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SURVEYS AND ACTIVITIES ON POST-EARTHQUAKE DISASTER

UNESCO-IPRED-RIHS INTERNATIONAL WORKSHOP
PADANG, INDONESIA, 6-8 JULY 2010

Research Institute for Human Settlements
Agency for R&D – Ministry of Public Works of Indonesia
Provincial Government of West Sumatera
Padang, Indonesia

INTERNATIONAL PLATFORM FOR REDUCING EARTHQUAKE DISASTERS (IPRED)

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Editorial coordinators: Fani Deviana
Yasuo Katsumi
Jair Torres

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For further information, please contact:

Section for Disaster Reduction
Natural Sciences Sector

UNESCO
1, rue Miollis
75732 Paris Cedex 15 France
Phone: + 33-1-45 68 38 92
Fax: + 33-1-45 68 58 21
Email: y.katsumi@unesco.org

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FOREWORD

The UNESCO–IPRED–RIHS Workshop on 'Surveys and Activities of Post-Earthquake Disaster' hosted by the Research Institute for Human Settlements (RIHS) and the Ministry of Public Works of Indonesia in cooperation with the Provincial Government of West Sumatra, and supported by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Japan International Cooperation Agency (JICA) provided an opportunity to advance international cooperation in the evaluation, prevention and mitigation of earthquake disasters. The meeting took place against a backdrop of an appalling loss of human lives and wholesale destruction of communities and infrastructure as a result of major earthquakes.

Natural disasters, including earthquakes, do not recognize geographical borders. The recent major earthquakes in Padang, Indonesia (2009), Haiti (2010) and Chile (2010), followed by the devastating earthquakes in New Zealand and Japan (2011) after the workshop, came as a tragic reminder of the urgent need for nations to make optimum use of knowledge and technology in order to reduce the risk of disasters. Efforts must be pursued so that all realistic measures are taken to ensure more resilient communities.

In July 2008, UNESCO launched the International Platform for Reducing Earthquake Disaster (IPRED) programme to identify gaps and priorities through the sharing of scientific knowledge and experience in the field of seismology and earthquake engineering, and to support the development of political will and public awareness, to ensure better earthquake preparedness and build a culture of safety for people around the world. Earthquakes are one of the major expected disasters, especially in the metropolitan areas located in seismic zones all over the world. UNESCO's IPRED programme is intended to advance partnership and networking and to help draw lessons from earthquake disasters.

The workshop, which aimed in particular at discussing activities for post-earthquake reconstruction, was very successful, providing a fresh impetus for coordinated initiatives in public preparedness and the rehabilitation of buildings. It considered the roles of national and local authorities before, during and after disasters as well as the need for more practitioners who are well-educated, trained and prepared. The outcomes of this workshop, compiled in this publication, will contribute to the reduction of earthquake losses, and to the health and safety of millions of people worldwide.

UNESCO wishes to express its gratitude to all those who have contributed to the success of the workshop. UNESCO thanks RIHS, the Ministry of Public Works of Indonesia, the Provincial Government of West Sumatra, and JICA for their cooperation in implementating the workshop and producing this book. The commitment and hospitality of RIHS, the Ministry of Public Works of Indonesia, and the Provincial Government of West Sumatra made the meeting a success. UNESCO extends its gratitude to the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan, whose generous financial and technical support has enabled the platform to become a reality. Special thanks also are due to the Building Research Institute (BRI) of Japan, and its International Institute of Seismology and Earthquake Engineering (IISEE), which serves as a centre of excellence for this platform.

Badaoui Rouhban
Director, Section for Disaster Reduction
UNESCO, Paris

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T. Imamura

Programme Specialist, Section for Disaster Reduction
Natural Sciences Sector, UNESCO, Paris, France

(From September 2010)
Director for International Building Codes Coordination, Housing Bureau
Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan
Email: imamura-t2y8@mlit.go.jp

ABSTRACT

The risk of disasters is increasing due to human behaviour and attitudes, including urbanization in developing countries, which is putting extra pressure on building construction. While hazards may be inevitable, disasters are not. We can break this link through proper prevention and disaster preparedness. UNESCO has been engaged in the study and mitigation of natural hazards since the 1960s, promoting knowledge and education aimed at enhancing disaster prevention and preparedness. The aim of UNESCO's IPRED programme is to identify gaps and priorities through the sharing of scientific knowledge and experience in the field of seismology and earthquake engineering, and to support the development of political will and public awareness, to ensure better earthquake preparedness and build a culture of safety for people around the world. UNESCO intends to contribute to the creation of a safer built environment, through its network, including IPRED, by advocating important issues in building codes and promoting education on disaster risk reduction, as well as school safety.

