession and aging of the population are accelerating especially in rural areas. The central parts of small- and medium-size cities have lost vitality, and so-called marginal settlements are increasing in farming, forestry and fishing villages. These factors make it difficult and complicated to maintain social functions to fight against natural disasters.

Under these circumstances, it is quite important in our country to take an action for adaptation to climate changes, where land is vulnerable to water and sediment disasters. The need for adaptation has widely been recognized in Europe, and various reports have been issued there. In Japan, initiatives to reduce greenhouse gases emission are being actively discussed, but both the central government and the people hardly recognize the importance of adaptation to water-related disasters. We cannot help but say that they do not seem to be greatly interested in the risk of increasing water and sediment disasters. The people has not long been experienced disasters, and they lack knowledge or awareness of disasters. They are also generally unprepared for them.

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Elsewhere, increases in extreme weather and climate events have caused flood disasters, such as those that have been occurring with larger frequency in the downstream deltas of Asian rivers. The latter type of disaster is exemplified by the unprecedented huge flood disaster that occurred in Myanmar in May this year. Japan, which is in the Asian Monsoon Region, has a natural and social geography similar to these countries. Japan should implement strong assistance programs based on accumulated knowledge and advanced technologies developed.

3. Recommendations

(1) Promoting adaptation
The Government of Japan, which has been promoting a policy to reduce greenhouse-effect gas emission to mitigate global warming, also should recognize the importance of adaptation to mitigate impacts from water-related disasters arising from climate change due to global warming.

(2) Commitment to the international society
The Government of Japan should contribute to the international society by making the following commitments at important international meetings and conferences.

(i) Preventing water-related disasters is a core adaptation activity. The Government should make every effort to contribute to the solution of water hazard issues all over the world. Saving lives is the priority, so the Government should cooperate in observation/monitoring, forecasting and warning activities and in preparation of hazard maps. Also, the Government should provide assistance in policy and technology development for management of river basins to support the welfare of river-basin coexistence communities and sustainable development in the Asian Monsoon Regions. The capacity-building program related to these issues is also a key to reduce the disaster.

(ii) Recognizing that disaster prevention must be a component of development programs, the Government should take Disaster Risk Impact Assessments mandatory in all development assistance plans.
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1. Introduction

Extreme rainfall events are increasing in many parts of the world. In Japan, the number of days of heavy rain, (daily precipitation of 200 mm or more) in the past 30 years has been approximately 1.5 times as many as that in the first 30 years of the 20th century. Analysis of long-term daily precipitation trends shows a decreasing trend in light rainfall and an increasing trend in heavy rainfall. Monthly precipitation patterns show months of abnormal drought. It has been pointed out that these phenomena are possibly the effects of global warming. The Fourth Assessment Report of the IPCC\(^1\) (AR4) warns that global warming will progress further if current levels of greenhouse gas emissions continue or increase and that this will result in greater changes in the climate system in the 21st century than those in the 20th century. Further, according to a scenario of stabilization, a low-end prediction based on remarkable reductions of greenhouse gas emissions indicates that about 2°C rise in the global mean surface temperature cannot be avoided. Even if greenhouse gas concentrations are stabilized, anthropogenic warming and sea level rise will continue for several centuries. Such global environmental change will significantly affect the scale and frequency of water disasters such as floods and storm surges.

Japan had prepared flood control plans by introducing the concept of probability based on long-term meteorological observation data for the past 100 years or more. However, with patterns of weather phenomena in a stage of irregularity as compared to the more regular probability patterns that had been observed up until recently, the risk of 200-year probable rainfall along the country’s large rivers has risen. The 200-year probable rainfall (rainfall with a probability of occurring once in 200 years) has been the level of rainfall used as the basic design rainfall probability standard for large and important rivers in Japan. This level of rainfall can now occur more frequently due to climate change. Occurrence of hourly rainfall of 50 mm have steadily increased. Their annual observation was 209 times between 1976 and 1985, 234 times between 1986 and 1995, and 288 times between 1996 and 2005.

In the Kanto alluvial plain, the land lies mostly below river flood levels, and more than one-fourth of the population of Japan lives in this area. Part of Tokyo situated in river mouth delta where population and assets are concentrated below sea level. Therefore, the area is more highly vulnerable to flooding and storm surges than comparable large cities in other advanced countries. An OECD report issued in December 2007\(^2\) listed Tokyo, Osaka and Nagoya as cities in Japan facing such risks.

With the country’s population and assets concentrated in metropolitan areas, Japan’s rural areas are characterized by decline of economic growth and increase of aged population. City centers in small- and medium-size cities are on the decline, and so-called marginal villages are increasing mainly in farming and forestry villages in mountainous areas. This has made it increasingly difficult to maintain resistance and preparedness to natural disasters in such areas.

Since Japanese lands are vulnerable to water and sediment hazards, it is crucial that
Japan embarks efforts to adapt to climate change, in addition to those to mitigate (reduce) greenhouse gas emissions. The need for adaptation is widely recognized elsewhere, particularly in Europe. The European Commission (EC) issued a report entitled *Adapting to Climate Change in Europe – Options for EU Action*, in June 2007. The need to reduce greenhouse gas emission has been widely discussed in Japan, but both the political and private sectors have not yet sufficiently recognized the importance of adaptation, and insufficient interest has been paid for the increasing risk of water and sediment disasters. Japan, which is highly vulnerable to such disasters due to prevailing natural and social conditions, needs to take effort for adaptation that matches or surpasses the efforts performed in Europe and North America.

Elsewhere, increases in extreme weather and climate events have caused flood disasters, such as those that have been occurring with larger frequency in the downstream deltas of Asian rivers. The latter type of disaster is exemplified by the unprecedented huge flood disaster that occurred in Myanmar in May this year. Japan, which is in the Asian Monsoon Region, has a natural and social geography similar to these countries. Japan should implement strong assistance programs based on accumulated knowledge and advanced technologies developed.

Based on the background mentioned above, this report proposes following initiatives that must be taken from a new viewpoint, especially regarding water hazards and adaptation measures. Water hazards can come from both an excess of water in the case of flood and a deficit of water at drought. This proposal deals with water hazards brought by excess of water.

(i) Preventing water disasters is a core adaptation activity. The Government should make every effort to contribute to the solution of water hazard issues all over the world. Saving lives is the priority, so the Government should cooperate in observation/monitoring, forecasting and warning activities and in preparation of hazard maps. Also, the Government should provide assistance in policy and technology development for management of river basins to support the welfare of river-basin coexistence communities and sustainable development in the Asian Monsoon Regions. The capacity-building program related to these issues is also a key to reduce the disaster.

(ii) Recognizing that disaster prevention must be a component of development programs, the Government should take Disaster Risk Impact Assessments mandatory in all development assistance plans.
2. Why is adaptation necessary?

(1) Concept of adaptation

Adapting to water hazards means striving to create a disaster-resilient society with high adaptive capacity. Water-disaster resilience is composed of the four elements outlined below.

(i) Risk Awareness/Risk Assessment

Risk Awareness and Risk Assessment refer to an understanding of global warming and its various effects, spontaneous selection of adaptive actions, and support within the society taking such actions. In other words, awareness is a major element in decisions made on the direction of adaptation. It is at the core of a Disaster Awareness Society.

(ii) Physical and Social Infrastructure

Infrastructure is an outcome of investments made by society to guarantee and maintain the continuity of social activities. It constitutes an important part of adaptation. The term infrastructure should include not only disaster-prevention facilities, supply and treatment lifelines, roads, transportation, and telecommunications, but also core social services such as the provision of education and medical services. Such infrastructure should continuously function. This is defined as “public assistance” in a narrow sense. The infrastructure includes both physical facilities and social capital such as human resource development systems.

(iii) Resistance

Resistance refers to the ability of facilities and society to act against external forces that can cause disasters. This has been conventionally defined as mitigation in the disaster-prevention field. The United Nations has recently begun to use the concept of prevention. Japan’s mitigation plans has long been focusing on constructing facilities and structures. Control of land use is another important method. Regulating land use to cope with global warming and such as long-term sea level rise will become important in the future.

Maintaining resistance is as important as maintaining infrastructure, but the former includes maintaining private facilities and activities, and therefore its scope is far more wider.

(iv) Preparedness

Preparedness refers to society’s preparation for assumed hazards that cannot be deterred. In many developing countries, this is limited to preparing for emergent responses immediately after disaster strikes. It is, however, necessary to adopt a viewpoint of rehabilitation of society as a whole. This is resilience narrowly defined. Along with recovery, it is particularly important to deal with long-term restoration and economic activities and the psychological stress suffered by victims. Preparedness includes anti-disaster immunity, which will be discussed later.

Figure 1 shows the interrelationships among above mentioned adaptations.
Development of these elements will enhance society’s capacity to adapt to water hazards brought about by global climate change. Described below is the increase in external disaster forces due to global climate change, increased imbalances between the damage-prevention capacity of nature and the society, and the necessity of adaptation to water hazards to cope with such forces.

(2) Concept of anti-disaster immunity

Land formation that has occurred over the ages has always been influenced by climate change. Civilizations have adapted to the natural disasters they experienced and people’s daily lives have changed in response to the experience of victimization. This has led to the cultivation of what can be thought of as “anti-disaster immunity,” a characteristic that is in addition to resistance achieved by building disaster-prevention facilities. It parallels to the immunity seen in nature. By adapting to natural hazards and constructing disaster-prevention facilities, communities have been able to deter damage to a certain extent from small- and medium-scale disasters that occur often. Periods during which huge disasters rarely strike can be regarded as periods in which the natural world and human society have adapted and acquired immunity against small- and medium-scale disasters. In such cases, a balance has been reached, more or less, between societies and external disaster forces. On the other hand, there is no immunity against disasters of a type beyond those that are often experienced — disasters that exceed people’s awareness.

However, a steady increase in external forces induced by the recent global environmental change will increase the frequency of large-scale water-related disasters. The balance between the society and such external forces may be extensively disrupted.
Recently, the anticipation has appeared that a new imbalance may be generated in the near future (Figure 2). This is the reason why adaptation is necessary against water related disasters.

Anti-disaster immunity is composed of the three factors described below.

(i) Disaster resistance in nature (natural immunity)

Like living things, the nature acquires immunity, when it has long been encountered severe wind and rain. In the case of sediment disaster, areas likely to erode have already done so, and areas not likely to erode remain with increased resistance against wind and rain. In Japan, when Typhoon No. 10 in 2003 hit the Saru River and Atsubetsu River basins, Hokkaido, rainfall of about 300 mm in 24 hours was observed, a level far beyond that of past data in this area. The many slope failures that occurred and the large volume of drift wood generated caused bridges to wash away and other severe damages. However, no such damage by rainfall of 300 mm in 24 hours may occur in Kyushu, where heavy rain often occurs. A maximum instantaneous wind speed of 50 m/s was recorded in Sapporo on the occasion of Typhoon No. 18 in 2004, and roadside trees in Sapporo and rows of poplars at Hokkaido University tumbled down. No such falls of trees may occur in Okinawa where Typhoons frequently hit. A rapid increase in external forces produces a new situation without immunity for disasters, an extremely hazardous situation for which no one can predict where damage will occur.

(ii) Residents’ disaster awareness and community resilience

A rise in external disaster forces in a given area will lead to severe damage, and residents’ disaster awareness will be enhanced. If, however, they face disasters of a scale that they have not experienced, people and assets will be greatly damaged due to the lack of judgment ability and the panic. Community resilience and strong local
construction firms are required for swift recovery from disasters.

(iii) Social infrastructure and preparedness

Anti-disaster immunity depends also on the quality of the social infrastructure for daily life.

Europe was hit by heat waves in August 2003. In Paris, temperatures rose to 38°C or more for 10 days. About 15,000 people in France and 30,000 people across Europe died due to heat-related illness. Houses in France do not have air-conditioners, because summers are normally cool there. The society therefore failed to respond to the heat wave. Cities where summers are hot and air-conditioners are commonly used might respond to that kind of heat waves. In Okinawa, 90% of the buildings are made of reinforced concrete. They are built to prepare typhoons, but this is not the case in other areas of Japan. Infrastructure for living has been developed by the past experience responding to such forces.

It will require long time, large cost and experience to improve the three elements described above that would constitute anti-disaster immunity in response to the rapid growth of external disaster forces. Slow improvement of anti-disaster immunity may not catch up with the rapidly increasing external disaster forces as seen in Figure 2, and the imbalance between the immunity and disaster forces can be generated. Such imbalance which can appear within a few decades or a century will lead to an undefended situation in which communities will lack immunity for disasters. The society will be exposed to the damage of unforeseen dangers. Today, there is lack of awareness for the situation caused by the imbalance. The conventional measures are insufficient for adapting to the rapidly increasing external forces. For adaptation to avoid extensive damage, it is vital to extract and quantitatively evaluate components of anti-disaster immunity as soon as possible. It is necessary to identify signs of disaster and environmental change, by small changes induced by global warming in nature and society, and to build up new disciplines and technology for prediction and prevention.

3. Approaches to adaptation

(1) Building community-based disaster awareness

The idea that “everyone should protect their own lives by themselves,” is fundamental of disaster prevention. There is a Japanese saying that “disaster will come when you have forgotten (in other words, disaster awareness will fade away with time).” Some people may have forgotten, but some even may have not experienced (or not had an opportunity to build the awareness) yet. In the midst of global environmental changes, both the magnitude and the aspect of disaster are changing. Can you protect your own life without an understanding of the disaster? From this viewpoint, emphasis should be laid on the necessity of building community-based disaster awareness. The basic requirements for the community being safe and secure against disaster are ‘Awareness’ and ‘Preparedness’.
‘Awareness’ means correct understanding and being always aware of natural disasters. ‘Preparedness’ means preventing and being able to appropriately cope with natural disasters.

Individuals should have the understanding and wisdom to cope with natural disasters, also should prepare against disasters at all time. However, modern communities are in a precarious situation. The reasons for this in regard to water disasters are described below.

The memories of severe water disasters in Japan between 1940s and 1960s have already faded away. At the present time, since river improvement, forest conservation and sabo works have been accomplished to certain extent, few people experienced disasters such as flood. It is therefore difficult for communities to pass on experience and wisdom to the next generation. Other problems are shortage of well-trained government personnel who can respond to disasters, increasing nuclear families, and increase of new residents in water hazardous areas. Factors such as the increase of aged people, decreasing the numbers of children, depopulation in rural areas and overcrowding in large cities, and changes in the industrial structure have led to increased vulnerability to disasters both in large cities and farming and forestry villages. Past experience is no longer a sufficient guide due to the changes in river basins caused by land development. In such circumstances, global environmental changes may induce unprecedented phenomena in the society.

Education is important in building community-based disaster awareness. Education on the area’s possible disasters should be conducted in elementary and junior high schools. Scientific education and practical training on global environmental changes (effects from global warming, population movements, and socioeconomic changes) are needed in high schools. Teachers must be trained for these purposes, and educational materials must be developed. Education and training programs supported by the government, the academic sector, and industry are needed to develop community leaders in disaster-prevention.

Furthermore, it is necessary to raise disaster awareness among the people by evaluating and communicating the vulnerability of society as a whole to natural disasters. For that purpose, preparation and effective promotion and utilization of hazard maps and other tools explaining the phenomena (what can happen) and countermeasures (what to do) are required.

(2) Developing physical and social infrastructures

Measures for adaptation include not only physical infrastructure (ex. flood control facilities), but also social infrastructure. Local communities have been weakened in Japan. It is necessary to reconstruct mutual aid system (social capital) for the occasion of disaster, which had been held by the Japanese communities in the past. This can be thought of as social technology against disasters. NPOs which can involve in such activities should be fostered.

Development of information systems is needed to overcome vulnerability to disaster.
The precise and appropriate information, including forecast/prediction and recovery/restoration information, can remarkably reduce damages from disasters. It is also important to develop and maintain lifelines such as medical services and water and energy supplies.

Reinforcing resistance capabilities of constructions for prevention against disasters is becoming increasingly important. With a sense of urgency, analysis of increasing trend of rainfall intensity must be reflected in planning and designing of new disaster-prevention facilities. Like the Netherlands, the United States has built levees designed to prevent overtopping from a 500-year flood in recent years. Levees must be continuously inspected and maintained to ensure the security of specified functions in the event of a severe flood, and dams must be properly controlled for flexible operation of water-use and flood-control. Conventional construction technology is not enough. Formulating a framework for the establishment of a new technical system for adaptive management is an urgent task. Future goals should include single-purpose flood control dam, i.e. dry dam that stores water only during floods. Here, detailed and precise predictions for climate change conducted by utilizing the Earth Simulator is indispensable.

In addition to prevention achieved by using such flood-control facilities, structures of cities and other areas must be changed into flood-proof type. It will be difficult to adequately respond to unprecedented and devastating floods triggered by global climate change by only using flood control facilities. Cities should have water-resistant or flood-proof structures. This includes houses with strong resistance to flood damage and countermeasures against underground flooding in metropolises. Ideal land use is another agenda item for the future.

(3) Planning for recovery and restoration

With the progress of global warming, it is becoming more important to assess damage from floods and storm surges, and to prepare recovery/restoration measures in advance. Improper implementation of recovery/restoration measures after a large-scale flood will endanger the sustainability of affected communities and have an extensive impact on post-disaster economic activities. Japan’s security and the world economy will be adversely affected if devastating flood disaster occurs in a central city in Japan.

In the past, developed countries have taken many initiatives to mitigate direct damage. However, only a few of them have focused on post-disaster recovery and restoration. In addition to the progress of global warming, the example of Hurricane Katrina and other major disasters have prompted many countries to launch studies and initiatives. In the United States, some reports have been issued recently on adaptation for the transportation network, but recovery and restoration are not covered. As a part of the impact assessment of post-disaster local economy in order to plan desirable recovery and restoration, Input-Output Analysis has been conventionally conducted.
the conventional method to devastating disasters such as Hurricane Katrina is still in the research stage, because detailed analysis of the phenomena has not yet been completed.

In the United Kingdom, various studies are in progress, learned from the two major floods in 2007. In this process, recovery and restoration have been recently added as study items.9)

Effective system of flood insurance that could play a vital role in recovery and restoration has been studied in some countries, including the United States, where insurance became a major issue in the aftermath of Hurricane Katrina.10,11) The amount of funds in the capital market generated by Cat bonds, a newly developed security, to assure the solvency of insurance, and reinsurance companies are rapidly increasing. But, it does not account for a large share of the insurance needed. There still remain many issues to be resolved, including the preference of insurance purchasers, nurturing self-help for damage mitigation, measures for the poor, and a degree of governmental involvement. Among others, a key issue to address is the ability to project the frequency and extent of damage that could be triggered by global environmental change in order to guarantee the normal functioning of the insurance system.

In Japan, the Cabinet Office’s Expert Examination Committee on Large-Scale Flood Countermeasures 12) has dealt with the issue on post-disaster countermeasures in the Tone and the Ara River systems. The study on detailed damage estimates is the first step, and the committee is expected to play an important role in planning the recovery and restoration measures, utilizing the results of the study. It is significant that the committee has been sharing information with lifeline administrators in the study. Not only the quick recovery of lifelines, the duration needed for drainage of the water flowing through levee breaches would also affect post-disaster recovery and restoration. Securing drainage pump function is a key for reducing this duration, as seen in the case of Hurricane Katrina recovery work. It is noteworthy that the effects of pre-disaster structural measures, such as waterproofing of drainage pumps and securing necessary heights for fuel-feeding system, were quantitatively identified on the basis of the time-span needed for drainage.

The Chubu Regional Bureau of the Ministry of Land, Infrastructure and Transport has organized the “Tokai Netherlands Regional Council against Storm Surge and Flood” in cooperation with many related organizations. The council has established a “Crisis Management Action Plan (1st Edition)”13) based on the specific damage estimates. This is a valuable attempt to build awareness among the related organizations by calling for the preparation of a wider-area evacuation plan. Hopefully, another revised plan will be made more specifically, focusing not only on emergency measures, but also on recovery and restoration measures.

Based on the current initiatives, the measures described below should be implemented for recovery and restoration.

(i) Nationwide studies of post-disaster recovery/restoration measures based on detailed disaster estimates and promotion of pre-disaster measures
It is said that nothing is better than pre-disaster measures in recovery and restoration. The such detailed disaster estimates as those conducted by the Cabinet Office and the Chubu Regional Bureau of the Ministry of Land, Infrastructure and Transport will serve to prepare pre-disaster structural and non-structural measures and to recognize the importance of those measures nationwide. Therefore, such estimates should be promoted nationally, and post-disaster measures should be promoted in the future.

(ii) Studies on adverse effects related to time-length needed for post-disaster recovery

The longer the recovery period, the greater the adverse effects on the victims—on their local culture and on their psychological or mental state. It is very likely that the adverse effects on the economy will be rapidly amplified over time in case functions of metropolis are damaged. With this in mind, studies should be conducted on various effects depending on the time-length needed for post-disaster recovery of major lifelines leading to full restoration, and the results should be shared with residents and the industry and be reflected in pre-disaster strategies for recovery.

(iii) Improving disaster prevention measures in the period of restoration

In view of the progress of global warming, it is indispensable to incorporate measures to improve disaster prevention in restoration efforts. Nagoya City made construction of flood-proof structures obligatory during restoration against the Ise Bay Typhoon hit central Japan in 1959. With the exception of disaster hazard areas, however, these types of measures are not conducted in Japan afterwards. As time is limited after disaster, it is better to study improvement of disaster prevention incorporated in post-disaster restoration efforts in advance.

(iv) Study of flood insurance

Various studies have been conducted on desirable flood insurance. They must be pursued further in coordination with the other studies discussed above, based on the damage estimates of large-scale floods. It is crucial that such insurance system must be designed to contribute to disaster-reduction efforts made by individuals and businesses.

(v) Continuous monitoring of adaptive capacity

Continuous monitoring of adaptive capacity of each area along with the phases of implementation of new disaster-prevention measures and post-disaster recovery/restoration can serve as a basic adaptation measure to changing climate. This work will be of use in accelerated development of recovery and restoration measures.

(4) Research and development for adaptation

The effects of climate change due to global warming vary from area to area. Japan’s territory stretches from north to south, from the subpolar zone to the subtropical zone. Changes in rainfall due to climate change should be studied in detail. Highly precise,
detailed projections of changes in each area are needed, including work done with the Earth Simulator.

Research and development on flood control facilities should achieve anti-disaster immunity that goes beyond conventional concepts. To definitely prevent unexpected devastating disasters, it is vital to establish a new engineering field as soon as possible to prevent devastating disaster by developing techniques of parameterizing and quantitatively evaluating components of anti-disaster immunity, and identifying signs of disaster and environmental change from smaller changes occurring in the natural world and in communities because of global warming. The development of disaster-reduction technology from the new viewpoint is an urgent task. Examples include wide-range water depth monitoring system needed to help prevent the collapse of landslide dams, and dry dam as a sediment control measure against large-scale slope failures in upstream areas.

4. Reforming the national land structure

In addition to the specific challenges mentioned above, it is necessary to consider reformation of national land utilization as a medium and long-term paradigm shift to cope with changes caused by global warming.

In regard to the structure of national land utilization, if the current socioeconomic structure is to be sustained, the concepts and methods of adaptation to be applied can be different between large cities where population and assets are concentrated and rural areas characterized by depopulation.

Located in low-lying areas, Japan’s large cities are especially vulnerable to water-related disasters, such as floods that are growing in scale and sea level rise caused by global warming. For example, dyke breakage during a flood can result in catastrophic damage in large cities. In this situation, the country may possibly face difficulties in view of political and economic security. Psychological damage to the people will also be severe. In such large cities, construction of disaster prevention facilities such as high-standard levees (super levees) should be implemented.

On the other hand, the rural population has been decreasing. The supply of low-cost energy that has supported and maintained societies with living spaces expanding into suburbs is becoming more uncertain. Under these circumstances, it is likely that sustaining societies inconsistent with efficient government services will become increasingly difficult. Therefore, investments to build compact cities and farming, forestry and fishing villages that are resilient against natural disasters will become important. In other words, it is time to consider opting for compact locations made suitable for living and economic activity. In this case, integration of roads and levees and flood countermeasures such as circle levees should be considered. The need for Japan to efficiently invest in this kind of adaptation becomes clearer by the aging and shrinking of population and by the possibility that the scale of economy may decline. Nationwide uniform investment is not necessary, and the investment should be made carefully and effectively, after fully identifying the properties and the
vulnerability of individual river basins and communities.

In addition to socioeconomic effects, the global warming can yield psychological effects on people and their sense of values. If it occurs, other scenarios should be employed. Japan’s social and land-utilization systems are vulnerable for water-related disasters, because population and assets accumulated and concentrated in alluvial plains. Japanese food supply highly depends on other countries. Overall reform for land use must be discussed also from the viewpoints of disaster-risk diversification and sustainability. In other words, comprehensive studies should be promoted, incorporating the viewpoint of reforming the structure of land use. Analysis and consideration from medium- and long-term standpoints are needed to derive the direction to sustainable, safe and secure land utilization. Full consideration must be made in treating the subject, including social values and the selection of residential areas by people; the possibility of maintaining and developing the rural economy in an era of globalization; the pros and cons of decentralizing economic functions now concentrated in large cities; and the roles of the government, municipalities and the private sector.

5. International contributions to prevention of water hazards

COP13 (the 13th Conference of the Parties to the Framework Convention on Climate Change) recognized for the first time in its Bali Action Plan that adaptation as well as mitigation is important in the effort to counter the effects of global environmental changes. This recognition in the international society has great political meaning, and both developed and developing countries have begun to step up initiatives for adaptation to climate change.

Water hazard countermeasures are crucial for adaptation to climate change. In this area, expectations for Japan, a country that has achieved economic growth while living and struggling with water over a long period of time in the Asian Monsoon Region, are very high. The country’s experience, technology and funds will be relied on.

International contributions win respect in the international community. This strengthens the Japanese national security and directly leads to greater economic strength based on its technology and experience. The same applies to European and North American countries. Diplomacy based on scientific and technological contributions became an intense international competition.

Under these circumstances, there has been an early recognition that disaster management should be placed at the center of Japan’s scientific and technological diplomacy. Japan hosted the Hyogo Framework for Action Conferences and established ICHARM (International Center for Water Hazard and Risk Management supported by UNESCO), which are highly evaluated internationally. However, the government’s system for promoting highly effective international contributions is not sufficient and is well behind those of Europe and America, particularly in strategic efforts. Japan’s ODA budget has been rapidly decreased from its peak in 1997, and the country’s international contribution system as a whole is being reviewed.
The major cause of natural disasters in developing countries are often poverty and governance issues, which sometimes transcend the lack of individual infrastructure in reducing disasters. Development may often result in the destruction of traditional patterns of life in developing countries. International contributions to disaster prevention should take these issues into account.

In view of the facts mentioned above, international contributions for disaster prevention should be implemented in ways outlined below.

(i) Integration of disaster prevention assistance and development assistance

Disaster prevention should not be limited to humanitarian assistance focusing on post-disaster rescue operations. It must be planned and implemented in connection with all development projects. It is necessary to review the standard adopted by the OECD’s Development Assistance Committee (DAC) and obligate implementation of the Disaster Risk Impact Assessment (DRIA) for all ODA items.

(ii) Strengthening and mobilizing assistance capabilities in advanced technology and policy technology

Japan should intensively strengthen and mobilize its capabilities as indicated below. They are areas pertaining to disaster-prevention assistance for which Japan is internationally competitive, and other countries are expecting highly.

- Advanced technology for long-term projections of climate change, observation/monitoring, forecasting and warning, information transmission technology, and hazard mapping.
- Policy and technology to manage river basin coexistence communities; measures supporting the sustainability of the Asian Monsoon Region.

(iii) Assistance in capacity building

The aim in providing assistance to developing countries should be to contribute to their independent, sustainable development. Capacity building and educational assistance should be enriched for that purpose. They have high expectations for water hazard programs, which should be the pillar of adaptation assistance for climate change.

(iv) Foster the development of a group of international engineers

Japan lacks a system to derive full benefit of experience and information of the engineers involved in international contributions especially of the government officials experienced overseas. This deters the country’s strategic international contributions. Creating an information hub and developing and maintaining groups of engineers with international experience are urgent task.

(v) System of strategic international contributions and scientific and technological diplomacy

Scientific and technological diplomacy based on international activity contributes to
national security. It is necessary to build a system beyond sectionalism to implement diplomacy in an integrated and efficient manner under a state strategy.

(vi) At important conferences to be held in the future, Japan should commit to making international contributions in the following ways:

• Adaptation focusing on water hazards: Japan should contribute to this adaptation throughout the world.

• Protecting human life is the priority: Japan will cooperate in observations/monitoring, forecasting and warnings, and hazard mapping.

• Building river basin coexistence communities to support sustainable development in the Asian Monsoon Region and providing political and technological assistance for its management.

• Assistance capacity-building programs in related above items.

• Disaster prevention should be included in development plans. Disaster Risk Impact Assessments should be included in mandatory part of all of Japan’s development assistance plans.
Marginal settlements  (p. iii, p. 1)

These are settlements where the elderly account for the majority of the population and where maintaining community life is difficult, as reflected in few weddings, funerals, or coming-of-age ceremonies; where residents find it difficult to cooperate in management of farmland; and where it is difficult to maintain community roads. According to the Ministry of Land, Infrastructure and Transport, in 7,878 settlements out of 62,273 settlements surveyed, the elderly (age 65 or over) accounted for the majority of the population (as of April 2006).

River-basin coexistence management  (p. iv, p. 2, 13)

Management of hydrological cycle systems for land and water to build human activities changing over time that remain in good balance with the natural environment (river-basin coexistence communities), and to realize sustainable life and production. Japan has been introducing this concept, as development of “River Basin Communities,” since its 3rd Comprehensive National Development Plan.

Adaptive Capacity  (p. 3, p. 10)

The ability to adapt is called adaptive capacity. It refers to the capacity to comprehensively adapt to changes by reducing damage resulting from climate change and extreme weather events and coping with the results and effects. As a broad concept, it includes construction of disaster prevention facilities, building disaster awareness of residents, and organizing residents’ mutual-aid.

Resilience  (p. 3)

The ability of a society to absorb effects of changes in the external environment and adapt to stresses and changes, while maintaining basic structures and functions. Important components include the ability to mount strong disaster-recovery efforts and competently handle restoration work.

Social Capital  (p. 3, p. 7)

There are many definitions, but Putnam defines the term as “features of a social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit.” Mutual-help in response to a disaster would fall under this definition.
Cat bond (Catastrophe Bonds)  (p. 9)

Bonds used for conditions such as an earthquake or hurricane in which the probability is low, but if one occurred, it would cause very great damage. Through securitization, this type of bond is used to transfer the risk of such a disaster to capital markets. This is a measure, other than reinsurance, used to secure solvency for insurance companies.

High-standard levees  (p. 11)

Under the River Law, high standard levees are defined as “levees having a standard structure designed to withstand floods in which the flow exceeds the design flood discharge, including cases in which the majority of land within the area of the levees is made available for normal use.” To avoid catastrophic damage involving dike breakage, construction is ongoing in five river systems in large cities, namely Tone, Ara, Tama, Yodo and Yamato. The city side of the embankment forms a vast gentle back slope that can be used for normal land use. Theses are also called “super levees.”
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I am Yumio Ishii, the chair of DRM-TG and chairman of CTI Engineering, an engineering consulting firm. Today, I would like to speak about the concept of integrated basin management, and introduce you to some of our projects in Japan.

1. Disasters are Social Phenomena

Before I start my discussion of the main subject, I would like to speak a little of the social and historical background of the disaster. As I said in my opening address, “Natural Disasters are Social Phenomena triggered by Natural Phenomena.” Social change induces change of the nature and the natural phenomenon becomes the cause of disaster.

Therefore, disaster risk management must be socially comprehensive and integrated. From the standpoint of water-related disasters, we must not confine ourselves in such a single and separated phenomena as flood flow in river channels, drought in paddy fields but to expand our scope to river basin. This is the fundamental concept of “Integrated Basin Management”.

Integrated Basin Management is the process of coordinating flood control, water use, and environmental conservation in an integrated manner across the entire river basin, while ensuring coordination among stakeholders.

2. History of Integrated Basin Management

Initially in Japan, water was managed in a way so that flood defense and water use were managed at a specific location or a “point”. A specific location was protected from floods or was a base for securing water for usage. Example of such traditional flood control scheme is called “Waju” in Japanese language, which means an area protected by a ring shaped levee.

In the end of 19th century, Japan began to build continuous high levees to protect the cities reclaimed around the river, and in 1930s began to build multi-purpose dams in the upstream to control flood discharge and to secure energy and water for
3. Comprehensive Flood Control

Traditional flood control aimed rapid discharge of run-off water into the sea through the river channel confined by high continuous levees. However, with the rapid urbanization, reclaimed swamps lost the water retarding capacity and the rainwater no longer infiltrated into the concrete paved ground causing higher runoff coefficient. It meant the traditional conventional measures could not cope with increased flood. Increase of flood peak discharge was caused by urbanization at the Tsurumi river in the western suburbs of Tokyo. The increase of 100% of flood peak discharge from original 650 m³/s by the same rainfall of 308 mm in 2 days had occurred after urbanization. With catchment area of 235 km², damage potential of 50 m$ in ’66, 350m$ in ’70 and 630m$ in ’75, and population of 450,000 in ’58, 1,880,000 in 2003 had occurred.

In 1974, challenging “comprehensive flood control scheme” was developed in the Tsurumi river basin for the first time in the history of flood control. The fundamental concepts of the scheme are:

The river was not merely linear water channel but the drainage basin and nonstructural soft-measures were put the same role as hard-measures

In order to minimize the damage as a whole, important areas are protected by high levees while some areas are specified as inundation permissible zones. Furthermore, some pumping stations were ordered to stop operation while inundation water stage were rising. Nonstructural measures such as land use regulation, promotion of flood resilient housing, disclosure of hazard maps, flood warning and evacuation systems were implemented. For the smooth implementation of the new scheme, public involvement system was introduced. Flood insurance, permeable pavement were studied.

Based on this scheme, the flood control projects were developed from traditional structural measures to new structural and non-structural ones. These measures were deployed in an integrated manner. Retarding basins were used for sporting arena and the Yokohama Soccer Stadium where the W-Cup games were held in 2002, was constructed on an elevated artificial ground above the retarding basin.

4. Comprehensive Sediment Control  - New Sabo Project -

We are also comprehensively managing sediments and land slide. Sediment is
comprehensively managed from its origin in the mountain to the seashore. Sediment issues were traditionally dealt with ‘Sabo’ works and forest conservation, however, sediment deposition in dams and exploitation of sand and gravel from river beds for concrete aggregate caused river bed degradation and coastal erosion. They caused rupture of bridge piers, mal-operation of water intake, degradation of water related eco-systems, rupture of break-water, attack of higher waves, degradation of scenery. In order to address these issues, comprehensive sediment control scheme was developed, which includes monitoring of sediment amount and quality, restoration of natural sediment flow and coastal restoration.

(Example) The once eroded beach near Fukuoka in western Japan was successfully restored by sand nourishing and jetty.

5. Water Use

Japan receives most of its rain during the rainy season. The average annual rainfall is about 1600 mm. This figure seems reasonably high but the per capita water resources of Japan is as poor as 6000 m$^3$. Most of its potential water resources flow out to the sea without being used. Thus, water shortage is also a major problem in Japan.

Under this situation, Japanese Government established “Water Plan 21” to deal with this issue of which the basic objectives were establishment of a Robust Hydrological Cycle by 2010-2015 as target years. In order to achieve the basic objectives, construction of a sustainable water use system, conservation and improvement of the water environment and restoration and education of water culture were deployed.

Japan has been building multi-purpose dams which serve for irrigation, domestic and industrial water uses, flood control, environmental flow and hydro-power generation. Currently, hydro-power is only 3.4 percent of power generated in Japan, however, I believe it will gain more attention in the future as the mitigation measure against global warming.

Water transfer between basins is another measure. Also, accommodation among water users during the drought period has been effective for utilizing the limited water resources in a coordinated and integrated way.

Groundwater is also an important water resource in Japan. However, the groundwater pumping drastically increased during the high economic growth and caused severe land subsidence of more than 2 m and intrusion of saline water. Regulation of groundwater usage and the shift to surface water development have improved the situation significantly, but the problem is yet to be fully resolved. Recently, over exploitation of groundwater used to melt snow on the street caused a severe ground
subsidence. However, many people misconceive today that developing groundwater is better than surface water development.

Desalination technology is advancing with improved membrane system but they must consider new hazard, pollution by waste brine water.

What’s important for the conservation of water is efficient use of the limited resources. For that, water recycling and rainwater utilization are effective solutions. Water recycling has rapidly spread in the industries due to regulation and water pricing. The steel manufacturing uses large amount of water, where the water reuse rate improved from 5% to 97 or 98% now.

(Example) CTI’s Fukuoka office utilizes rainwater and recycled water for its service water supply, and conserves about 80% of all miscellaneous water uses.

On the other hand, we must consider the water issue globally and recognize the quantity of imported virtual water of 64 b ㎥/y which is comparable to domestic irrigation water use.

6. Environmental Conservation

Water quantity is not the only issue. Quality and the environmental and ecological functions of water must also be protected. The rapid economic growth induced a serious water pollution problem in Japan. However, the sewerage system and water quality improvement measures have improved the water quality significantly. Currently in Japan, 71% of all population is connected to sewerage system. The coverage rate is 98% in cities with population of over one million. The Sumida river in Tokyo used to have BOD of 40mg/l in 1961. It has improved to 3.9mg/l in 2002. The sewerage system is the vein for a human body if the water supply is the artery. The water supply system will not function without the sewerage system. Many large cities in Japan face the issue of combined sewers but improvements are being made. Enforcement of discharge regulations and water pricing also contributed to the water quality improvements.

Ecological functions of rivers are also being protected. All river improvements in Japan including flood control must be based on the nature-oriented river works, which aims to preserve or create the natural environment and scenery that are in harmony with culture and history of the community.

Environmental flow is set for rivers by regulations and is discharged by dams. Power generation facilities are also required to cut their power generation for discharging environmental flow.

Water is an important factor for scenery. Waterfront improvement contributes to
scenery improvement as well as vitalization of the commercial areas surrounding the waterfront by attracting customers and tourists.

(Example) Japanese river engineers have been involved in river restoration projects since 1970's. The Furukawa River Restoration Project in Tokyo was a pioneering one. A water amenity space was created in the urban city of Tokyo for the first time in Japan. The Furukawa river is so restored as ordinary discharge is flowing on the ground surface whereas sewage and flood is discharged through underground tunnel. The Furukawa today is a two-storied river.

(Example) A historical heritage of Meganebashi bridge- Eye-Glasses bridge in Nagasaki in western Japan was flushed away by the historically biggest flood. The restoration work must solve two problem of beautiful scenery and safe discharge of flood at the same time. The answer to the question was the reconstruction of the bridge with two diversion tunnels in the both banks.

(Example) Under the new policy of “Nature-Oriented River Management”, restoration works are implemented in accordance with flood control works at the Kushiro river, Hokkaido.

(Example) JSCE is actively involved in the implementation of the new policy. The Izumigawa river landscaping project was awarded to Grand-Prix by JSCE.

7. Coping with Climate Change

One of our new concerns is climate change. The IPCC’s 4th assessment report warns that the climate change will induce more frequent flood and drought disasters in many parts of the world. In order to adequately adapt to the future climate change risks of increased foods and droughts, integrated basin management is a must.

We must first improve the prediction accuracy of climate change, as it will change our safety levels against floods and droughts. We must contribute to mitigation of climate change by reducing GHG emissions from water related projects and activities. We must then adapt to the climate change impacts by fully utilizing our existing structures or constructing new ones if required. We may have to also change our land use or ways of living in order to minimize the negative impact of future climate change.

8. Conclusion

Water must be managed in an integrated manner across the entire river basin together with stakeholders so that people can sustainably enjoy its benefit.

We have learned and accumulated experiences on integrated basin management over
a long period of time. With regard to the water environment, we were a little too late in realizing the importance of its protection, and we are now making a great deal of effort in restoring the environment that we have lost. We must ensure that such mistakes are not repeated in other parts of the world, by contributing our experiences and technologies for improving and protecting water environment.
RESPONSE OF THE PEOPLE AFTER RECEIVING
THE TSUNAMI WARNING

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Abstract
Although the tsunami warning system in Japan is one of the most developed and sophisticated in the world, we have the serious problem in response of the people receiving the warning through TV and ration and public communication. Only 10% of them could make the action to save their lives and/or evacuation to the safety area. This paper describes the issues in Japan as well as others where the recent tsunamis caused the damage, in order to identify the key to solve it.

1. Introduction and JMA warning system
We in Japan has severely been suffered by the tsunamis around Japan and in the far field such as the 1960 Chilean tsunami. The most devastating damage is the 1896 Meiji Sanriku tsunami, causing more than 22,000 casualties as shown in Fig.1. More than 50 years have passed since the initiation of the tsunami forecast system in Japan in April 1952, with the announcement system judged by the real-time seismic network to be of the highest density. In April 1999 the Japanese Meteorological Agency (JMA) began operation of a new tsunami warning system designed to provide quantitative information about tsunami arrival time and wave height, dividing the coast of Japan into 66 operational regions. This system is expected to give the coastal communities detailed information for appropriate evacuation. The system, using a seismographic network composed of 150 highly distributed sensors, can determine the epicenter and magnitude of an earthquake. Based on this information and a tsunami modeling database obtained prior to the event, the coastal attack of tsunamis, JMA (2008) is able to estimate tsunami arrival time and height in a relatively short time. The quantitative information forecast is issued to the communities via satellite/TV media within 5 to 7 minutes after the tsunamigenic
earthquakes. At the present, the earthquake early warning enables the tsunami issue within a few minutes after an earthquake.