KEYWORDS

UNESCO, IPRED, disaster risk reduction, earthquake, building codes, education, school safety

INTRODUCTION

Earthquakes are not directly related to climate change, but the risk of natural disasters is ever increasing because of population growth, increasing urbanization and continuous unregulated construction of buildings. More importantly, many existing buildings may not withstand future earthquakes.

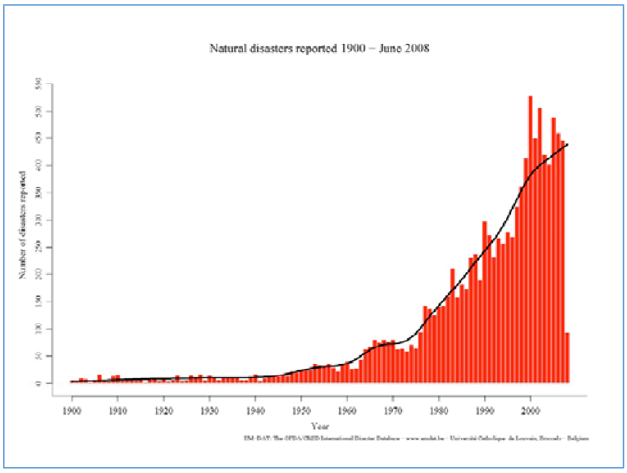

Figure 1 Reported natural disasters (EM-DAT)

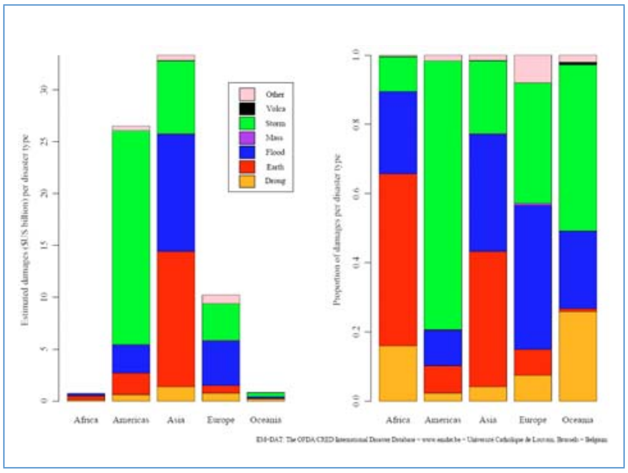

Figure 2 Estimated damage by disaster type and region (EM-DAT)

Over the past months and years images of death and destruction caused by various natural disasters worldwide have haunted us. The tragedy caused by the earthquakes in Wenchuan, China (May 2008), Haiti (January 2010) and Chile (February 2010) are dramatic reminders (The Great East Japan earthquake and tsunami occurred in March 2011 while this paper was being prepared, after the author had returned to Tokyo.) Recently, we have also witnessed how fires and floods can disrupt a nation like Australia. According to EM-DAT, the number of natural disasters has increased dramatically since the beginning of the last century. Since 1950, and in particular over the last 20 years, the rate of disasters has accelerated (Figure 1).

It may be no exaggeration to say that major disasters are still ahead and increasingly, natural disasters are becoming a global issue, for a number of reasons: increasing vulnerability and exposure, population growth, increasing urbanization, continuous unregulated construction of buildings that may not withstand natural disasters, environmental degradation and poorly planned development, as well as global climate change, which may produce further extreme climatic events.

According to EM-DAT, the estimated damage caused by natural disasters in the past 20 years has been significant on the Asian and American continents. Earthquake disasters have struck Asia in particular, and also caused significant damage in Africa (Figure 2).

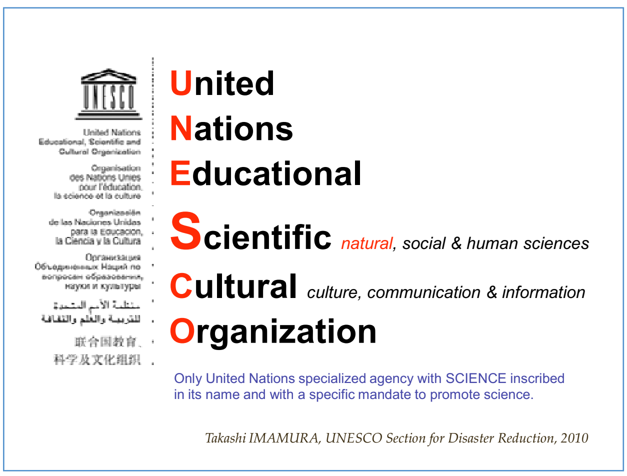

Figure 3 UNESCO is the only United Nations specialized agency with "science" in its name