Figure 1 Great Sanriku tsunami of 1896 that occurred in Miyagi and Iwate prefectures, as documented in Fuzoku-gaho, an illustrated magazine

2. Response of the people

The strong ground shock of the May 26, 2003, in Sanriku south earthquake (M=7) was observed around both prefectures in Iwate and Miyagi, the northern main island of Japan. The seismic intensity in the coastal area ranged from 4-6 in the JMA (Japanese Meteorological Agency) scale, which suggests a tsunami generation. Actually, the earthquake was too deep to generate a tsunami. However, had the earthquake been shallower, a tsunami would have attacked the coastal area within 10 minutes. It is estimated that only 10% of the residents would have evacuated to elevated areas on their own initiative, despite the experience of the 1896 tsunami, the 1933 Showa, and the 1960 Chilean tsunamis on the Sanriku coast (Ushiyama & Imamura, 2004). The Sanriku community has expended great efforts to reduce the effects of tsunamis: education, public awareness campaigns, and tsunami protection works. As a similar case, on March 26, 2001 in Okinawa and September 26, 2003, November 15, 2006 and January 13, 2007 in Hokkaido and Tohoku, the tsunami warnings, including quantitative information such as arrival time and wave heights, were issued via television and radio. Despite the number of
residents who heard the broadcasts, few were able to evacuate the area, which suggests the information is available, but the activities necessary to avoid the disaster are not being implemented.

3. Countermeasure for tsunami disaster reduction including the risk information

The Japanese coastal area has been altered drastically and rapidly due to the construction of emergency countermeasures such as wave breaks and sea walls after the 1959 Ise storm surge and the 1960 Chilean tsunami. Rapid economic and industrial growth have resulted in dramatic changes in land-use, configuration of human communities, and high density transport networks on the coast. Various facilities to accommodate this growth—facilities that did not exist at the time of the previous tsunamis in Japan—have been built on the coast, and the harbors and ocean are congested with a large number of fishing and leisure boats as well as large combustible tankers, suggesting the increase of vulnerability. And we in Japan have the possibility of catastrophic damage caused by earthquake and tsunami. According to the results of a special committee in the Central Disaster Management Council (CDMC) in 2003 (Prime Minister Cabinet Office, 2003) investigating earthquakes and tsunamis in Tokai, Tonankai, and Nankai, a tsunami with greater than 10 m wave height is predicted to affect the entire coastal area of the Western Pacific coast of Japan, in which the disaster reduction structure system, such as sea walls, no longer protects the coastal region and its inhabitants against tsunamis (Fig.2). We are now facing the possibility of damage in seaside industrial areas, including large scale fires, failure of power plants and industries, and the cessation of sea transport services.

Information on tsunamis both before and after generation is the key countermeasure to reduce resultant damage, especially the loss of human lives. A hazards map with tsunami inundation simulated by numerical analysis is an essential tool (Cabinet office, 2004). The accuracy of the simulation must be improved in order to design a system to organize members of the community: the residents, local government officials, and tsunami experts. Such risk communication on the map through them is becoming more important. Real time information from data of observation and simulation just after the generation is also essential. Experts need to continue to refine observation technology, such as wave meters with ultrasonic and pressure capabilities and GPS sensors to detect the tsunami following an earthquake. However, neither improved information gathering nor refined tools for prediction will motivate residents of threatened areas to evacuate.
Researchers specializing in information recognition and motivation must address what information people need to encourage them to evacuate at the appropriate time.

Figure 2  Tsunami propagation in the western part of Japan estimated by a special committee in the Central Disaster Management Council (CDMC)

4. Tsunami information and response of the people after the 2004

We investigated the tsunami information/warning and response of the people including evacuation documented in the reports and videos in recent tsunamis including the 2004 Sumatra, in order to discuss the essential role of the early tsunami warning. There three stages for carrying out safety evacuation after the earthquake; the first is to collect the information of tsunami warning and natural phenomenon such as strong shakes and abnormal on the coast, the second is to make decision of evacuation based on the risk perception, the third is to select proper route and place for safety evacuation from tsunami attack. Unless the three stages should be completed adequately, people could not be survived. We found the balance between tsunami warning and risk bias in individual on response. If the risk on the warning overcome the risk bias, they could make the decision of evacuation, which suggest us an idea of proper and essential role of the warning system. Moreover, in daily life, the functions with risk communication and education so on are important to decrease the risk bias.
5. Comparison between the 2006 SW Java and the 2007 S Sumatra

Those are not case in Japan but valuable to discuss the process/ways for tsunami mitigation. Since the 2004 Sumatra earthquake, there are series of earthquakes followed by the tsunamis. The worst of the tsunami damage among those is the 2006 SW Java. Table 1 shows the comparison between 2006 SW Java (Imamura, 2007; BAKORNAS, 2006) and 2007 S Sumatra, including the earthquake intensity, tsunami runup and damage on the human and houses. Although the magnitude of the 2006 is smaller than the 2007, the tsunami and its human damage of the 2006 is much larger than the 2007, on the other hand, the intensity of the 2007 is larger than the 2006, causing the much more houses damage. This suggests that the severe houses damage due to the strong quake by the earthquake of M8.4 in 2007 is significant, however the quick response of the people after the quake and tsunami information on TV and radio based on the awareness of the tsunami after the 2004 could save their lives. What is the public awareness and how is it improved and maintained are our questions in tsunami disaster mitigation and preparedness to reduce human loss.
Table 1 Comparison between the 2006 SW Java and the 2007 S Sumatra

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<tr>
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<th>2006 SW Java</th>
<th>2007 S Sumatra</th>
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<td>Earthquake Magnitude and Max. Modified Mercalli Intensity scale</td>
<td>M7.7, MMI&lt; 5</td>
<td>M8.4, MMI=7-8</td>
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<td>Dead</td>
<td>637</td>
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References:


Abstract: In the present research, tsunami vulnerability assessment of Cox’s Bazar, Bangladesh’s southern-most district has been performed with respect to the potential tsunamigenic earthquakes in the Bay of Bengal through numerical modeling. At first the potential of occurrence of tsunamigenic earthquakes in the Bay of Bengal and in the vicinity has been investigated and later the effect of tsunami on the coast of Bangladesh has been explored through the numerical modeling of wave propagation for different possible tsunami sources, different subduction depths and different orientations of subduction faults. The study of tsunami propagation showed that if any tsunami originates in the Bay of Bengal or in the vicinity, the continental shelf along the coast of Bangladesh would significantly reduce the wave height of tsunami propagation.

Key words: Bangladesh, Cox’s Bazar, Numerical Simulation, Tsunami, Vulnerability.

1 INTRODUCTION

The great Sumatra–Andaman Earthquake and Indian Ocean Tsunami of 2004 have triggered renewed interest in the study of historic earthquakes and ocean disturbances in the Indian Ocean as well as in the Bay of Bengal region. Bangladesh, one of the most vulnerable countries to natural disasters, is situated in the active plate collision zone and the country is endangered due to large earthquakes. Though Bangladesh was relatively less affected by the devastating tsunami of December 2004, there is a grave concern whether and to what extent the country’s coastal population is vulnerable to tsunami hazard. The southern part of Bangladesh, lying beside the Bay of Bengal has millions of people residing in the coastal region. Therefore it is urgent to assess whether the huge population of this region are at risk of tsunami.

The present study evaluates the potential for tsunamigenic earthquake in the Bay of Bengal and attempts to assess the vulnerability of Bangladesh’s southern-most district Cox’s Bazar to tsunami-generated inundation. At first, the available knowledge and views on the existence of tsunamigenic faults, tsunami potential and associated risk of the region are summarized from historical records and documents. Then for different possible scenarios the effect of tsunami waves on the Cox’s Bazar coast has been evaluated through 2D numerical simulation. Finally inundation of the study area has been calculated using a 3D model.

Since 1980s, scientists have thought that the subduction zone of the tectonic plates bearing India and Southeast Asia meet, which also caused the 2004 Sumatra-Andaman earthquake, continues north through the Bay of Bengal and along the Myanmar coast. As previous data from this region did not show any active subduction, the danger of large earthquakes in the more northern part of the bay was considered to be nominal which led to little concern about the subduction zone in the northern Bay of Bengal along the coast of Myanmar. Recently, Phil Cummins (Cummins, 2007), a senior seismologist at Geoscience Australia, made an intensive study on this issue and highlighted that the Myanmar coast has the potential for large, tsunami-generating earthquakes. According to him, the tectonic environment of this part has similarities to other subduction zones that experience giant megathrust earthquakes, stress and crustal strain observations, which indicate that the seismogenic zone is locked. Historical records also indicate that giant tsunamigenic earthquakes occurred there in the past. To him, these are all consistent with active subduction in the Myanmar subduction zone and he suggests that the seismogenic zone extends beneath the Bengal Fan. He concluded that there is probability of giant earthquakes off the coast of Myanmar. Though the threat does not appear to be immediate, but if so happens a large population will be exposed to a significant earthquake and tsunami hazard. Cummins (2007) also suggested that further geodetic measurements and geological studies in the area along the coast of Myanmar (Arakan portion) and Bangladesh are essential to determine whether the ground is really moving in a way consistent with a locked subduction zone which might be building up stress towards a tsunamigenic earthquake.
2 ASPECTS OF TSUNAMI VULNERABILITY ASSESSMENT

Vulnerability of an area to tsunami hazard is assessed based on analysis of the potential of the hazard in the area and wave propagation into the area. Activities involved in a tsunami vulnerability assessment are:

2.1 Analysis of Tsunami Potential

Analysis of tsunami potential involves determination of tsunamigenic faults in the region and determination of the potential of tsunamigenic earthquakes in those faults. *Earthquake of specific magnitude and epicenter depth would be required for the generation of tsunami.*

2.2 Tsunami Propagation

Tsunami wave propagation depends on the topography of the ocean floor, presence and characteristics of continental shelf and slope and topography of the surrounding terrain. Digital Elevation Model of the study area would be required to determine the effect of tsunami in the area.

3 SEISMOTECTONICS OF THE INDIAN OCEAN REGION

According to Gupta (2005), there are three major belts globally which account for almost 95% of earthquake activity. Among them the Alpide-Himalaya seismic belt which starts from southeast Asia near Java-Sumatra, continues through Andaman Nicobar Islands, India-Myanmar border region, swings through north of India in the foothills of Himalayas and then moves west through Iran into Greece and Italy. This is the second most active belt. Scientists at Columbia University's Lamont-Doherty Earth Observatory (LDEO) report direct evidence that one of the Earth's great crustal plates is cracking into two (ICMAM, 2005). Orman et al. (1995) have confirmed that the Indo-Australian Plate, long identified as a single plate on which both India and Australia lie, appears to have broken apart just south of the equator beneath the Indian Ocean. The break has been underway for the past several million years, and now the two continents are moving independently of one another in slightly different directions. According to USGS, the Indian tectonic plate has been drifting and moving in a north/northeast direction (Fig. 1) for some 50 million years, colliding with Eurasian tectonic plate and forcefully raising the Tibetan Plateau and the Himalayan Mountains. As a result of such migration and collision with both the Australian and the Eurasian tectonic plates and sub-plates, the Indian plate's eastern boundary is a diffuse zone of seismicity and deformation, characterized by extensive faulting and earthquakes that can generate moderate to destructive tsunamis (ICMAM, 2005).

To the east, of Indian Ocean, subduction of the Indo-Australian Plates beneath the Burma and Sunda Plates has formed the extensive Sunda Trench - a very active seismic region where large earthquakes are frequent. The volcanoes of Krakatau, Tambora and Toba, well known for their violent eruptions, are byproducts of such tectonic interactions. A divergent boundary separates the Burma plate from the Sunda plate in the north. The Burma plate encompasses the northwest portion of the island of Sumatra as well as the Andaman and the Nicobar Islands, which separate the Andaman Sea from the Indian Ocean. Destructive tsunamis can originate from earthquakes that occur along these principal tectonic sources. The major tectonic feature in the region is the subduction zone Sunda Arc or the Sunda Trench that extends approximately 5,600 km (ICMAM, 2005) between the Andaman Islands in the northwest and the Banda Arc in the east. The Australian Plate subducts beneath the Sunda Plate (which forms part of the larger Eurasian Plate in the Pacific). The Sunda Arc consists of three primary segments; the Sumatra segment, the Sunda Strait Segment and the Java Segment. These locations represent the area of greatest seismic exposure, with earthquake magnitudes of 8 or even more on the Richter scale - as the 26 December 2004 proved. Active tectonic interaction of this great arc has produced destructive earthquakes and tsunamis in the distant past and as recently as 1977, 1992 and 1994 (ICMAM, 2005).
Tsunamis are rarer in the Indian Ocean as the seismic activity is much less than in the Pacific. However, there have been 7 records of Tsunamis set off by Earthquakes near Indonesia, Pakistan and one at Bay of Bengal. **Fig. 2** shows few catastrophic tsunamis and their locations in the Indian Ocean (Satake, 2004). Eighty percent of the tsunamis in the Indian Ocean are from Sunda arc region where on an average tsunamis are generated once in three years (Rastogi et. al., 2006). In rest of the Indian Ocean tsunamis can be generated once in ten years or so.

![Fig. 2 Locations of Catastrophic Tsunamis in the Indian Ocean](image)

**4 HISTORICAL TSUNAMIS IN THE BAY OF BENGAL**

Though the Indian subcontinent is in a seismically active region, tsunamis along the coastline of India and Bangladesh have been rare, but not unprecedented. In earliest known and well documented tsunami in the Bay of Bengal (Mathur, 1998) occurred on 02 April 1762, caused by an earthquake on Myanmar’s, Arakan Coast. The epicenter is believed to be 40 km south-east of Chittagong, or 61 km north of Cox's Bazar, or 257 km south-east of Dhaka, Bangladesh. The earthquake triggered on April 2, 1762 was felt all over Bengal and more severely in the northern part of the east coast of the Bay of Bengal. This earthquake had thrown volumes of water and mud from the fissures. At a place called Bakrchanak near the coast, a tract of land sank, and 200 people with all their cattle, were lost. In the northwest coast of Chedua Island, about 22 ft above sea level, there said to have caused a permanent submergence of 60 square miles near Chittagong (Khan, 2007). The Arakan coast was elevated for more than 160 km. The water in the Hoogly River in Kolkata rose by two meters. The rise in the water level at Dhaka was so sudden that hundreds of boats capsized and many people were drowned. This is the earliest well-documented tsunami in the Bay of Bengal.

An earthquake on 11th November 1842 near the northern end of Bay of Bengal (Rastogi et. al., 2006) caused a tsunami by which water levels of the distributaries of the Ganges Delta were agitated. Boats were tossed about as if by waves in a squall of wind. The December 1881 tsunami in the Bay of Bengal has been studied in detail by Roger Bilham of the United States and Modesto Ortiz of Mexico (Berninghausen, 1966). The earthquake of magnitude Mw 7.9 occurred at Car Nicobar Island on 31 Dec. 1881. A tsunami was generated by this earthquake in the Bay of Bengal. Though the run-ups and wave heights were not large, its effects were observed in the Andaman & Nicobar Islands and were recorded on the east coast of India (Rastogi et. al., 2006). Waves attributed to this tsunami were also observed at Batticaloa and Trincomalee on the east coast of Sri Lanka (Berninghausen, 1966). No tsunami was reported from tidal gauges in Myanmar (Ortiz and Bilham, 2003). Analysing the data from eight tide gauges surrounding the Bay of Bengal at that time, they concluded that the tsunami generated had a maximum wave height of 0.8 m ~ 1.0 m. These analyses of the amplitude and waveform of the tsunami indicates that the 7.9 magnitude quake was due to a 2.7m slip of a 150 km long rupture in the subduction front on the Indian/Andaman plate boundary off Car Nicobar, which resulted in a 10 ~ 60 cm uplift of the island. The results of their simulation appears to match fairly well with the original tide gauge data of the wave heights at various points, which they have been able to retrieve from archival sources. The analysis shows that wave heights reached were of the order of 0.5 m and the tsunami waves arrived about 4 hours after the event. The source of the waves was about 2,440 km from the Indian coast. Unofficial accounts have placed the wave height at Chennai to be about 1.5 m.

A tsunami was noticed at Dublet (mouth of Hoogly River) near Kolkata (Rastogi et. al., 2006) due to earthquake in the western part of the Bay of Bengal in 1884 (Murty et al. 1999) that reached up to Port Blair. The next major earthquake that resulted in a tsunami in the Bay of Bengal was of magnitude 8.1 earthquake in the Andaman Sea (12.9°N, 92.5°E) in June 1941 (Rastogi et. al., 2006) and the tsunami did hit the east coast of India, damaging masonry structures and property in places like Chennai. It had a magnitude of 7.7 (Mw). It was centred in the Bay of Bengal, roughly, 20.5 kilometres west of Flat Island, India. The quake ruptured the region near the Andaman Island. Murty et. al. (1999) suggest that the height...
of the tsunami wave was of the order of 0.75-1.25 m. Tremors from the earthquake were felt in cities along the Coromandel (eastern) coast of India and even in Colombo, Sri Lanka. Tremors were also experienced at Calcutta (now Kolkata), Chandernagor, Cuttack and also at Sylhet, Bangladesh.

The impact of Sumatra-Andaman earthquake and consequent tsunami of December 2004 was also felt all over Bangladesh. It was reported that all the water bodies of the country including the Bay of Bengal were agitated for about 2 hours and riverbeds were found to be elevated at few places by few meters. Some buildings in Chittagong got cracked and two deaths were caused in the coast.

5 EVALUATION OF TSUNAMI POTENTIAL IN BANGLADESH

Infrequent occurrence of tsunamis in the Bay of Bengal region kept the geoscientists of this region almost unconcerned about the potentiality of tsunami hazard. According to the Geological Survey of Bangladesh, there are some evidences of Paleos-Tsunamis and low height tsunamis, but evidences of devastating tsunamis are not available. From the historical records it has been found that Bangladesh has experienced few major tsunamigenic earthquakes of magnitude between 7 and 8. But, from the aeismotectonic point of view, Bangladesh is located in a quite vulnerable zone. However, the above records do not justify strongly whether the coastal belt of Bangladesh is tsunamigenic or not. Considering the orography of the continental shelf, water depth, and tectonic framework of the Bay of Bengal, tsunami vulnerability status needs to be recast.

5.1 Risks from Indian Ocean

Eighty percent of the tsunamis of the Indian Ocean originate in Sunda Arc covering Java and Sumatra (Rastogi et. al., 2006). The Sunda belt extends northward to Andaman-Nicobar Islands where some well-documented tsunamis. Along the Sunda arc, great earthquakes of magnitude 8.5 or greater can repeat every two centuries at a site but smaller tsunamigenic earthquakes can repeat every few decades. Along the Andaman–Sumatra trench the convergence rate is 15–20 mm/yr, giving return periods of 400 yr for M 8.5 earthquakes, with a slip of around 8 m (Caltech, 2004). However, some great earthquakes have occurred more frequently: M 8.5 earthquakes of 2005 occurred at the rupture zone of M 8.7 earthquake of 1861, and rupture zone of the 1833 M 8.7 earthquakes encompassed the 1797 M 8.2 earthquake rupture zone. Though smaller tsunamigenic earthquakes of magnitude 7.5 to 8.0 have occurred more frequently, but at intervals of over a few decades, like 1907 and 1935, major earthquakes occurred near the 1861 source zone. From these considerations the probability of a severe tsunami hitting through Bay of Bengal and the regions in vicinity, within a couple of decades, from Andaman–northern Sumatra region appears to be low, which has already produced 2004 and 2005 great earthquakes. Moreover, though the fault mechanism solutions of number of earthquakes along Andaman-Nicobar Island south of Port Blair show dominancy in thrust fault rupture but that of the North of Port Blair is considered to be mostly strike-slip. It indicates that North of Port Blair zone is less potential of creating any tsunami. The southern Sumatra segment is rather a potential zone for a great earthquake.

The plate tectonics theory predicts that great earthquakes recur at the plate boundaries more or less regularly. So, the probability of a 2004-sized tsunami on the Indian coast may continue to be negligible. But the current mega disaster has thrown new light on threat perceptions in the region from distant tsunamis in the Indian Ocean since tsunami run-up from 2004 earthquake also affected the distant shorelines of eight nations: Thailand, Sri Lanka, Myanmar, Malaysia, Bangladesh, the Maldives, Kenya, and Somalia.

5.2 Factors Affecting Tsunami Potential in Bangladesh

(i) Geodynamics and Tectonics of Bangladesh

Geologically, the Bengal basin is the result of convergence of three lithospheric plates namely Indian Plate, Eurasian Plate and Burmese Plate (Hasan et. al., 2007). Bangladesh is located within the Indian Plate which, at the eastern end, runs southward along a large dextral strike slip fault and continues through Burma to connect with the subduction of the Indian Plate under the Indonesian Plate. The different rates and direction of convergence of these plates as well as the rotational nature of Indian Plate greatly influenced the Bengal Basin in its geodynamic sense. The pull-apart segments of lithospheric plate beneath the Andaman-Nicobar and Arakan-Yoma tectono-stratigraphic province exhibit the oblique (both strike-slip and thrust) motion during the convergence. The fault plane solution of the earthquake events located in the eastern region of Bangladesh demonstrates dominantly strike-slip fault mechanism. The strike-slip fault solution for most of the earthquake events in the eastern region of Bangladesh is indicative of a changing pattern from convergence and subduction to strike-slip displacement in the Bengal basin. Again the earthquakes located in the Western Coast of Bay of Bengal (Table 1, after Hasan et. al., 2007) also show the strike-slip fault dominancy. Hence, characteristically the most Bay of Bengal region does not fulfill the major criteria for the generation of any potential tsunami.

<table>
<thead>
<tr>
<th>Event No.</th>
<th>Date</th>
<th>Location</th>
<th>Focal Depth</th>
<th>Nature of Faulting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24 Nov 1972</td>
<td>11.7N 85.4E</td>
<td>50</td>
<td>Strike-slip</td>
</tr>
<tr>
<td>2</td>
<td>30 Aug 1973</td>
<td>15N 84.3E</td>
<td>43</td>
<td>Strike-slip</td>
</tr>
<tr>
<td>3</td>
<td>23 June 1976</td>
<td>21.5N 88.7E</td>
<td>50</td>
<td>Strike-slip</td>
</tr>
<tr>
<td>4</td>
<td>01 July 1985</td>
<td>18.4N 87.2E</td>
<td>10</td>
<td>Strike-slip</td>
</tr>
</tbody>
</table>
Besides this, Hasan et. al. (2007) have identified that some favorable geological conditions such as thick sedimentation in the Bay of Bengal and in Bengal fan, high density of seawater around along the coast (suspended load) and anticlockwise oceanic current at Bay of Bengal (winter time) reduced the effect of Sumatra 2004 tsunami and will provide protection against future tsunamis. In addition, once the large amount of pent-up energy in the compression zones of the plate boundaries have been released, it takes another buildup of energy for another event of similar magnitude. This is unlikely in the short-term. Since a large amount of pent-up energy in the compression zones along the plate boundaries has been released in the recent earthquake of 26th December 2004, it will take years for another incident of the same magnitude to recur.

(ii) Distance from Epicenter and Tsunami Energy Dissipation

It is presumed that if any tsunamigenic earthquake occurs in the Sunda Arc, the most seismically active zone near the Indian Ocean, it would have very less probability of affecting Bangladesh. Because of being at a long distance from the epicenter, the coastal area of Bangladesh will be hit by greatly reduced energy of the tsunami wave. On the other hand, the plate boundary near Bangladesh, the principal source of tsunamigenic fault is north-south oriented along the direction of rupture zone. Since tsunami amplitudes are largest perpendicular to the fault, tsunami may not be substantial in Bangladesh coast from this fault zone.

(iii) Influence of Location and Topography

The impact of Tsunami is influenced by the arrival time of the Tsunami waves from generation point and difference in the tidal heights of waves generated at the coastal sites. From the observation made by six tidal gauges established along the east coast of India by Survey of India (SOI observations), it was found that the extent of damages occurred at different ports from Sumatra Earthquake, have been clearly determined by unobstructed straight line location of the site from the epicenter of the earthquake and the continental slopes at the tide gauge sites. It was also found that the locations, in spite of being in the direct line from epicenter, where the underwater topography was gentle rather than being abrupt, there the tidal waves raised less. This finding leads to the assumption that the tsunamigenic earthquakes generated at the south-eastern Indian Ocean will be obstructed before hitting the Bangladesh coast which lies at the northern end of Bay of Bengal and the steep continental slope (average width 17 km) will reduce the propagating tsunami wave to the coast.

(iv) Influence of Continental Shelf in Bangladesh

Continental shelves are regarded as portions of continental masses which are locally submerged. They are very flat, with gradient less than 1:500. The width of the continental shelf off the coast of Bangladesh varies considerably. It is less than 100 km off the south coast of Bangladesh, between Hiron Point and the Swatch of No Ground and more than 250 km off the coast of Cox’s Bazar. Seabed evidence suggests that the dominant transport of fine-grained sediment on the continental shelf of Bangladesh is from south and west. Sediments are fine seaward and westward with the thickest accumulation of mud near the submarine canyon, Swatch of No Ground. Most of the continental shelf of Bangladesh is covered by silt and clay. The shallow part (less than 20m) of the continental shelf off the coast of Chittagong and Teknaf is covered by sand and the intertidal areas show well-developed sandy beaches. Sand waves observed on the continental shelf in this area have considerable relief (3-5m), implying a high-energy environment. Even the shallower part of the southern continental shelf off the coast of the Sundarbans, Patuakhali, and Noakhali is covered by silt and clay; and extensive muddy tidal flats are developed along the shoreline. Some of the shoals and sand ridges present on this part of the continental shelf show an elongation pattern pointed towards the Swatch of No Ground. This indicates that even under present oceanographic conditions, sediments are being tunneled to the deeper part of the Bay of Bengal through the Swatch of No Ground.

It can be considered that the 200 km long continental shelf with a gradient 0.5 m/km in the upper 100 km zone and a gradient 2 m/km in the lower 100 km zone and then an abrupt shelf break with a gradient about 20 m/km acts as a potential barrier to the motion of the stressed water column.

(v) Influence of other Tsunami Generating Sources

Swatch of No Ground and eastern canyon shoulder of Bengal Basin show layers of sediments with intercalated slump deposits and also growth faults. The growth faults indicate the instability of the canyon wall. Although there is no record of tsunami that originated from Swatch of no ground, there are records of slumps and growth faulting (Hasan et. al., 2007). Thus detail investigation and study are needed to determine its potential for tsunami generation. The east side of Maheshkhali Island has a very narrow coastal area on the bank of the Maheshkhali Channel and fringed by the hill range. In Maheshkhali, in very recent years, two earthquakes of magnitude 5.2 and 4.3 occurred (Hasan et. al., 2007). The eastern flank of Maheshkhali Anticline is faulted. There is a probability of earthquake triggered landslide in the eastern side of this island, which may create local tsunami in the closed Maheshkhali Channel with some devastating effect on the Cox’s Bazar coastal area. However, at present the depth of the channel is shallow in relation to generating devastating tsunami.

5.3 Tsunami Hazard Assessment by ICZMP

Considering the state of tsunami vulnerability and potential seismic sources, the coastal belt of Bangladesh is classified into three tsunamigenic zones by Integrated Costal Zone Management Plan (Uddin, 2005) as shown in Fig. 3. The zones are:

(i) Tsunami Vulnerability Zone - I: Chittagong-Teknaf coastline-Most vulnerable. The intradeltic coastline is very close to the tectonic interface of Indian and Burmese plates. The active Andaman-Nicobar fault system is often capable of generating tsunami waves.
Fig. 3 Tsunami Vulnerability Map of Bangladesh (Uddin, 2005)

(ii) Tsunami Vulnerability Zone – II: Sundarban-Barisal coastline–Moderately vulnerable. This old deltaic belt is vulnerable to local tsunamis due to the presence of Swatch of No Ground.

(iii) Tsunami Vulnerability Zone – III: Barisal-Sandwip estuarine coastline – Low vulnerability. The estuarine coastal belt is considered to be less vulnerable due to the presence of numerous islets and shoals in the upper regime of the continental shelf.

The classification reveals that Bangladesh coast has been identified as low to high vulnerable to tsunami hazards. The Cox’s Bazar coast falls within Zone-I, which is reportedly most vulnerable. However, evaluation of the potential tsunami hazard requires analysis of tsunami wave propagation from the potential tsunami sources. Analyses performed for tsunami propagation during this study is discussed in the following sections.

6 ANALYSIS OF TSUNAMI PROPAGATION

In the present study, assessment of tsunami hazard at the Cox’s Bazar coast has been performed through numerical simulations. The entire calculation was performed by a two step approach. The first step was to calculate the wave propagation from different potential sources of tsunami in the Indian Ocean, in order to obtain the wave height distribution along the Bangladesh coast. A computation domain consisting of courser grid was used for this purpose. The second step was to calculate tsunami run-up considering the local topographical features to determine the inundation map. For the first part of the computation a 2D numerical model based on Boussinesq wave model was used. The bathymetry, covering from 70°E to 84°E and 20°N to 120°N extracted from ETOP02 dataset with a resolution of 2 minute was used. This would include the December 26, 2004 Sumatra tsunami source in the south and entire Bangladesh coast in the north. The breaking and run-up of tsunami was not considered at this stage. To exclude the possible effects of reflection from the southern boundary calculation was stopped before it affected the results. From this computation, tsunami arrival time as well as wave height distribution along the coastline at the Cox’s Bazar coast of Bangladesh was determined. Also, the approach velocity of tsunami propagation was obtained at this stage.

The first part of the calculation was performed for several potential sources of tsunami which was determined from historic evidences. For those cases where the wave height distribution was significant near the coast the second stage of the calculation was performed. Then tsunami run-up was calculated using a 3D model where the wave height distribution and tsunami approach velocity, obtained from the first stage of calculation, was utilized as the input flux at the open boundary. This computation was performed using finer grids and included the effects of local topographic features.

6.1 Modeling Tsunami Propagation

In this section some aspects of the numerical model for tsunami propagation will be discussed. Compared to the wave length and the wave height, tsunami can be considered as a long wave in the deep ocean since it has a wave length of several hundreds of kilometers, the depth to length ratio is in the order of $10^{-2}$ and the wave steepness is in the order of $10^{-3}$.

According to Kajiura (1963), Aida (1978) and Imamura (1995) in the theory of long waves, the vertical acceleration of the water particles are negligible compared to the gravitational acceleration except for propagation over a continental shelf or propagation in a river. Consequently the vertical movement of water particles has no effect on the pressure distribution. Hence depth integrated equations are widely used as governing equations for tsunami propagation simulations. The following shallow water wave equation by Imamura (1995) was introduced for tsunami propagation calculations;

$$\frac{\partial \eta}{\partial t} + \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} = 0 \quad (1)$$

$$\frac{\partial P}{\partial t} + \frac{\partial}{\partial x} \left( \frac{P \eta^2}{d} \right) + \frac{\partial}{\partial y} \left( \frac{P \eta Q}{d} \right) + g d \frac{\partial \eta}{\partial x} \frac{\tau_x}{\rho} = A \left( \frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} \right) \quad (2)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{Q \eta^2}{d} \right) + \frac{\partial}{\partial y} \left( \frac{Q \eta P}{d} \right) + g d \frac{\partial \eta}{\partial y} \frac{\tau_y}{\rho} = A \left( \frac{\partial^2 Q}{\partial x^2} + \frac{\partial^2 Q}{\partial y^2} \right) \quad (3)$$

Where $x$ and $y$ are horizontal coordinates and $z$ is the...
vertical coordinate. $\eta$ is vertical displacement of water surface above the still water level, $g$ is the acceleration of gravity, $d$ is the total water depth given by $d = h + \eta$, where $h$ is the water depth. Where $\tau_x$ and $\tau_y$ are bottom frictions in the $x$ and $y$ directions. $\Omega$ is the horizontal eddy viscosity which is assumed to be constant in space and time.

$M$ and $N$ are considered as depth averaged water discharge across the unit with of model domain given as:

$$M = \int_{-h}^{0} u d\bar{z} = \bar{u}d$$

$$N = \int_{-h}^{0} v d\bar{z} = \bar{v}d$$

Where $\bar{u}$ and $\bar{v}$ are depth average water velocities in $x$ and $y$ directions respectively. However based on very small wave height to length ratio and wave steepness, tsunami can be considered as a linear long wave in the deep ocean. Based on the Aida (1978) and Shuto (1991) it is shown that linear long wave theory gives the best representation of the tsunami waves in the deep ocean and even up to a considerable depth in the near shore. Therefore non-linear terms of the above equations (2) and (3) can be dropped in tsunami propagation calculations in Deep Ocean.

As the tsunami approaches shallow water it starts to feel the effect of sea bottom than that of Deep Ocean. Wave steepness becomes high. Hence it starts to deform by disappearing trough and increasing crest. Ultimately the shape of the wave becomes more similar to a solitary wave profile. Such waveforms are generally categorized as N waves. Hence nonlinear effects are important at this stage. According to tsunami wave theory reviewed by Satake and Tanioka (1995), which explains that linearity of waves, are valid even up to 50m depths.

Other specialty is since depth of the oceans can never be greater than 5.0 km the majority of the tsunami is considered as shallow water waves. However, all the individual waves resulting in a tsunami generation do not travel by the same speed. Long period waves over run the short period waves, so that a tsunami wave train after traveling across an ocean tends to reach shore with regular long period waves followed by short period waves. This phenomenon is known as dispersion.

Hence in this research, the main calculations are divided into two parts where the linear long wave equation is considered in deep ocean propagation. Calculations in the shallow water are based on the original equation proposed by Imamura (1995).

**Tsunami Propagation in Deep Ocean**

Following equation has been considered as governing equations in deep ocean propagation

$$\frac{\partial \eta}{\partial t} + \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} = 0$$

**Bottom Friction**

Commonly used bottom friction formula given by Manning is considered, after Imamura (1995);

$$\tau_x = \frac{g n^2}{d^{1/3}} M \sqrt{M^2 + N^2}$$

$$\tau_y = \frac{g n^2}{d^{1/3}} N \sqrt{M^2 + N^2}$$

Where, $n$ is the Manning’s roughness coefficient, which is given by:

$$n = \sqrt{\frac{f D^{1/3}}{2g}}$$

For propagation of tsunami in the deep ocean $n$ can be considered as 0.03. However the effect of bed friction is not much significant in deep ocean propagation.

**Coriolis Force**

Since the consideration domain is of several thousand of kilometers, it is important to consider the effect of the Earth rotation. Coriolis force is given by Maa (1990);

$$f_\omega = 2\Omega \sin(\phi) Q$$

$$f_\phi = 2\Omega \sin(\phi) P$$

Where $\Omega$ and $\phi$ are angular speed of earth rotation and altitude of the location being considered respectively. The effect of the rotation of earth is not so significant for tsunami propagation over a short distance close to the equator.

**Horizontal Eddy Viscosity**

The term $A$ represents the Horizontal Eddy viscosity coefficient. Yan (1987) showed that horizontal eddy viscosity is around $0.001\text{m}^2\text{s}^{-1}$ for simulation of current field. Anyhow use of high eddy viscosity coefficient tends to result in stable calculation but other hand it tries to damp the wave heights unnecessarily.

**Numerical Scheme**

From the early stage of developing the numerical simulation, the finite difference based upon the Taylor expansion series has one of the most fundamental and standard numerical methods. In finite difference approach continuous domain is descriptive so that dependent variables exist only in discrete points. However numerical schemes in marching problems can be divided as explicit and implicit. For explicit scheme only one unknown appears in the difference equation but in implicit scheme there are two or more unknowns appear,
requiring simultaneous solution of several equations involving the unknowns. There are several schemes available for simulation of long waves. Staggered Leapfrog, Crank-Nicholson and two-step Lax-Wendoff. Among them staggered leapfrog is the widely used since it is explicit, stable, efficient and produce enough accuracy in tsunami simulation. Crank-Nicholson is the basic implicit scheme and requires more CPU time compared to leapfrog scheme, Lax-Wendoff method is more popular in modelling shock waves and discontinuous flows, such as tsunami generation due to impact of meteorites.

In this study, staggered leapfrog scheme introduced by Imamura (1995) and Aida (1978) is used in secutirizing the linear long wave equation. Following shows the one dimensional discritisation of the linear long wave equation neglecting friction, Coriolis and eddy viscosity terms, which is given for one dimensional case by;

\[
\frac{\partial \eta}{\partial t} + \frac{\partial P}{\partial x} = 0 \quad (7)
\]

\[
\frac{\partial P}{\partial t} + gd \frac{\partial \eta}{\partial x} = 0 \quad (8)
\]

Discritization of Equation (7) and (8) are given by:

\[
\begin{align*}
\frac{\eta_{j+1/2}^{n+1/2} - \eta_{j-1/2}^{n-1/2}}{dt} + \frac{M_{j+1}^{n+1} - M_{j}^{n}}{dx} + O(dx^2) &= 0 \\
\frac{M_{j+1}^{n+1} - M_{j}^{n}}{dt} + g \left( \frac{d_{j+1/2} + d_{j-1/2}}{2} \right) \left[ \frac{\eta_{j+1/2}^{n+1/2} - \eta_{j-1/2}^{n-1/2}}{dx} \right] + O(dx^2) &= 0
\end{align*}
\]

Where \(dx\) and \(dt\) are the model grid size and simulation time step respectively. Where the \(O(dx^2)\) is the truncation error of the second order approximation, which is in fact the difference between the partial derivative and its finite differential representation.

**Simulation Grid**

Selection of grid type, size and cell size is far most important in finite difference models since there is a high tolerance of results in depends upon the model domain, type of grid and cell size. Most commonly used grid is the rectangular grid. However Tsuji (2005) discussed that influence of the curvature of earth is important if the calculation domain has a length more than 1000 km. In that case he suggests using polar coordinate system to represent the governing equations. Grid size was carefully chosen to make the effects of numerical and physical dispersion equal. Shuto (1991) has suggested that there are at least 20 grid cells to be used in representing one full wave length. Again Shuto (1991) suggest that considering finer mesh and coarser mesh, coarser mesh will give better approximation in representing the linear long wave.

Imamura et al. (1990) showed that the choice of the grid size can be evaluated using the Imamura number, \(I_m\), defined as;

\[
I_m = \frac{dx}{\sqrt{2.g.\eta_{max}}} \left( \frac{c_0 dt}{2.h} \right)
\]

Where, \(c_0 = \sqrt{gh}\)

For simulating the linear long wave equation value of \(I_m\) should be less than 1.

In this simulation a rectangular grid of \((1021 \times 1024)\) has been selected. For deep (depths are greater than 2000m) ocean propagation calculations a cell size of \(dx\) of 2 min (3704 m) is used. Fig. 4 shows the arrangement of model grid used in this study.

On the other hand CFL condition should also be satisfied for stability in the numerical calculations. This is given by:

\[
\frac{dx}{dt} = \sqrt{2.g.h_{max}}
\]

Approaching to the shoreline \(h\) become smaller, hence in order to maintain the stability condition smaller \(dx\) is selected in near shore area keeping the \(dt\) constant. For these calculations, the \(dt\) was selected as 1.0 s, hence, which satisfies the CFL condition for the \(dx\) and \(h\).

**Model Input Data**

For any hydrodynamic modeling input data are very important. In case of tsunami simulation it is essential to have a reasonably accurate bathymetry and also correct tsunami initiation conditions. Accurate bathymetry would give a better result, even though the results of the numerical simulations are not up to the real life figures having appropriate boundary conditions. To initiate the tsunami, subduction of water surface was give as input. For 2004 Sumatra tsunami subduction model developed by Koshimura was used and for other hypothetical cases subduction amplitude and length were assumed. Fig. 5 shows the Koshimura subduction model in a 2D view along a section, where the trough is in the direction of Indian
Ocean or Sri Lanka and the crest is on the Sumatra side.

![Wave height graph](image)

**Fig. 5** Koshimura subduction model (2D view)

**Bathymetry Data**
The widely used ETOPO 2 global data by NOAA are used to generate the model bathymetry.

Numerical Experiments and Results of Tsunami Propagation
To investigate the effects of different locations of tsunami generation, different amplitude and length of tsunami subduction, different orientation of the subduction as well as proximity of the tsunami generation to the coast, several numerical experiments were conducted in this study. Table 2 shows the list of numerical experiments. **Fig. 6** illustrates these cases.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Tsunami source</th>
<th>Amplitude</th>
<th>Orientation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 0</td>
<td>Sumatra coast</td>
<td>6m</td>
<td></td>
<td>Original tsunami: Dec 26, 2004</td>
</tr>
<tr>
<td>Case 1</td>
<td>Myanmar coast</td>
<td>6m</td>
<td>Angular</td>
<td>Shorter length of subduction</td>
</tr>
<tr>
<td>Case 2</td>
<td>Myanmar coast</td>
<td>6m</td>
<td>Angular</td>
<td>Longer length of subduction</td>
</tr>
<tr>
<td>Case 3</td>
<td>Myanmar coast</td>
<td>9m</td>
<td>Angular</td>
<td></td>
</tr>
<tr>
<td>Case 4</td>
<td>Myanmar coast</td>
<td>6m</td>
<td>Straight</td>
<td></td>
</tr>
<tr>
<td>Case 5</td>
<td>Bay of Bengal</td>
<td>6m</td>
<td>Straight</td>
<td>Far from the coastline</td>
</tr>
<tr>
<td>Case 6</td>
<td>Bay of Bengal</td>
<td>6m</td>
<td>Straight</td>
<td>Nearer to the coastline</td>
</tr>
</tbody>
</table>

**Table 2** List of Numerical Experiments

![Image 1](image)

(a) Case 0

![Image 2](image)

(b) Case 1

![Image 3](image)

(c) Cases 2 and 3

**Fig. 6** Cases (0 to 3) of tsunami generated at different sources and with different subduction depths (figure continues to next page)
Effects of the Location of Tsunami Generation

As discussed earlier, location of the source of tsunami might be decisive where it will affect a coast or not. Radial line that can be drawn straight from the tsunami source to the coast can give an idea regarding this. To investigate this issue Case 0 (the Sumatra tsunami of 2004 December) is tested along with Case 2, where the source of tsunami was in the Myanmar coast and from this point straight line can be drawn to the coast of Bangladesh.

**Fig. 7** Comparison of tsunami wave heights of Case 0 and Case 2

Fig. 7 shows the wave height distribution for Cases 0 and 2, when maximum wave height occurred at Cox’s Bazar of Bangladesh. For both the cases maximum wave height do not go above 0.2m at Cox’s Bazar indicating that the wave has already been dissipated when it crossed the continental shelf.

**Fig. 8** Comparison of tsunami arrival times at continental shelf for Case 0 and Case 2

Fig. 8 shows the tsunami wave height and arrival time for Cases 0 and 2 at the edge of continental shelf around 20km offshore from the Cox’s Bazar coast. Even tough both the cases show similar arrival time, the arrival wave height for the Case 2 is much larger compared to Case 0.

Effects of the Subduction Amplitude of Tsunami

It may be rational to think that a tsunami with a larger subduction amplitude occurring at the Myanmar coast might have a greater impact at the coast of Bangladesh. For this reason Case 3 was compared with Case 2, where both the tsunamis have their origin at Myanmar coast but the first one have 6m.

**Fig. 6** Cases (4 to 6) of tsunami generated at different sources and with different subduction depths (figure continued from previous page)
Fig. 9 Comparison of tsunami wave heights of Case 2 and Case 3

Fig. 9 shows the wave height distribution for Cases 2 and 3, which are very similar. Maximum wave height was 0.24m for Case 3 where as it was 0.17m for Case 2, indicating very small threat at Cox’s Bazar coast.

Fig. 10 Comparison of tsunami arrival times at continental shelf for Case 2 and Case 3

Fig. 10 shows the tsunami wave height and arrival time for Cases 2 and 3 at the edge of continental shelf and as expected they show exactly the same arrival time with a slightly larger wave height for Case 3.

Effects of the Subduction Orientation of Tsunami (case 2 and 4)

Other than the subduction amplitude, it is also believed that the direction of the fault line at the earthquake source may control the tsunami propagation. In other words, the orientation of the subduction may affect the tsunami wave height at the coast as the tsunami is assumed to propagate perpendicular to the fault line. To investigate this phenomena, Cases 2 and 4 were compared where both the tsunami sources are located at Myanmar coast but the afore mentioned one is in an angular position with respect to the Bangladesh coast and the later one is perpendicular.

Fig. 11 Comparison of tsunami wave heights of Case 2 and Case 4

Fig. 11 shows the tsunami wave height and arrival time for Cases 2 and 4 at the edge of continental shelf. Case 4 has a smaller wave height at the edge of the shelf and interestingly it also has a longer arrival time in that area which may also be due to the shallow areas of Andaman-Nicobar island of the Bay of Bengal.

Effects of the Proximity of Tsunami Source (case 5 and 6)

Two more cases were tested to investigate the effect of proximity of the tsunami source from the coast line. For both the cases tsunami source were at the Bay of Bengal at two hypothetical locations (as there is no fault line in those areas). For both the cases same amplitude and length of subduction were used, while Case 5 was located further from the coast line compared to Case 6. Wave height distribution did not show any significant difference at the Cox’s Bazar coast. Fig. 13 shows the tsunami wave height and arrival time at the edge of the continental shelf and as Case 6 was nearer to the coast it shows shorter arrival time as well as larger wave height at the vicinity of the continental shelf.
From the discussion of the above four subsections it is clear that the continental slope and the location of continental shelf plays important role in retarding the tsunami propagation to the Bangladesh coast.

**Effects of Continental Shelf**

The effect of continental shelf on tsunami propagation is shown chronologically in Fig. 14. It shows the height of tsunami wave in the ocean at every 30 minutes after the tsunami generation.

From the Fig. 14, it is evident that when the wave hits the edge of the continental shelf initially the wave height is further amplified (100 minute) and later some part of the wave is reflected back to the offshore direction and only a small portion travels towards the coast with a much smaller wave height (110 and 120 minutes). The amplitude is further dropped when it travels over the continental shelf and reaches to very small value when it reaches to the coast.
7 MODELING TSUNAMI INUNDATION

The previous section discussed the modeling of tsunami propagation from potential tsunami source up to the coastal zone using 2D Boussinesq Wave Model. The study provided the tsunami height expected along the Bangladesh Coast. The study has been extended in this section to investigate how the tsunami would inundate the land of Cox’s Bazar district. Digital Elevation Model for the whole district was first developed for the ground surface topography. The propagation of tsunami water over the topography was thus investigated using numerical model based on Navier-Stokes Equations.

7.1 Overview of the 3D Model

The numerical model solves mass conservation and 3D Navier-Stokes equations for the conservation of momentum. It consists of two parts: hydrodynamic sub-model and water quality sub-model. The hydrodynamic sub-model is a f-plane quasi-3D sigma-coordinate baroclinic circulation model including temperature and salinity (Sasaki and Isobe, 1996) and the water quality sub-model incorporates phytoplankton, zooplankton, nutrient cycling processes, detritus and dissolved oxygen (Koibuchi and Isobe, 2001). As part of a recent work by Hussain (2006), turbulence has been treated explicitly and equations for turbulent quantities such as turbulence velocity scale (or equivalently turbulence kinetic energy) and turbulence macroscale are also solved following Mellor-Yamada’s (1982) turbulence closure scheme. For solving the governing equations semi implicit (in vertical direction) finite difference scheme has been used with free surface dynamics. Two of the common approximations: hydrostatic approximation and Boussinesq approximation has been adopted in this model. Upwind scheme has been used for advection. Regular orthogonal Arakawa C grid has been used for horizontal discretization.

7.2 Development of Digital Elevation Model for Cox’s Bazar

Digitizing FINNMAPS: Base maps (also known as FINN Maps) covering the near-shore area of Cox’s Bazar District, were collected from Bangladesh Inland Water Transport Authority (BIWTA). A total of seventy nine FINN Maps were digitized covering the whole of Cox’s Bazar using UTM (WGS84) projection. Spot height data were extracted by onscreen digitizing. These data were further used for preparation of DEM.

DEM Preparation: The study area in Cox’s Bazar is around 2000 square kilometers. The FINN maps were geo-referenced to fit them in the correct spatial position in the world space. Then the points on the maps are digitized along with their attributes. This process was followed repeatedly to cover the study area. Elevation of the individual spots was used to make the Digital Elevation Model. The spot height data were found ready from previously digitized map from paper format which were randomly spread over the study area. The data was then converted to regular grid so that it can be used for numerical simulation which is based on orthogonal grid arrangement.

For running the Tsunami model with an effective accuracy 500 meter grid size was used. For this reason, with the help of GIS application grid lines were inserted with an interval of 500 meters and the circle of 150 m radius was put on the each intersection. The points only inside the circles are taken into consideration. At the end the point which has the closest proximity to the center of the circle was picked up for making the grids in desired intervals.

7.3 Development of Inundation Maps

As the numerical experiments did not show any significant wave heights approaching the Cox’s Bazar coast of Bangladesh, one hypothetical wave with a height of 2m was induced at the southern coast to observe the inundation and wave height in the Cox’s Bazar area. The arrival direction of this wave was straight from the south as shown in Figure 44. On the right panel of Fig. 15 the wave height distribution along the Cox’s Bazar coast is shown. Maximum wave height reached around 1.5m and from the figure it is evident that the wave moves along the coast resembling an edge wave (as seen from the ebb type wave in the blue zone of the waves).

Fig. 15 Tsunami wave to the Cox’s Bazar coast, Bangladesh

Fig. 16 shows the wave height distributions and velocity vectors at three different time intervals after the 2m wave was induced at the southern coast of Bay of Bengal. From the figure it is evident that as the wave travels along the Cox’s Bazar coast it takes the shape of edge wave and when it gets trapped in the northern part maximum wave height is incurred. This is why some of the velocity vectors show south-ward direction in the vicinity of the trapped zone.
8 CONCLUSIONS

Though Bangladesh is situated in a seismically active zone, the fault plane solution of the earthquake events in the region show strike-slip dominancy, which has less potential of generating tsunamigenic earthquake. But if tsunami occurs in The Bay of Bengal or Indian Ocean, then the coastal area of Cox’s Bazar might be in a vulnerable condition. However risk from the most tsunami-generating region near Indian Ocean, Sunda Arc covering Java and Sumatra, is relatively low. According to the plate tectonics theory an earthquake releases the strain that accumulates over centuries. So it is predicted to take very long time before anything like Sumatra 2004 erupts again. Still there are segments to the south and some other areas that are gaining built-up strain. Again, Andaman-Nicobar Islands, situated to the North of Sunda belt, is considered as less seismically active zone which leads to the assumption that probability of a severe tsunami hitting through Bay of Bengal from Andaman–northern Sumatra region to be low. Since sufficient data is not available from the coasts of Andaman Islands, Bangladesh and Myanmar, it is high time for scientists to get together to generate data on stress and strain measurements. The fault near Myanmar had not generated an earthquake for hundreds of years which is an important issue to be considered this regard. Thus, evidence of palaeo-earthquakes and tsunamis along the Myanmar coast, Bangladesh and northern Andaman should be studied seriously.

From the numerical simulation, it has been observed that if a similar tsunami like Sumatra 2004 originates at the Myanmar coast, the maximum wave height does not rise above 0.2m at Cox’s Bazar coast, indicating that the wave has already been dissipated when it crossed the continental shelf. Though arrival time was similar for the cases with tsunami originating at the Sumatra coast and at the Myanmar coast but larger wave height was found in case of tsunami in Myanmar region. When subduction amplitude was increased on the tsunami originating at the Myanmar coast, the maximum wave increased slightly, indicating very small threat at Cox’s Bazar coast. The topography of the ocean floor also appeared to control the tsunami propagation in the Bay of Bengal significantly. The study showed that much of the wave energy has been dissipated in the shallow areas of Andaman-Nicobar islands, and the wave height beyond the shallow zone became much smaller compared to the former one. Smaller wave height was observed at the edge of the shelf and interestingly it also had a longer arrival time in that area which may also be due to the shallow areas of Andaman-Nicobar Island of the Bay of Bengal. Also, it was found that tsunami generated nearer to the coast have shorter arrival time as well as larger wave height at the vicinity of the continental shelf compared to the one generated further from the coast. Through the Tsunami Model it was revealed that the continental slope and the location of continental shelf play important roles in retarding the tsunami propagation to the Bangladesh coast. The phenomenon can be described like that when the wave will hit the edge of the continental shelf initially the wave height will be amplified, then some part will be reflected back to the offshore direction and finally a small portion will travel towards the coast with a much smaller wave height. The amplitude will further drop when the wave travels over the continental shelf and finally the wave reaches the coast with a very small amplitude.
ACKNOWLEDGEMENT

The study was conducted as part of a research project funded by United Nation Office for Project Service (UNOPS) through Comprehensive Disaster Management Program (CDMP) of the Ministry of Disaster Relief and Rehabilitation of Bangladesh Government. The authors would like to acknowledge the contributions of research assistants: A. B. Afifa Imtiaz, Md. Zahid Hasan Siddiquee and Mahfuza Shamim.

REFERENCES


INTRODUCTION

Urbanization generally boosts expansion of urban areas, improvement of lifestyles, high population density and high grade of land utilization. Those urbanization processes have resulted in an expansion of impermeable areas such as roofs and pavements, and a reduction of water surface areas and green lands. These land use changes bring about surface runoff increase that rises flood risk and subsurface runoff reduction that lowers normal flow of rivers and springs in relevant basin (Fig.1 and Photo 1). Urbanization also makes land price higher and more difficult to obtain land space to construct flood control infrastructures. Therefore, comprehensive flood mitigation measures and preservation of well-balanced hydrological system in basin are very important for urban rivers.

This paper is composed of five main parts. In the first part, a brief of the typical basic concept of rainwater treatment allotments in comprehensive flood control planning for an urban river basin in Japan is introduced. In the second part, the history of Japanese governmental policies using stormwater storage and infiltration, including those to involve private sector, and how to practically implement them is described. In the third part, besides normal stormwater reserve in flood control reservoirs, special efforts and how to store it in school grounds, parking lots etc. are also introduced. The multipurpose uses of stormwater reservoirs as communication places of region (community ponds) or biotopes of ecological networks in a river basin (ecological ponds) are detailed with successful actual examples. In the fourth part, the basic technical investigations and the methods necessary to implement stormwater infiltration and useful practical experiences are described. How to diffuse extensively stormwater infiltration facilities and their maintenance in private sector including grant policies are detailed. In the fifth part, as conclusions, some successful points from the writers’ view are described.
infiltration facilities are classified broadly into either on-site facility or off-site facilities.

![Classification of storage facilities by river administration](image)

Fig.2 Classification of storage facilities by river administration

The typical basic concept of rainwater treatment allotments in comprehensive flood control planning for an urban river basin in Japan is shown in Fig.3. Total rainfall as an external force against a river basin is treated into the five kinds of places or facilities which are natural lands (allotment ①), rainwater storage and infiltration facilities for basin-wide measures which restrict the movement of rainwater and store water at the site (on-site) of rainfall to control runoff (allotment ②), off-site storage facilities in sewer system such as retarding pond (allotment ③), off-site storage facilities along rivers such as anti-disaster reservoirs or regulating reservoir in large-scale housing development area (allotment ④) and river channel and sewer system (allotment ⑤).

In the conventional planning, the allotment ④ & ⑤ is counted as a basic design flood discharge. Since the river channel improvement is already limited in the very crowded city area, the allotment ① & ② have become very important to be counted for flood control. Therefore, it becomes necessary to reinforce the artificial water retention and retarding facilities of the allotment ②. Rainwater storage and infiltration facilities play a crucial role in this allotment ②.

![Structural description of rainwater treatment allotments in comprehensive flood control for urban river basins](image)

Fig.3 Structural description of rainwater treatment allotments in comprehensive flood control for urban river basins

The structure of typical comprehensive mitigation measures for urban rivers having been implemented in Japan is shown in Fig.4. Not shown in this figure, the regulations for storm drainage pumping in the low land zone have also been planned to avoid inundation due to dyke breach. In Japan urban zones have usually developed in low land zones of river downstream. The inundation due to the breach will be more immense than those by inner flooding. Rainwater storage and infiltration facilities belong to the basin-wide measures displayed by the Italic letters in the ellipse.

![Structure of comprehensive flood mitigation measures for urban river basins](image)

Fig.4 Structure of comprehensive flood mitigation measures for urban river basins

3 BRIEF HISTORY OF POLICIES AND PRACTICES OF STORMWATER STORAGE AND INFILTRATION IN JAPAN

3.1 Central governmental administration

A brief history 2) of main policies and actions relevant to
application of rainwater storage and infiltration in Japan is shown in Table 1. However following explanations should be added to the table:

- Regulating reservoir herein means a rainwater storage facility that was treated as temporary structure to treat runoff increase due to area development because its downstream river’s discharge capacity is insufficient. When the river capacity becomes enough the reservoir may be removed. The scale of design rainfall is 1/30. Anti-disaster reservoir is planned a permanent structure, its design rainfall scale is 1/50.
- Due to urbanization, some irrigation ponds become unnecessary or storage for original need decreased, they are rehabilitated to regulate flooding.
- Under the implementation of Comprehensive Flood Mitigation Projects, main principles of housing development of cities or municipalities have requested housing developers to implement rainwater storage and/or infiltration facilities to obtain the approval for development. The criterion of development area for the request is above 500m² or 1000m².

<table>
<thead>
<tr>
<th>Year</th>
<th>Main actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>Technical standard for regulating reservoir in large-scale housing development area</td>
</tr>
<tr>
<td>1973</td>
<td>Grant for anti-disaster reservoirs</td>
</tr>
<tr>
<td>1975</td>
<td>Technical standard for anti-disaster reservoirs</td>
</tr>
<tr>
<td>1977</td>
<td>Implementation of Comprehensive Mitigation Measures against Flood Damage proposed in its Interim Findings by River Council</td>
</tr>
<tr>
<td>1978</td>
<td>Grant for on-site stormwater storage works</td>
</tr>
<tr>
<td>1979</td>
<td>Seventeen rivers designed for Comprehensive Flood Mitigation Project</td>
</tr>
<tr>
<td>1983</td>
<td>Grant for on-site storage works and infiltration facilities of stormwater</td>
</tr>
<tr>
<td>1984</td>
<td>Grant for rehabilitating irrigation ponds for flood regulation</td>
</tr>
<tr>
<td>1986</td>
<td>Technical Guidelines for Basin-wide Storage and Infiltration Facilities</td>
</tr>
<tr>
<td>1987</td>
<td>Guidelines for multipurpose utilization of anti-disaster reservoirs</td>
</tr>
<tr>
<td>1991</td>
<td>Establishment of Association for Rainwater Storage and Infiltration Technology (ARSIT)</td>
</tr>
<tr>
<td>1994</td>
<td>Grant for storage works and infiltration facilities of stormwater in sewerage work</td>
</tr>
<tr>
<td>1996</td>
<td>Preservation of Well-Balanced Water Cycle proposed by River Council</td>
</tr>
<tr>
<td>1997</td>
<td>Revision of River Law. Environmental view point is added to flood control and water use. River improvement master plan should be reflected with the opinion of inhabitants.</td>
</tr>
</tbody>
</table>

These facilities (regulating reservoirs) were treated as temporary ones until the time when their downstream rivers reach the specified sufficient discharge capacities by rever improvement. There was a trend for 20 years from 1980 to 2000 that the (temporary) regulating reservoirs were filled up for other uses, although the river improvements in the downstream had not been completed in most of the rivers specified for Comprehensive Flood Mitigation Project. In 2003 the new Act for Urban Inundation Prevention for Specified Urban River Basins was established for the following main purposes:

(i) To eternize the existed regulating reservoir for the basin-wide allotment,
(ii) To impose construction of rainwater storage and infiltration facilities as legal obligation for actions to increase rainfall runoff,
(iii) To introduce a new system that a municipality may ask other ones’ share cost of rainwater storage and infiltration facilities by negotiation and agreement when they also receive the benefit from the flood regulation effect of the facilities,
(iv) To enable sewerage administration to ask inhabitants introduce storage and infiltration before discharging rainwater to public sewer system by municipal regulations,
(v) To reinforce the coordination between river flood management and sewerage storm drainage etc.

From Table 1 we can see the following features of process implementing rainfall storage and infiltration in Japan:
- On-site stormwater storage was introduced earlier than infiltration. The grant for infiltration facilities was 5 years after that for storage. The infiltration grant was almost applied for the facilities in public schools and organizations.
- The grant for storage works and infiltration facilities of stormwater in sewerage work was established 10 years later than that in river administration.
- Until 1991 the function of infiltration was still not counted for flood management plan in some rivers.
- The guidelines for multipurpose utilization of anti-disaster reservoirs that are also applied to other kind of storage facilities were created 12 years after the technical structure standards. This lateness is probably due to the low interests to the amenity and value added of flood management structures, in particular for small-scale ones at that moment.

3.2 Local governmental administration
Many municipalities also have been established the grant for their inhabitants’ infiltration facilities since 1984. Recently the number of municipality having the grant for infiltration facilities with purpose of restoring natural springs has increased.

3.3 ARSIT’s main technical standards and guidelines
The main technical standards and guidelines that the Association for Rainwater Storage and Infiltration Technology (ARSIT) published are shown in Table 2. However, at the present only one of them is translated into English.
## Table 2  Main technical standards and guidelines published by ARSIT

<table>
<thead>
<tr>
<th>Year</th>
<th>Technical Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>Technical Standard for Infiltration Facilities-Survey and Planning (translated into English)</td>
</tr>
<tr>
<td>1997</td>
<td>Technical Standard for Infiltration Facilities-Structure, Construction and Maintenance</td>
</tr>
<tr>
<td>1997</td>
<td>Data Book of Rainwater Storage and Infiltration Facilities</td>
</tr>
<tr>
<td>1997</td>
<td>Guidelines for Planning and Designing Ecological Ponds</td>
</tr>
<tr>
<td>1997</td>
<td>Guidelines for Planning and Designing Community Ponds</td>
</tr>
<tr>
<td>1998</td>
<td>Examples of Community Ponds</td>
</tr>
<tr>
<td>1998</td>
<td>Handbook for Rainwater Utilization</td>
</tr>
<tr>
<td>1998</td>
<td>Toward Restoring Water Cycle in Urban</td>
</tr>
<tr>
<td>2005</td>
<td>Rainwater Storage and Infiltration Facilities-Products Catalogue</td>
</tr>
<tr>
<td>2006</td>
<td>Manual for Installing Rainwater Storage and Infiltration Facilities of Individual Houses</td>
</tr>
</tbody>
</table>

### 4 STORMWATER STORAGE

#### 4.1 Off-site and on-site facilities

Stormwater facilities are classified to two main types of off-site and on-site as shown in Fig.2. For off-site type, the inflow from river to reservoir is conducted through a lateral weir. Photo 2 is a typical example of this type. As the design flow hydrograph is generally sharp, the treatment by this storage type has usually more economic benefit than that by flow. This type is used for the allotment ④.

![Photo 2](image)

*Photo 2 An example of off-site reservoir (Myoshoji, Tokyo)*

For on-site type that is used for the allotment ②, the inflow is surface runoff of reservoir catchment that flows directly to or through a sewer system. Those small-scale facilities are ones installed at parks, school grounds and parking lots, which may be in open form or under ground, and vacant lots between buildings or on flat roofs of them (Fig.5).

#### 4.2 Scale of storage volume

The volume scale of storage facilities for the allotment ② is determined by necessary volume or allowable discharge for unit development area that vary with flow capacity of main downstream river. These values are specified by river administration and are usually 300-1,300 m³/ha or 0.01-0.05 m³/s/ha.

![Photo 3](image)

*Photo 3 An example of stormwater regulation in school ground*
4.3 Multipurpose uses
Before 1980 the amenity of on-site stormwater storage facilities was not interested so much many ones were fenced to prevent the public’s entry for safety (Photo 4).

Photo 4 An example of a reservoir fenced off

After that the higher land price provoking higher land use along with the public’s amenity interest have promoted the multipurpose utilization of these facilities though they were being treated as temporary ones. From the 1990s’beginning the importance of river ecosystem has more focused in Japan, in 1995 Nguyen, the first of writers of this paper suggested ARSIT investigate and study how to create the ecological functions for regulating reservoirs and anti-disaster reservoirs and named this kind of reservoir as “ecological pond” and ARSIT published the technical guidelines for planning and designing ecological ponds in 1997. (The term “pond” was used as it is short and can be distinguished from “reservoir of dam” which scale is larger.) Reservoirs with other multipurpose, mainly recreation and sports, were named as “community pond”.

For the community ponds, the smaller flooding frequency the better to use them. To reduce it the two types shown in Fig.6 may be applied.

Photo 2 is an example of multi-basin type. The multipurpose part is being used as a space for an elevated apartment building and its park and tennis courts.

Photo 5(1) is an example of multi-step type. The multipurpose part is being used for tennis courts. For the strong storms its flooding situation is shown in Photo 5 (2).

Photo 5(1) An example of multipurpose utilization as tennis courts (Kirigaoka, Yokohama City)

Photo 5(2) A flooding situation of the above reservoir

Photo 6 shows a beautiful design of rainfall storage facilities in Yokohama city. It is being a place of recreation and relaxation in urban. As special events, sometimes music concerts and exhibitions of arts etc. are held.

Fig. 6 Methods to reduce flooding frequency of a part of reservoir for multipurpose
**Photo 6** A beautiful design of stormwater storage facility (Yokohama Business Park, Yokohama City)

Photo 7 shows an example of ecological ponds. Photo 8 is another that has a normal water surface as it is located at the uppermost upstream of a river and supplied by ground water and spring water though the ecological level of around land is not so high. Many wild birds at all days of year, in particular, swans in every winter from 1994 come and heighten the nearby inhabitants’ interest to the natural environment. A volunteer club was established to help pond maintenance after the swans’ coming. The fee to use multipurpose facility (e.g., tennis court) is free or low. The revenue is used to operate and maintain facility. In the case of free fee, the regular users usually help its maintenance.

**Photo 7** An example of ecological pond (Kamisouyagi, Yamato City)

**Photo 8** A reservoir annually visited by swans (Nanatsugi, Funabashi City)

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**5 RAINWATER INFILTRATION**

5.1 Types of infiltration facilities

There are many types of infiltration facilities. The usually used ones are permeable box, trench and pavement. These types are applied for loam layer. In addition, dry permeable well is also used in the case a gravel layer exists. Fig.7 shows the locations of infiltration facilities installable in a housing area.

**Fig. 7** Locations of infiltration facilities installable in a housing area.

Photo 9 shows the typical infiltration facilities applied for an individual house. The permeable connection box is a facility with the peripheral part of a permeable box filled with crushed stones to infiltrate collected rainwater into the ground from the side and the bottom. The permeable trench is a facility with an excavated trench filled with crushed stones. In the trench, a permeable connection box and a connected perforation pipe are installed to guide and infiltrate rainwater into the ground from the side and the bottom of the trench.
Typical infiltration facilities applied for individual houses.

5.2 Infiltration capacities and clogging

A crucial point to determine the feasibility of infiltration facility is permeability of soil layer. The Kanto region including Tokyo and its neighborhood has a good condition to install infiltration facilities that it is covered with volcanic ash of Mt. Fuji which layer is called Kanto loam. Its permeability is good enough, the order of $10^{-3}$ cm/sec in a saturated hydraulic conductivity.

It is simple to investigate the permeability of soil layer for infiltration. First a hole of diameter 20 cm is dug by hand auger (Photo 10). Next while keeping the test head constantly equal to the design head of planned infiltration facility the flow of injected water to the hole is measured (Fig.8). From the final flow the saturated hydraulic conductivity of soil layer is calculated by a specified formula. This formula and others to estimate the capacities of various infiltration facility types are described in ARSIT’s Technical Guidelines for Rainwater Infiltration Facilities 4).

As mentioned in the previous section, the promotion of infiltration facility has been delayed compared with storage facilities. However, it has become popular especially around in well urbanized cities such as Tokyo metropolitan areas since the design method was authorized by the Technical Guidelines for Rainwater Infiltration Facilities published by ARSIT in 1995.

One of the important issues relevant to infiltration facility is a clogging due to the suspended solid and fallen leaves included in the inflow. In the case infiltration facilities only receiving rainwater from roofs made of tile or concrete or slate almost no clogging occurs from our experiences. However, in the case they receive stormwater from streets or roads, it is necessary to install filtering devices such as a refuse removal basket, a bottom filter and other filters as shown in Fig.9 in order to protect the clogging at the infiltration surface. In this case the checking and cleaning of the filtering devices are necessary at least once a year and just after a heavy storm. Therefore, it is very important to establish an effective maintenance system for them.

Recently there were two important follow-up researches to investigate the capacity of infiltration facilities after constructed 20 years: one in a housing complex 5) and another in a storm drainage system of sewerage 6). Both the
two investigations reported the capacities of infiltration facilities are still effective as designed. However, a few of facilities dropped their capacities due to accumulation of large amount of settlement. The facilities introduced in the first case are counted to be 49 permeable boxes, 494m of permeable trench, 143 m of U-shaped ditch and 3,580 m² of permeable pavement in Akishima Tsutsujigaoka Housing Complex which developed area is 27.8 ha. The facilities introduced in the second case are counted to be 244 permeable street boxes in the catchment area of 15 ha.

5.3 Scale necessary for basin-wide allotment

The principle to determine the rainfall intensity necessary to cut by infiltration facilities for the basin-wide allotment described in the section 2 is the same to that for storage facilities. The cut rainfall intensities equivalent to 300-1,300 m³/ha are around 10-40 mm/hr. Because the capacity of a unit infiltration facility is not so large, the necessary scale of infiltration facilities becomes immense in the case the cut rainfall intensity and the specified catchment area are large and it is infeasible by only them for the cost or installation space. In this case the combination of infiltration and storage is indispensable.

5.4 Infiltration for springs restoration

As described in the introduction, urbanization not only increases flood flow but also reduces normal flow of rivers that is very important for their ecosystems. One of the backgrounds of Japan River Council’s proposal on Preservation of Well-balanced Hydrological System is the public’s heightened interest to the restoration of rivers’ normal flow and natural springs. Many municipalities have had the grant for inhabitants’ infiltration facility installation for this purpose. In addition, many NGOs also are very positive in the actions to restore springs and rivers’ normal flow.

Compared with flood management the scale of cut rainfall intensity to infiltrate almost annual rainfall to underground is small. For example, the total rainfall of rainfall with intensity below 5 mm/hr is equal to 80% of total annual rainfall. Therefore, the scale of infiltration facilities for this purpose is small. A successful case of infiltration facility installation promotion is that of Koganei city, a city in Tokyo metropolitan area, promoted the install of 50,000 infiltration boxes. The percentage of infiltration facility installation reached 48%. The main cause of this success is the strong collaboration among the inhabitants, the municipality (sections of river, sewerage and environment) and NGOs.

6 CONCLUSIONS & RECOMMENDATIONS

From the process of introducing stormwater storage and infiltration to the flood management and their diffusion described above we can extract the features and useful lessons for future or other countries as follows: (1) When the speed of river improvement cannot catch up that of urbanization to obtain a sufficient safety level against flood, large-scale stormwater reservoirs are effective to scope with surface runoff increase by development. In the initial phase the contribution of Japan Housing Corporation that was established in 1955 and integrated with Land Development Corporation to become Housing and Urban Development Corporation in 1981, was large because it applied the policies and the research results of the central governmental organizations to the real projects and conducted the in-site basic researches to develop rainwater storage and infiltration or in-site investigation to ensure their effects.

(2) The amenity and the multipurpose utilization of stormwater storage facilities should be positively promoted as they may contribute to activation of the inhabitants’ community in developed area and to preservation of river basin ecosystem. The multipurpose utilization involves the inhabitants of developed area in their collaboration to the maintenance and their awareness of facilities importance for the flood management of their area.

(3) In the case the permeability of subsurface soil layer of river basin is good, it should promote basin-wide rainwater infiltration although the infiltration facilities have supplemental role for flood control compared with storage facilities. Their important benefits are no open space requirement for installation and returning rainwater into the subsurface. To promote a basin-wide stormwater infiltration and storage extensively an effective institution to involve inhabitants and private sector’s collaborations is indispensable.

(4) To diffuse rainwater infiltration to inhabitants’ individual houses it should determine the cut rainfall intensity for infiltration facility not large so that the cost is not high burden for them, namely, desirably below 5 mm/hr. Even if the capacity of each house is small, the total effects for runoff reduction will be significant if the number of facility is large.

Because the capacity of each infiltration facility is small and the occurrence frequency of inundation is rare, it may be difficult for the public to understand its importance for flood control. However, the normal flows of river and springs that are small and familiar with their living, so it is easier to understand its importance for the restoration of these flows. Therefore, it should appeal rather the effects of rainwater infiltration facilities to the environment than those to flood control.

Sewerage administration should recommend the inhabitants to install infiltration facilities to treat roof rainwater before discharge its overflow to public sewer system. The sewerage administration also has benefit of the reduction of rainwater volume to be treated.

(5) To promote the diffusion of rainwater storage and infiltration to inhabitants or private sector it is necessary that central and local governments positively construct them in public buildings or facilities.

(6) The stormwater-regulated schoolyards and their infiltration facilities are good education materials to make students aware of the necessity of rainwater storage and infiltration in area flood control and importance of maintaining them to keep them effective.
REFERENCES

APPENDIX

Table 3 Basic dimensions of the above introduced reservoirs

<table>
<thead>
<tr>
<th>Name</th>
<th>Location (City name)</th>
<th>Type</th>
<th>Storage Volume (m³)</th>
<th>Storage Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myoshoji</td>
<td>Tokyo</td>
<td>E</td>
<td>30,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Kirigaoka</td>
<td>Yokohama</td>
<td>D</td>
<td>96,000</td>
<td>29,318</td>
</tr>
<tr>
<td>Yokohama Business Park</td>
<td>Yokohama</td>
<td>E</td>
<td>5,831</td>
<td>994</td>
</tr>
<tr>
<td>Kamisouyagi</td>
<td>Yamato</td>
<td>D</td>
<td>75,000</td>
<td>31,000</td>
</tr>
<tr>
<td>Nanatsugi</td>
<td>Funabashi</td>
<td>D</td>
<td>206,500</td>
<td>50,000</td>
</tr>
</tbody>
</table>

Note: D.: concrete dam, E: entrenched type
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Abstract

This paper examines flood disasters caused by climate change focusing on two floods occurring on Japan’s southwest island of Kyushu during record precipitation exceeding 1,000 mm. Our examination results emphasize the urgent necessity of implementing dam measures to prevent serious dam accidents at all costs and adequate action against driftwood and other waste materials to prevent them from interfering in dam operation.

Changes in natural weather and other patterns, e.g., heavy rainfalls 1,900mm recorded in the Miyazaki Prefecture during Typhoon 14 in 2005 and 1,200 mm in the Kagoshima Prefecture Sendai River basin in five days of torrential rain in 2006, have made it clear that conventional measures for coping with such occurrences are no longer adequate. Just 300 mm of precipitation during Typhoon 10 in 2003, for example, triggered catastrophic results in Hokkaido, where heavy rainfall rarely occurs and there is non immunity against 300mm rainfall. Since global warming and its attendant influences are expected to continue and to bring condition of non immunity against an increased potential of disaster to whole country, the need for better knowledge and ideas on disaster prevention are urgently required.

Keywords: river flood, abnormal rainfall, dam, driftwood, Kyushu area

1. INTRODUCTION

Japan – a country in which 22% of all large-scale earthquakes in the world occurred – has long been the target of potential disasters caused by typhoons, heavy snow, high precipitation, and earthquakes, etc., that are aggravated by physical problems such as stark geographical features and social fragility such as large city located on vulnerable alluvial plains. Although Japan accounts for only 0.3% of the world’s land, it is the target of 17% of all disaster damage.

Global warming is being increasingly cited as a cause of unusual geographical effects such as torrential rains, drought, and typhoons. Many of Japan’s social and physical disaster prevention infrastructures were constructed during high economic growth periods, and are now superannuated. Cuts in public works expenditures have made it difficult to update such infrastructures. Those employed by the construction industry have dropped from a peak of 6.85 million in 1997 by 1.17 million (17.1%) in the 8 years since 1998. Reduced public works expenditures immediately weaken disaster prevention capacity and the capacity for local reconstruction.
Disaster generally reveals social vulnerable groups, weak points in cities and regions and momentary catastrophes. It is, of course, important to prevent disaster and minimize damage, and swift postdisaster reconstruction is also needed. Postdisaster restoration and reconstruction in Japan strongly depends on local medium and small construction companies. Once a disaster occurs, especially in local cities or mountainous areas, local construction companies contribute to reconstruction by working devotedly day and night.

Declining construction opportunities and decreasing numbers of employees are related to weakening of local reconstruction capacity and regional decline. It is understandable Japan cannot exist with only in large cities, taking account of foods and energy. If the scale of physical forces of disasters is maintained, public works expenditures must be cut, because infrastructures have been already improved. However, according to IPCC Fourth Assessment Report (AR4), physical forces of disasters will surely increase because of global warming. Given the above considerations, we must act now to implement improvements in disaster prevention by, for example, ensuring adequate investment for the future. Occurrence of a large-scale disaster cannot be met by protestations that it was “beyond expectation,” for example. Who assumes the expectation and has the responsibility? Disasters beyond expectation occurring, no one takes responsibility for his/her expectation.

Global warming originates in environmental issues. Confronting problems with the environment and disaster prevention, we must play a significant role and take responsibility. Both problems should be closely related each other.

2. INCREASE OF PHYSICAL FORCES OF DISASTERS

2.1. Global warming shows its signs

IPCC Fourth Assessment Report (AR4) in February 2007 stated that by the end of this century, temperatures would rise by 1.8 to 4°C, sea levels would rise up to 59 cm (without considering ice melting in Greenland and Antarctica), and human acts have caused global warming with high possibility.

Japan’s currently temperate climate is expected to eventually become subtropical, raising the prospects of heat waves, droughts, infectious disease, food shortages, sediment disasters, flooding, and storm surges.

The disaster caused in the U.S. southeast in 2005 by Hurricane Katrina triggered significant damage since the hurricane was classified into category 5. Katrina’s maximum wind velocity was 82 m/s and the maximum high tide level caused by the storm surges reached 8.5 m. Webster et al. (2005) reported that the number of hurricanes reaching categories 4 and 5 has almost doubled in the last 35 years. Recent trends toward rainfall intensification in Japan has already shown up in data, e.g., the occurrence of torrential rain recorded at 100 mm or more hourly averaged 2.2 per year in the 20 years from 1976 to 1995, but more than doubled to 4.7 per year in the decade from 1996 to 2005. Flood damage in the Tokyo Metropolitan area in the decade from 1995 to 2004 was 108.2 billion yen, 94% of which, i.e., 101.8 billion yen, was from damage due to inside waters. Tokyo Metropolitan Government sewer systems were designed to handle hourly precipitation of 50 mm, but this design standard becomes inadequate in the face of recent rainfall intensification.

Among recent floods in Kyushu, Typhoon Nabi (0514) in August to September 2005 brought heavy rainfall to Miyazaki Prefecture, reaching 1,900 mm over three days in some locations. Moreover, in the case of the torrential rain stimulated by seasonal rain fronts in July 2006, the amount of precipitation over a
period of 5 days reached 1,200 mm, triggering heavy damage in the Sendai River basin in Kagoshima Prefecture. As mentioned earlier, the Kyushu region is increasingly confronted with torrential rain exceeding 1,000 mm. Does the tendency in the increase in disaster spread northwards as the climate in Japan becomes more subtropical?

2.2 Typhoon Nabi Mimi River Basin Disaster

2.2.1. Disaster features

Typhoon Nabi caused torrential rains, strong winds, and storm surges nationwide, causing serious damage in Miyazaki, Kagoshima, Oita, and Yamaguchi Prefectures with housing and bridges washed away.

The upper reaches of the Mimi River in Miyazaki Prefecture are the site of hydraulic power generation by Kyushu Electric Power Co., Inc. The main river is home to 6 dams for power generation – the Kamishiiba, Iwayado, Tsukabaru, Yamasubaru, Saigo, and Ouchibaru Dams, counting from upstream. Typhoon Nabi caused large amounts of waste, mainly driftwood, that accumulated in dam reservoirs (Figure 1). Since these dams intend to make driftwood flush down through spillways downstream, it seemed that the large amount of driftwood reached downstream and caused problems downstream. Large landslides occurred along the river at 5 km upstream from the Tsukabaru Dam, 0.5 km downstream from it at 3 sites, 1 km upstream from the Yamasubaru Dam, and 1.5 km downstream from it at 2 sites. The landslides occurred just downstream from the Tsukabaru Dam are typically large and portend potentially a large number of urgent problems to be solved in the future.

![Figure 1](image-url) Large volume of driftwood in front of the spillway of Yamasubaru Dam (Source: Kyushu Electric Power Co., Inc.)

2.2.2. Landslides occurring on slopes downstream from the Tsukabaru Dam

At a site 500 m downstream from the Tsukabaru Dam, slopes failed at 3 almost continuous sites for over 1 km (Figure 2) and large amounts of sediment, including trees, estimated at 3.25 million m$^3$ [Kyushu Electric Power Co., Inc. (2005a)], flowed into the river and formed a natural dam at 22:00 on September 6. Judging from the flow changes into the Tsukabaru Dam (Figure 2) and the Yamasubaru Dam (Figure 1), the water level behind the natural dam rose to 62 m as about 3.5 million m$^3$ accumulated, and the dam broke down at past 23:00 [Sabo Publicity Center (2005)].

Because the natural dam formed immediately downstream from the Tsukabaru Dam, the manmade dam helped to block water behind the natural dam, which was truly fortunate. Water level downstream from the Tsukabaru Dam rose to 62 m, however, with the unexpected buoyancy acting on the Tsukabaru
Dam body, requiring that the danger in such a situation be reviewed. Little data appears to exist on natural dam formation and collapse. A slope failure of 3 million to 4.3 million m³ occurring in the Naka River in Shikoku in 1892 is estimated to have been roughly the same scale [see, Inoue et al. (2005)]. In this case, water estimated at 72.5 million m³ accumulated until the natural dam broke, sweeping into the lower reaches and taking over 60 lives. In the case of Typhoon Nabi, another natural dam reportedly temporarily formed from failed sediment at Tobase in the Omaru River basin [see, Taniguchi et al. (2005)]. We consider scenarios on the possible occurrence and enlargement of disaster in this case.

![Figure 2](image)

**Figure 2** Tsukabaru Dam and the site of slope landslides (Source: Miyazaki Prefecture Department of Public Works)

1. **What if the Tsukabaru Dam had been located elsewhere?**

Had the Tsukabaru Dam been located elsewhere, water collecting upstream behind the natural dam could have extended significantly from the original 500 m, dramatically increasing its volume. If the natural dam had broken all at once, this could have triggered catastrophic damage due to flood surges several tens of meters high (Figure 3). Satofuka et al. (2007) simulated this scenario.

![Figure 3](image)

**Figure 3** Scenario 1 involving extensive damage
(2) If the slope failure had occurred upstream from the Tsukabaru Dam?

In this scenario, the slope failure shifted 500 m upstream. This could be quite possible, because it depends on whether slope failure occurs upstream or downstream of the dam. A large volume of sediment including trees would have poured into the dam’s reservoir, causing water behind the dam to overflow all at once (Figure 4). The case of the Vaiont Dam in Italy in 1963 resulted in the deaths of 2,600 people [see, Jansen (1980)]. The damage of the worst possibility is beyond description. Some small scale slope failures really occurred upstream from the dam in this case. Similar situations could be also triggered by earthquake.

![Figure 4](image)

**Figure 4** Scenario 2 involving extensive damage

(3) If the water level in the dam had risen further (even without occurrence of slope failure)?

In this scenario, precipitation was somewhat more, or blockade of spillway of dam was more significant because of driftwood or wastes. Overflow beyond the dam would have been phenomenal, possibly damaging or destroying the dam (Figure 5). This could have also triggered catastrophic damage due to flood surges. In fact, inflow into the dams for power generation, including the Tsukabaru Dam, greatly exceeded their designed flood volume. The designed flood volume of Tsukabaru Dam is 2,650m$^3$/s and measured maximum inflow was 3,040m$^3$/s. The designed flood volume for the Yamasubaru Dam is 3,387m$^3$/s and its measured maximum inflow was 4,110m$^3$/s. This actually led to overflow of some dams [Kyushu Electric Power Co., Inc. (2005b)].

![Figure 5](image)

**Figure 5** Scenario 3 with a high possibility of extensive damage

### 2.2.3. Dam role and problems

Capturing driftwood in the six dams of Kyushu Electric Power Co., Inc., it is thought that dams in the
Mimi River have significantly reduced damage in the middle and lower reaches, where the majority of people lived. Driftwood blocking the spillway raised the dam’s water level beyond the dangerous level (Figure 1). As mentioned, further heavy rainfall could have caused water in the reservoir to overflow the dam and in the worst case destroyed the dam itself.

The above six dams are intended for power generation, not flood control. At times of flooding, their gates are fully open to make flood and driftwood pass through the spillway. In the case of a power generation dam, driftwood and other waste are assumed to flow downstream since the electric company, or the operator of the dam, must bear costs for disposing of driftwood, etc., captured in dam. Because such dams are usually constructed in the upper reaches of rivers, capturing driftwood and other waste should be used positively to prioritize the protection of life and property of those who live in the lower reaches. In other words, it is at least necessary to install a sturdy log boom that cannot be destroyed by driftwood in front of the dam spillway. For this, we need legal improvements and administrative guidelines to fully use dams for capturing driftwood. One possible requirement is that administrative organizations bear the cost for removing and disposing of accumulated driftwood and other wastes.

Driftwood flowing down to the sea washes ashore on neighboring beaches (Figure 6), and collision by ships with such driftwood is an increasing concern. The disposal of driftwood is a heavy burden on fisheries personnel and local administrative organizations near beaches, and drastic measures are required, including legal improvements permitting driftwood to be disposed by burial on beaches.

2.2.4. Damage to bridges in the Mimi River basin and need for measures against driftwood

In upper Mimi River reaches, three bridges were washed away. These were truss or beam bridges that easily catch driftwood and wastes. If only the upper part of water is blockaded by driftwood in a large river like the Mimi River, damage is often limited only to the bridge. Such bridges cannot support increasing fluid dynamic force and are finally washed away.

In medium and small rivers, driftwood accumulates before bridges, often leading to total blockage (Figure 7). If driftwood caught in bridges blocks the river, greater damage may occur, since river water can only flow around blockages or bridge abutment is washed away (Figure 8). Such bridge losses lead both economic and human ones, e.g., in the 2003 Hokkaido torrential rain disaster in which bridges were washed away and abutments eroded, causing those driving across bridges to fall into rivers and be washed away. Another example is the 2004 Toyo flood disaster in Ehime Prefecture in which a bridge whose stream was blocked by driftwood suffered a “hydraulic jump” in which river water hit housing on both banks, resulting in loss of life.
Because driftwood occurrences and movement are poorly known, issues involving driftwood are not considered at all in current river planning. This is the current situation in which traditional river planning cannot be appropriately realized due to massive amounts of driftwood raised in recent rainfall intensification. Even the flood that allows originally the river water to flow without problem can cause destruction of bridge abutment or embankment due to blockage by driftwood in bridge, triggering possible disaster. Accordingly, studies on driftwood must be promoted in connection with disaster prevention and corrective action.

3. CITIES AND OTHER REGIONS BECOMING MORE VULNERABLE TO DISASTER

3.1. Shift from equilibrium to non-equilibrium

Prior to the Tokugawa Era (1603-1867), human activities in Japan had little effect on defense against natural disasters. The development and introduction of modern technology have improved disaster prevention capacity (resistance capacity of nature against disaster + infrastructure for disaster prevention) since the Meiji era. Physical forces of disasters has been mostly maintained (Figure 9). However, this balance is being upset by recent increases of physical force of disasters, yielding to a state of imbalance. Disaster prevention capacity consists of ① resistance capacity of nature, ② human awareness of disaster prevention, and ③ social infrastructure for disaster prevention.
3.1.1. Resistance capacity of nature against disaster

Nature has more resistance by repeated severe wind and rain. In sediment disasters, only slopes vulnerable to landslide fail and slopes resistant to landslide remain, increasing resistance. Typhoon Etau (0310) brought rains of 300 mm per 24 hours in the Saru River basin and Appetsu River basin, in Hokkaido, in August 2003, causing numerous slope failures and generating large-scale damage (Figure 10) such as bridge washout (Figure 8) due to the buildup of driftwood and other debris [see, Hasegawa et al. (2005)].

A similar event in Kyushu, where strong wind and rainfall are common, would not have caused such damage. In another example, the maximum instantaneous wind velocity during Typhoon Songda in September 2004 reached 50 m/s in Sapporo City, felling large trees along streets in the city and a famous row of poplars at Hokkaido University – an event that would not have occurred in Okinawa, where many typhoons occur frequently. As physical forces of disasters increase, natural resistance rises, although nature is initially vulnerable. However building resistance takes time (Figure 9).

3.1.2. Human awareness of disaster prevention

Because human beings experience large damage with the increase of physical forces of disasters, human awareness of disaster prevention improves. Confronted sometimes with unprecedented disasters, human is likely to panic, suffering human and economic losses.

3.1.3. Social infrastructure of disaster prevention
Measures against disaster cannot be taken in a short period, because it takes long time and much cost to improve the infrastructure for disaster prevention.

In an unusual August 2003 heat wave in Europe, temperatures in Paris exceeded 38°C for over 10 days, killing 15,000 in France and 30,000 in Europe because such heat was unprecedented in the normally relatively cool European summer and people had no air conditioning. The reaction would have differed in a country where summers were normally hot.

3.2. Problem of vulnerability caused by imbalance

As mentioned above, long time, much cost and many sacrifices are necessary until the three factors consisting disaster prevention capacity improve. Strengthening of disaster prevention capacity is behind the increase of physical forces of disasters, resulting in large gap and non-equilibrium between them.

Under such circumstances, we are highly likely to be vulnerable to disasters beyond our expectations. Discussions of global warming often touch on when and how bad it will get. Some predict that apple-growing regions in Japan’s northeast Tohoku will eventually be famous for oranges, and that the apples will be grown in what is now frigid Hokkaido. Such discussion will be surely possible when a new equilibrium will have been established in the future, but it will take long time to reach such a new equilibrium. The problems caused by the non-equilibrium during transition period can be hardly recognized.

It is difficult for us to predict what “disasters” may occur. Japan is expected to grow socially and economically vulnerable as its birthrate drops and its society ages. To prevent large-scale disasters within the limited resources and keep our country safe, the efforts and the knowledge of researchers and engineers are indispensable.

4. PREVENTING LARGE-SCALE DISASTER

4.1. Possible measures

While large-scale disasters due to collapse of natural or existing dam must be prevented, rainfall over 1,000 mm in several days is not rare in recent years such as large amount of precipitation by Typhoon Nabi or heavy rainfall in the Kagoshima Prefecture Sendai River basin in 2006. What kind of measures can be effective to possible large-scale disasters?

4.2. Measures against dam disasters

4.2.1. Measures

In the upper reaches where natural dam is likely to be formed by slope failure due to abnormal rainfall, water level gauges measuring also deep locations are recommended to be installed at appropriate intervals. The data from gauges are transmitted to the relevant offices in real-time to analyze them. Occurring flood, the water levels rise similarly. Blocked river course, water level upstream from a natural dam rises rapidly, while that downstream from it drops. Accordingly abnormal condition can be easily detected using the devices (Figure 11). Normally it takes 2 to 3 hours until the natural dam collapses and therefore emergency evacuation warning can be issued to evacuate the residents in the lower reaches. It costs not much.
4.2.2. Recommendation of flood control dam without slide gate in spillway

Flood control dam without slide gate in spillway has been reviewed, planned and built in some sites. This type of dam was applied to disaster prevention dam for agriculture, but has recently attracted public attention because of its less impact on natural environment. It has the following characteristics (Figure 12).

a) Spillway without slide gate is provided at the almost same level as that of river bed, flowing water constantly without impoundment. Accordingly sediment and fish pass through the dam. Under the normal operation it is the condition of river without dam, loading little burden on environment.

b) This kind of dam is intended for safety of residents and the consensus can be easily attained among them.

We recommend active construction of flood control dam without slide gate in spillway in the lower reaches of the river for the following reasons:

c) There is no need for human operation of dam because of the natural regulation of flood. Human operation of dam often leads to the misunderstanding that “dam is the cause of flood”.

d) Natural dam or existing dam collapsing, or large amounts of sediment pouring into reservoir and water overflowing dam, flood surge would be received in flood control dam without slide gate in spillway to alleviate damage downstream from dam.

e) Flood control dam without slide gate in spillway can be easily converted into storage dam with low cost and in short period, if water resources problem such as shortage of irrigation water and tap water becomes more serious due to e.g. global warming.

![Figure 11](image1.png) Measures against dam disasters using water level gauges

![Figure 12](image2.png) Measures against dam disaster (construction of dam without slide gate in spillway)
4.3. Review of dam operation

Torrential rain triggered by a seasonal rain front in southern Kyushu in July 2006 caused damage in the Sendai River basin in Kagoshima Prefecture. Large-scale flooding filling the Tsuruda Dam located in the river’s middle reaches forced dam operation to be shifted to so-called provisory operation or “the operation at the time of flood beyond the planned scale”, and the maximum discharge of 3,572 m$^3$/s was run down in spite of the planned discharge of 2,400 m$^3$/s. Volume of flood control dam is limited, thus flood control capacity of dam has its limitation in the case of abnormal rainfall beyond expectation. As physical forces of disaster increase, the conditions under which provisory operation of dam is applied are predicted to increase nationwide in the future. Residents living below Tsuruda Dam requested that a committee be formed to review dam operation. After 5 meetings by the committee and 3 workshops by a technical working group, Tsuruda Dam operation was formally revised and implemented from the 2007 flood season.

4.3.1. Tsuruda Dam flood control

Tsuruda Dam flood control was implemented at 14:40 on July 22, 2006 (Figures 13 and 14). In this control, the water level at Miyanojo in the lower reaches of the river dropped by 1.3 m and the arrival of the maximum water level was delayed by 4 hours (Figure 15).

![Figure 13](image)

**Figure 13** Flood control at Tsuruda Dam in designed high water discharge

![Figure 14](image)

**Figure 14** Flood control in July 2006
4.3.2. Flood control at Tsuruda Dam

The following issues were pointed out about in Tsuruda Dam flood control by experts and local residents:

(1) Water was started to be stored in reservoir as dam flood control at inflow of 600m$^3$/s which is considered to begin to cause damage in the lower reaches. It seems too early. On later arrival of large flood, there was little room for water storage capacity in dam.

(2) In the operation, discharge from the dam was equal to or less than inflow into the dam during flooding. However, the increase rate of discharge from the dam immediately after the shift to provisory operation was larger than that of inflow into the dam. This gave fear, misunderstanding and distrust toward the dam to the suffered residents in the lower reaches.

(3) Issue (1) has two options in flood control – (i) using the limited flood control storage to control frequent medium and small-scale floods, and (ii) preparing only for large-scale floods. Selecting (i), on arrival of large flood dam has no room for water storage as flood control. Selecting (ii), it is likely to be difficult to prevent even medium and small-scale flood despite enough room for water storage in dam. Present accuracy of rainfall forecast makes it impossible to use one of the two options depending on rainfall circumstances.

(4) Under current operation, dam shifts to provisory operation considering weather information when 80% of water storage capacity of dam is used. But on arrival of large-scale flood beyond expectation, the rest of 20% cannot take all the inflow into dam. If the reservoir was full before arrival of the maximum inflow, it could not be mitigated by dam, resulting in unfavorable discontinuous increase of discharge from dam. Therefore, it is necessary to shift dam operation to provisory operation earlier.

4.3.3. Examination and results

After the examination of technical possibilities, the following was implemented:

(1) Review of water level at provisory operation start

To create room for excessive flooding and prevent rapid increase of discharge from dam after the shift to provisory operation, 80% water volume was revised to that of 70% (Figure 16). On reaching 70% water volume, dam operation is not automatically shifted to provisory operation, but is decided considering
forecasted rainfall, etc.

(2) Review of operation after start of provisory operation

In the past, the relation between storage water level and discharge was fixed, planned discharge was set as an objective discharge at the surcharge water level, and a quadratic curve was applied to operation, but in such fixed operation, storage water volume could not be made use of fully to changing inflow into dam (at left in Figure 17). As a result, excessive discharge could be triggered despite enough room in dam.

The discharge curve is reviewed hourly after peak inflow into the dam (at right in Figure 17), assuming that constant inflow will continue for a while in the worst case. Inflow is thus set as an objective inflow at the surcharge water level, a quadratic curve is generated, and discharge is decided based on a new discharge curve. This is repeated hourly and new discharges are decided successively based on new discharge curves, so even after a shift to provisory operation, discharge can be decided flexibly for inflow into the dam (Figure 18), so discharge is determined to use the remaining storage water volume effectively.
4.3.4. Summary of dam operation review

Due to examination by the Tsuruda Dam Flood Control Examination Committee and the Technical Working Group, the following conclusions were obtained: in provisory operation for flooding beyond the planned scale, the water level at start is set at 70% of dam volume, objective discharge is reviewed hourly after peak inflow into the dam, and a new storage water level-discharge curve is generated. If these improvements had been applied to the flood in July 2006, they could have made dam operation flexible, lowered maximum discharge by about 210 m³/s, and made increase rate of discharge from the dam lower. By setting a new standard, dam can operate its flood control function not only to medium and small-scale floods but also large-scale ones beyond expectation. This review of dam flood control is, to our knowledge, the first case of its kind in Japan.

5. CONCLUSIONS

Flood disasters in Kyushu has been brought by unexpected precipitation, e.g., over 1,900 mm in three days. Recent rainfall features large amounts of precipitation concentrated in small areas. In this manner increase of physical forces of disasters can be experienced. In the past, the resistance capacities of nature and infrastructure had been adequately built against physical forces of disasters, so a kind of equilibrium had been almost kept, although damage had sometimes been caused by the instantaneous large physical forces of disasters. As physical forces of disasters have increased in recent years, nature and infrastructure cannot provide adequate resistance capacities, resulting in a kind of non-equilibrium. So it is quite difficult to forecast how disaster beyond expectation is. For eliminating disaster, the capacity of disaster prevention needs to be reinforced to respond to increasing physical forces of disasters. But it is...
impossible in a current situation. Based on this recognition, now is the time to implement a new “disaster prevention concept”. We have to consider disasters beyond expectation, implement measures for alleviating such disasters, and work to prevent abnormal weather due to global warming from progressing. We can say “Disaster prevention involves also education and awareness”.

Based on the foregoing, we recommend the following:

(1) Dam is effective for capturing driftwood and other waste as indicated by the example of Nibutani dam in the case of the 2003 Hokkaido Flood. It can prevent or mitigate flood damage triggered by bridge blockade etc. in the lower reaches where many citizens live. Accordingly, the function of dam for capturing driftwood should be maximized.

(2) Some old dams for water utilization are provided with little volume for flood. As such dams cannot endure heavy rainfall in recent years, swift measures should be taken to prevent catastrophic disaster like dam collapse.

(3) A natural dam was formed by large-scale slope failures in Mimi River basin in 2005. Because such slope failures or landslides could lead to collapse of natural dam or break of existing dam, comprehensive project for disaster prevention should be planned taking forest conservation and flood control into account. Sediment disaster cannot be avoided in Japan with stark geographical features in spite of such efforts with intensification of rainfall. We recommend active construction of flood control dam without slide gate in spillway in the lower reaches in mountainous areas to reduce damage from dam disaster.

(4) Water level gauges should be installed at appropriate intervals and data should be acquired in real time to detect blockade of river course or formation of natural dam.

(5) With driftwood captured in bridge and blocked in river course, flooding is likely to occur. Under the current circumstances in which physical forces of disasters and number of driftwood have been increased, studies and measures against driftwood should be developed.

Increase of physical forces of disasters can be distinctively recognized especially in Kyushu marking over 1,000 mm of torrential rains. Instantaneous physical forces cause disasters, so the possibility should be also considered that physical forces of disasters beyond expectation would hit us in unpreparedness. With progress of global warming, the situations in Kyushu with which we are now confronted may spread northward in Japan in the future. The above recommendations should therefore be swiftly implemented.

Based on the Sendai River flood disaster in July 2006, Tsuruda Dam flood control was concretely revised and improved and a new procedure was implemented in 2007 -- the first, to our knowledge, such example in Japan. The 14-member examination committee consisted of 3 academic experts -- 2 in civil engineering and 1 in economics; 1 working in mass media; 2 in administrative organizations -- 1 at the national level and 1 at the prefectural level; and 8 others -- 2 local government heads and 6 representatives of local residents. Eight of the 14 are local representatives. This committee does not decide by majority vote, but local residents are reliable to the fact that local representatives account for the majority. Mistrust which existed between the administrative organizations and the local residents at first has been gradually shifted to reliability between them. Administration of flood control cannot be realized without cooperation with local residents, so the method which this examination committee took is a model case. We hope this example would be referenced nationwide.
REFERENCES


ESTIMATING PROBABILITY DENSITY FUNCTIONS FOR TSUNAMI EVACUATION ACTIVITY DURATIONS FROM EXPERT PANEL INTERVIEWS

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Abstract
Evacuation is a life saving activity in many disaster situations. Thus evacuation planning is an integral component of disaster mitigation. It is essentially a composite activity whose elements differ depending on the type of disaster. For an example, the evacuation taking place in an event of tsunami is different to that of flooding or volcanic eruptions. The composite evacuation process may be modeled as a network of sub-activities. One output of such modeling is a probability distribution (PD) of the total time required for evacuation which is an essential component of disaster planning. A difficulty with this approach is obtaining the PD of the duration of each sub activity, as typically a sufficient number of “experiments” cannot be carried out to collect data. The paper describes an approach for establishing probability density functions for each sub-activity utilizing the inputs from expert panel interviews.

Key Words: probability density function, expert panel interviews

1. INTRODUCTION
The word evacuation is meaningful when it is associated with time. The time spent on the evacuation process is one of the factors that is used to measure the success of evacuation. Typically, weather forecasts and disaster warnings provide an estimate of the arrival time of a disaster such as a hurricane or a tsunami. Evacuation planning based on availability of such estimates, in turn, demands estimates of the time required to complete a successful evacuation (Sherali et al, 1991). Given the uncertainties involved, such an estimate by definition must be a probability distribution function (PDF). However, an evacuation involves many separate sub-activities with associated time periods, each of which must be described by its own PDF.

For example, in the event of a tsunami [Fernando et al (2008), Ruwanpura et al (2008)] warnings are issued to local authorities such as the Police, who in turn inform households, businesses and other locations within their territory. The warning may also be issued directly via media and electronic devices. Subsequently, in a household, the activities that occur include informing family members, cross checking with additional sources, collecting personal belongings, deciding on the route and destination, and the actual evacuation. One way to obtain such estimates on each activity duration is by taking measurements during mock evacuations (Aguirre, 1983). But the likely benefit is outweighed by the formidable overall expenses and the organizational difficulties. Measurements may also be made during actual evacuations. While some data is available based on the above, they are insufficient to obtain PDF’s of every activity.

It is proposed to conduct a survey among knowledgeable professionals or “experts”. Each expert’s view as to how much time a particular sub-activity may consume can be collected. Three values, a minimum, a maximum and a mean are sought for each activity. The selection criterion for the experts is based on their educational background and awareness of the evacuation process. The number of respondents may vary depending on the availability but the ideal requirement is to sample at least 30 experts. The higher the number of participants, and the better their expertise, the denser the distribution becomes and closer it reaches to reality (Samiiuddin et al, 1993). But the estimation of a probability density function based on each individual’s input is a
challenge due to many reasons. First, the three value response is not necessarily a triangular distribution as assumed in PERT (Lee and Shi, 2004). The values may simply correspond to three points of an unknown distribution. Once a PDF from the response of an expert is estimated, it can be utilised to generate simulated data. Similar data from all experts may then be combined in a frequency distribution, and an appropriate fit for the combined PDF is obtained using the Chi-Square Test and similar statistical criteria.

2. EXPERT PANEL INTERVIEWS AND IDEALIZATION OF COLLECTED DATA.

Expert panel interviews differ from road side interviews. Since the education level of the respondents contributes to the quality of the output, random selection of people from road side interviews may deteriorate the anticipated quality. Further, the pre-selected panel allows follow up of their inputs if required. Their “expert” ability to judge the correct duration values may be ranked from a scale of 0 to 1. This ranking may ideally be obtained as a self-evaluation or assigned at the interviewer’s discretion. However the idea is to weigh the inputs based on their personal ability. The question may be directed to each individual such that a minimum, maximum and a mean value for the duration of a particular activity could be obtained. The interviews should essentially be unbiased and conducted independently. A rule of thumb in statistics requires the number of data to be 30 or more for the sample parameters to be generalised to the population parameters. The number of members in the expert panel may thus be selected accordingly. Each respondent yields a three point distribution for the activity duration and the points are identified as \(a\), \(b\) and \(c\). Values \(a\) and \(b\) stand for the minimum and maximum duration while \(c\) describes the mean. The eccentricity of the mean \(c\) in the \(a-b\) range suggests to establish \(F_1(x)\) and \(F_2(x)\) which are the idealised normal distributions with their 95% probability cut offs defined by \(a\) and \(b\). The two distributions share the common mean \(c\) but possess different standard deviations \(\sigma_1\) and \(\sigma_2\).

Fig 1 - Formation of Joined Truncated Normal Distribution

Fig 1 shows the “three point distribution” discussed. The eccentricity of \(c\) causes the biased accumulation of the density in the \(a-b\) range. The two functions are normalized such that the underlying combined area becomes unity. The resulting new distribution is essentially a joined truncated Normal and shown in Fig 1. The process is extended for all the 3- value sets \((a, b & c)\) obtained from each respondent. Data generated from the resulting truncated distributions are finally added up and a PDF is fitted that effectively describes the duration of the selected activity.

3. ASSESSMENT OF THE BEST FITTING DISTRIBUTION

It is important to compare this idealization with few simplified but similar approaches. A uniform distribution may be assumed instead of normal, with the limiting values \(a\) and \(c\), and disregarding the mean \(b\). Secondly, the mean is incorporated with the triangular distribution with \(a\) and \(c\) as the limits. The PDF’s generated from each of the two methods can be compared against the above PDF from the joined truncated Normal idealisation. A real life example is selected to visualise the three approaches and to observe their validity. The duration parameters, i.e. \(a\), \(b\) and \(c\) for a tsunami evacuation activity: “move to a higher ground” are obtained from 32 respondents. The three idealisations yield three different PDF’s as shown in Fig 2. The curves generated from the more simple approaches, i.e. uniform and triangular, possess relatively lower peaks. Further the latter appear as a bimodal distribution with two peaks, which is understandably due to the discontinuity near the mean in the idealised normal distribution.
Fig 2 – Resulting Probability Density Functions from the three approaches.

Known distributions could be fitted against the resulting PDF’s and the best fit is obtained. If the analyser opts to consider the personal ability of each interviewee, the idealised distributions may first be multiplied with normalised personal ability values prior to the addition of each. This exercise assumes equal ability for simplicity, which nullifies the effect of the personal ability index. Twenty four different distributions were fitted to the data and an interesting result surfaced with Johnson SB distribution claiming the best fit for all the three scenarios. In fact, the literature reveals that the Johnson SB distribution is essentially a bounded Normal distribution (Slifker and Shapiro,1980). If the lower and upper limits are denoted by ε and ε + λ respectively, the standard normal deviate, Z can be computed from Eq (1):

\[ z = \lambda + \eta \ln \left[ \frac{x - \varepsilon}{\lambda + \varepsilon - x} \right] \] ..........................eq (1)

In more comprehensive terms, the Johnson SB probability density function can be expressed as a function of Normal distribution as seen in Eq (2) (Johnson and Balakrishnan,1994) and (Yu,2004):

\[ f(x) = \frac{\alpha_2}{x(1-x)} \phi(\alpha_1 + \alpha_2 \ln \frac{x}{1-x}) \] ..........................eq (2)

with 0<x<1: \( \alpha_1, \alpha_2 > 0 \)

The variables \( \alpha_1 \) and \( \alpha_2 \) are the shape parameters with \( \Phi \) being the probability density function of the standard normal distribution. The selection of the most appropriate statistical distribution inevitably generates further exercises as to how close it relates to the observed PDF. Three standard goodness of fit tests namely, Kolmogorov-Smirnov (K-S), Anderson –Darling (A-D) and the more familiar Chi-squared goodness of fit tests namely, Kolmogorov-Smirnov determine how close it relates to the observed PDF. Three distribution inevitably generates further exercises as to distribution. The selection of the most appropriate statistical test surfaced with Johnson SB distribution claiming the best fit for all the three scenarios. In fact, the literature reveals that the Johnson SB distribution is essentially a bounded Normal distribution (Slifker and Shapiro,1980). If the lower and upper limits are denoted by \( \varepsilon \) and \( \varepsilon + \lambda \) respectively, the standard normal deviate, Z can be computed from Eq (1):

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The variables \( \alpha_1 \) and \( \alpha_2 \) are the shape parameters with \( \Phi \) being the probability density function of the standard normal distribution. The selection of the most appropriate statistical distribution inevitably generates further exercises as to how close it relates to the observed PDF. Three standard goodness of fit tests namely, Kolmogorov-Smirnov (K-S), Anderson –Darling (A-D) and the more familiar Chi-Squared test are used and the results are presented in Table 1:

<table>
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<th>Criterion</th>
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<th>Idealisations</th>
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<td>Kolmogorov-</td>
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<td></td>
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<tr>
<td>Anderson - Darling</td>
<td>Critical Value (95%)</td>
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<td></td>
<td>Statistic</td>
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<tr>
<td></td>
<td>Reject?</td>
<td>no</td>
</tr>
<tr>
<td>Chi- Squared</td>
<td>Critical Value (95%)</td>
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<td></td>
<td>Statistic</td>
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</tr>
<tr>
<td></td>
<td>P-Value</td>
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</tr>
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</table>

Table 1 - The selection of best fit via goodness-of-fit statistics.

It is observed that the p-value is almost unity for all the three idealised distributions if we use the K-S or the Chi-Squared test. However the A-D test approves only the Uniform idealisation at a 95% level of confidence. Whilst this discrepancy is explained by the distinct idiosyncrasies of the three tests, an insight to the pros and cons of each would help us to reach a better decision on as to what method is to be followed in the long run.

The K-S test is undoubtedly one of the best statistical tools that does not require a minimum sample size like the Chi-Square does (Hogg et al, 1995). However, it suffers from being too sensitive near the center than at the tails. Fortunately, what is more important in a typical emergency sub-activity (e.g. evacuation) is the mean duration. Conversely, the Anderson-Darling test gives more weight to the tails and in fact is a derivation from the K-S test (Stephens, 1974). The rejection of Triangular and the Normal idealisations are better explained in this fashion as the tails of the fitted Johnson SB distributions deviate from the corresponding observed PDF’s. But this level of sensitivity is not captured by the rest of the two and in fact the Chi-Squared test equally approves the three scenarios. It suffers the drawback of needing frequency values bigger than 5. The test is therefore invalid for the activities whose durations spread over a wider time span with lesser number of participants available for the survey. However it can be noted that the extra sensitivity of the A-D test does not prevent us from selecting the appropriate idealisation among the closely contesting candidates. The selection of Johnson SB as the best fitting distribution for the considered activity is supported by the above example. Nevertheless, the exercise needs repetition for many activities in order to select a single generic distribution for all activities or to find best fitting distribution for each individual activity. The goodness-of-fit test statistics indicate that the three idealisations can equally be selected despite the trivial difference in the p-value in the Normal idealisation. The discrepancy is due to the Johnson SB’s lack of co-operation with bi-modal PDF’s.

4. CONCLUSION

Many disaster modelling exercises rely on heavy volumes of field data. If the data is supposed to describe a distribution of a particular activity/ies then the method described in the paper may be effectively applied. The method is absent from complex mathematical calculations yet serves the intended purpose amicably. One aspect of proper definition of the distribution is to describe entire data range with a few parameters and thus avoid manipulation of bulk data. Hence derived distribution parameters may be utilised as a criteria for comparison of various evacuation processes. It also eases the subsequent analysis / simulation of sequenced activities.
exact cut off of the 95% probability limit in the Normal distribution is 1.96$\sigma$ but is conveniently taken as 2$\sigma$. The error generated from this is expected to blur with the uncertainty in the selection of 95% level. The decision to use 95% or any other value depends on the nature of the interview. The interviewer must judge the level of absorption of his questionnaire and the confidence in the resulting responses in order to determine the overall percentage of confidence. Conversely, the questions can be so directed to obtain the desired confidence level. The expected level may even be stated upfront to the learned panel. This study explores the different idealizations that can be adopted to interpret responses from the interviews/surveys. The simplest method is based on the assumption that duration varies uniformly but it totally neglects the mean value aspect. The PDFs from the idealizations with triangular and Normal distributions do not provide drastically better fits compared to the former as seen from the P-values. However the Johnson SB distribution altogether describes them remarkably well. Preliminary investigations reveal that the upper and lower bounded distributions are better explained by the Johnson SB which will be an encouraging starting point for the future explorations of data related disaster related activities.

5. ACKNOWLEDGEMENTS
The support of NSERC and CRC Program of Canada and the University of Calgary is gratefully acknowledged.

6. REFERENCES


APPENDIX  Briefs of WFEO, SCJ, JFES and JSCE

1. The World Federation of Engineering Organizations (WFEO)

Founded in 1968 by a group of regional engineering organizations, under the auspices of the United Nations Educational, Scientific and Cultural Organizations (UNESCO) in Paris, the World Federation of Engineering Organizations (WFEO) is a non governmental international organization that brings together national engineering organizations over 90 nations and represents some 15 millions engineers from around the world.

WFEO is the world wide leader of the engineering profession and cooperates with national and other international professional institutions in developing and applying engineering to the benefit of humanity.

WFEO and UATI (International Union of Technical Associations and Organizations) jointly created in 1994 the International Council for Engineering and Technology (ICET), one of the twelve NGOs formally associated with UNESCO.

WFEO, UATI and FIDIC (International Federation of Consultant Engineers) created in 1992 the World Engineering Partnership for Sustainable Development (WEPSD).

Role

• WFEO provides information and leadership to the engineering profession on issues of concern to the public or the profession;

• WFEO serves society, and is recognised by national and international organizations and the public, as a respected and valuable source of advice and guidance on the policies, interests and concerns that relate engineering and technology to the human and natural environment;

• WFEO facilitates communication and cooperation among engineering organizations and with other organizations particularly those of the UN system and international non governmental institutions dealing with science, engineering, technology and business;

• WFEO fosters peace and promotes sustainable development on a global basis as well engineering education and training, the exchange and sharing of technology and application of ethics concern and conduct;

• WFEO brings together the developed and the developing nations for mutual benefit;

• WFEO facilitates relationships between governments, business and people by contributing an engineering dimension to discussions on policies and investments;

• WFEO is working on the transferability of engineering qualification.

Activities

Most of the technical activities of the Federation are carried out by 6 standing committees, which cover particular areas of engineering:

• Committee on Education and Training (CET)
Committee on Information and Communication (CIC)
Committee on Technology (ComTech)
Committee on Capacity Building (CCB)
Committee on Energy (CE)

Many projects relating to the professional interests of members are undertaken in cooperation with other world bodies: those of the UN system (UNESCO, UNEP, UNIDO, UNDP, UNCSD) as well as the World Bank, the Council of Academies of Engineering and Technological Sciences (CAETS), the Global Environment Facility (GEF), the International Council for Sciences (ICSU), the World Business Council for Sustainable Development (WEPSD)...

**Membership**

The Federation consists of National, Regional, or Affiliated Members (one engineering organization per country), according to specific circumstances, and International Members (group of national engineering bodies organised on a geographical or other international basis).

Organizations, firms or individuals who wish to interact with the Federation but do not fulfil the membership conditions are incorporated as Associates.

**Management Structure**

The General Assembly, the supreme governing structure of the Federation, meets biennially. Between meetings, the affairs of the Federation are directed by the Executive Council, urgent business being transacted by the Executive Board.

The Secretariat headed by the Executive Director, conducts the day-to-day business in consultation with the President.


For more details please refer to the above website.
2. The Science Council of Japan (SCJ)

The Science Council of Japan was established in January 1949 as a "special organization" under the jurisdiction of the Prime Minister for the purpose of promoting and enhancing the field of science, and having science reflected in and permeated into administration, industries and people's lives. Following are its two functions:

- To deliberate on important issues concerning science and help solve such issues.
- To make coordination among scientific studies to achieve higher efficiency.

The SCJ consists of 210 members and some 2,000 associate members officially representing 820 thousand Japanese engineers and scientists.

The SCJ organization comprises a General Assembly, an Executive Board, three Section Meetings (Humanities and Social Sciences, Life Sciences, and Physical Sciences and Engineering), 30 committees based on fields of specialties, five Administrative Committees for operation, and issue-oriented ad hoc committees.


For more details please refer to the above website.
3. The Japan Federation of Engineering Societies (JFES)

The Japan Federation of Engineering Societies is the sole incorporated organization in Japan consolidating 102 academic and engineering organizations as its regular member. The number of individual members belonging to these member organizations adds up to about 600,000 with some duplication. JFES covers entire areas of engineering, namely fundamentals (e.g. physics and informatics), metallurgy, mining, mechanical engineering, civil engineering, architectural engineering, electrical and electronics engineering and chemical engineering. JFES’ member list is shown in Appendix 1.

The object of JFES is to promote by the cooperation of membership organizations the progress of engineering and industries through the following activities:

1. To foster cooperation between membership organizations
2. To participate in the domestic and international activities representing members
3. To submit proposals and petitions to government and public with regard to the welfare of engineering societies and engineers
4. To undertake research and investigations on engineering subjects
5. To sponsor and co-sponsor engineering events
6. To do all others to fulfill the object

JFES has traditionally advocating the importance of capacity building of engineers. One of the recent achievements is the contribution to the establishment of the accreditation system for the engineering education in universities and colleges. It is a co-founder of the Japan Accreditation Board for Engineering Education inaugurated in 1999. Following the engineering education in school, JFES is currently focusing its effort to foster the continuing education of professional engineers. In 2002 it established the PDF (Professional Development of Engineers) Council within itself and has been working on to organize a system to coordinate continuing education programs and engineering licenses for engineers. Other current activities of the common interest of the members include participation in WFEO (See the last paragraph.), sponsoring symposiums and seminars on the subjects common to the members, and promoting information exchange among secretariats of members regarding the operation of academic and engineering societies.

JFES was founded on 18 November, 1897 by the 23 graduates from the Japanese first college of engineering for the purpose of exchange of knowledge and information among each other. The graduates were from seven departments: civil, electrical, mechanical, architectural, chemical, mining and metallurgical engineering. It made an outstanding contribution to the start-up of Japanese modern industry by undertaking the publication of technical magazines, the sponsorship of seminars,
the presentation of rewards to engineering achievements, the research on countermeasures against natural disasters, etc. JFES was awarded the status of corporation by the Japanese government on 31 January, 1901. According the expansion of Japanese industry from late 19th century, engineering societies were founded dedicated to specific engineering areas and individual members of JFES left to join such specially focused societies. Hence, in 1922, JFES was reorganized as a federation of the engineering societies and this structure has been followed until today.

In 1971, Prof. OSATAKE, Tonau, then Vice President of JFES, attended the third General Assembly of WFEO as an observer and was invited to join WFEO. After returning Japan he discussed this invitation with the Science Council of Japan (SCJ), an advisory organization for the cabinet regarding scientific issues. The Japanese government granted for SCJ to apply for the WFEO membership and SCJ made an application in conjunction with JFES. This application was admitted by the Executive Council of WFEO in September 1972. JFES interrupted the contribution to WFEO in 2003 because of its financial problem but resumed the activity in May 2005 by organizing the international activity committee. It has been supporting the SCJ’s. It is scheduled to be an associate member of WFEO after November 2007.

For more details please refer to: http://www.jfes.or.jp/
## Appendix 1

### List of JFES Members

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<th>No</th>
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<td>Japanese Society for Artificial Intelligence</td>
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<td>The Japan Society for Precision Engineering</td>
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<td>29</td>
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<td><a href="http://www.iee.or.jp/">http://www.iee.or.jp/</a></td>
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<td>Research Group of Electric Furnace Steel</td>
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<td>The Institute of Electrical Installation Engineers of Japan</td>
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<td>The Telecommunications Association</td>
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<td>The Institute of Electronics Information and Communication Engineers</td>
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<td>Society of Grinding Engineers</td>
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<td>The Japan Institute of Energy</td>
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<td>61</td>
<td>The Society of Photographic Science and Technology of Japan</td>
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<td>43</td>
<td>Japan Association for Fire Science and Engineering</td>
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<td>The Society for Biotechnology Japan</td>
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<td>The Adhesion Society of Japan</td>
<td><a href="http://www15.ocn.ne.jp/%7Eadhesion/">http://www15.ocn.ne.jp/%7Eadhesion/</a></td>
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<td>The Japan Society of Mechanical Engineers</td>
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<td>Society of Plant Engineering Japan</td>
<td><a href="http://www.sopej.gr.jp/">http://www.sopej.gr.jp/</a></td>
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<td>The Japan Society for Computational Engineering and Science</td>
<td><a href="http://www.jsees.org/">http://www.jsees.org/</a></td>
<td>68</td>
<td>The Society of Materials Engineering for Resources of JAPAN</td>
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<td>Japanese Society of Tribologists</td>
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<td>Japan Concrete Institute</td>
<td><a href="http://www.jci-net.or.jp/">http://www.jci-net.or.jp/</a></td>
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<td>The Japanese Society for Non-Destructive Inspection</td>
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<td><a href="http://www.jfps.jp/">http://www.jfps.jp/</a></td>
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<td>98</td>
<td>The Society of Environmental Instrumentation Control and Automation</td>
<td><a href="http://eica.jp/">http://eica.jp/</a></td>
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<td>88</td>
<td>The Society of Rheology, Japan</td>
<td><a href="http://www.srj.or.jp/">http://www.srj.or.jp/</a></td>
<td>99</td>
<td>NPO: Precision Engineering and Science Network</td>
<td><a href="http://www.pen.or.jp/">http://www.pen.or.jp/</a></td>
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<td>Robotics Society of Japan</td>
<td><a href="http://www.rsj.or.jp/">http://www.rsj.or.jp/</a></td>
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<td>Japan Society of Dam Engineers</td>
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<td>91</td>
<td>Japan Society of Corrosion Engineering</td>
<td><a href="http://www.jcorr.or.jp/">http://www.jcorr.or.jp/</a></td>
<td>102</td>
<td>NPO: Institute of Environmental Restoration /Creation on Osaka Bay Coastal Zone</td>
<td><a href="http://www.osakawan.or.jp">http://www.osakawan.or.jp</a></td>
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4. Japan Society of Civil Engineers (JSCE)

Japan Society of Civil Engineers (JSCE) was established as an incorporated association in 1914 entrusted with the mission to contribute to the advancement of scientific culture by promoting the field of civil engineering and the expansion of civil engineering activities. Since its establishment, JSCE has endeavored to achieve the above mission, through extensive activities including scientific exchange among members, researchers / promotion of science and technologies relating to the field of civil engineering, social involvement, etc. Over the years, the JSCE membership has increased significantly from the initial 443 members to approximately 39,000 members at present, and is currently engaged in various wide-ranged activities around the world.

With the birth of the 21st century, JSCE has reconfirmed its goals to exert perpetual efforts

1) to propose an idea for social infrastructure development in the future from civil engineers' perspective,
2) to acquire a steadfast relationship of mutual trust with the society,
3) to promote scientific and technological researches/studies with a high degree of transparency, and
4) to evaluate public works from a neutral standpoint, and to reach a social consensus on those proper standards.

Furthermore, JSCE will implement such new indispensable programs as Civil Engineers' Qualification System, Continuing Professional Development, etc., for the benefit of creating an environment where civil engineers can widely take on an active role in the international community, and where civil engineering technologies may contribute to the amenity of the people both in and outside of Japan.

The above text is excerpts from the article "Remarks upon Publication" published in "Civil Engineering, JSCE" vol.39, 2001.

Works of JSCE
- Publication of Periodicals for Mutual Communication among Civil Engineers
- Editing of Books and Publications on Civil Engineering
- Open "Place" for Presenting the Results of Studies and Researches
- Presenting Awards to Promote Development and Further Research in Civil Engineering
- Civil Engineering Library
- International and Domestic Communication with Relative Academic Societies and Associations
- Cooperation in the Development of Infrastructure

Source: http://www.jsce-int.org/introduction.shtml

For more details please refer to the above website.