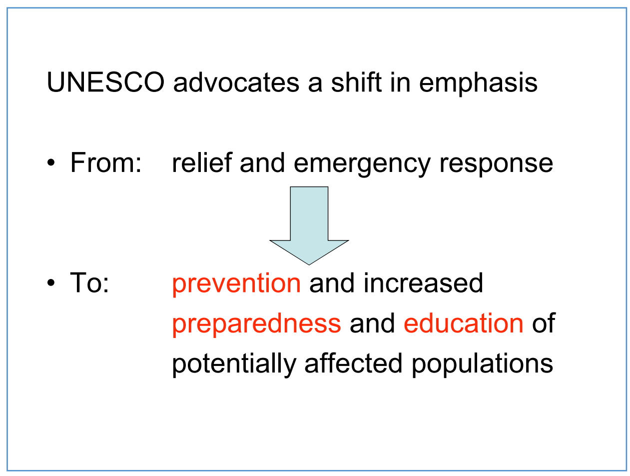

Figure 4 UNESCO advocates a shift from relief to prevention efforts

Ms Irina Bokova, Director-General of UNESCO has pointed out that "UNESCO should become the leader and mobilizer of governments, specialized agencies and the scientific community in the field of science, innovation and new technologies, including green technologies, under the slogan "Science and Technology serving Humanity." Indeed, UNESCO is the only United Nations specialized agency with science inscribed in its name and a specific mandate to promote it. Most of UNESCO's activities regarding natural hazards are carried out within its Natural Sciences Sector (Figure 3). Disaster Risk Reduction (DRR) activities also involve other programme sectors including the Education, Culture, and Communication and Information Sectors. In addition, UNESCO's contribution is managed by units both in Headquarters and Field Offices. Altogether, UNESCO advocates a shift in emphasis from relief and emergency response to prevention and increased preparedness and education of potentially affected populations (Figure 4).

UNESCO has been engaged in the study and mitigation of natural hazards since the 1960s. Its scope of work concerns promoting knowledge and education aimed at enhancing disaster prevention and preparedness. The purpose is to promote a better understanding of earthquakes and other hazards, as well as to enhance preparedness and public awareness through education and training. UNESCO is an active partner in the International Strategy for Disaster Reduction (ISDR) system.

UNESCO's long-term goals for DRR include promoting better understanding of earthquakes and other hazards, enhancing public awareness through education and communication, promoting disaster-resistant building codes and safer construction, supporting the development of hazard risk mapping, observing and establishing early warning networks for natural hazards, integrating DRR into education, and protecting cultural monuments and sites (Figure 5). UNESCO's DRR efforts focus not only on earthquakes but all other natural hazards in order to prevent disasters (Figure 6).

Figure 5 UNESCO's long-term DRR goals

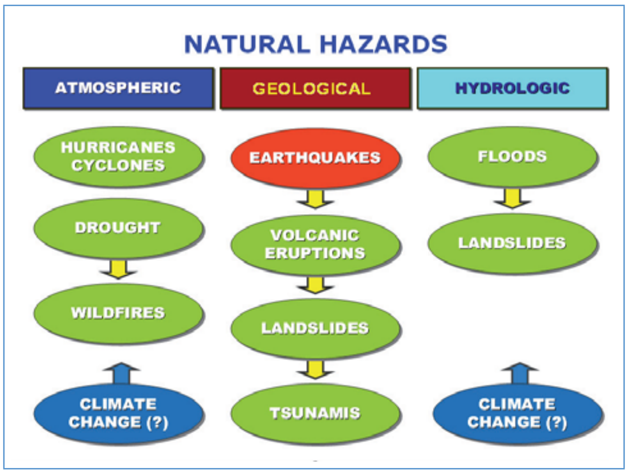

Figure 6 Natural hazards tackled by UNESCO

Unfortunately, the disaster cycle reveals that most resources for disaster-related activities are spent when disasters occur, in emergency-response and relief operations (Figure 7). Much less funding and efforts are invested in the other phases of the cycle, namely mitigation, disaster preparedness and the pre-disaster phase in general. This trend must be reversed in order to reduce losses.

Disasters are increasingly caused or aggravated by human behaviour and attitudes. While hazards are inevitable, disasters are not (Figure 8). Because disasters can be prevented or mitigated, Ms Margareta Wahlström, Assistant Secretary-General of UN/ISDR, has stated that all disasters are man-made, caused by hazards. We can break the link through proper prevention and disaster preparedness. Notaby, earthquakes themselves do not kill people, but falling buildings and other infrastructures do, turning risk into a disaster. We can, and must, prevent disasters by ensuring a safer environment.

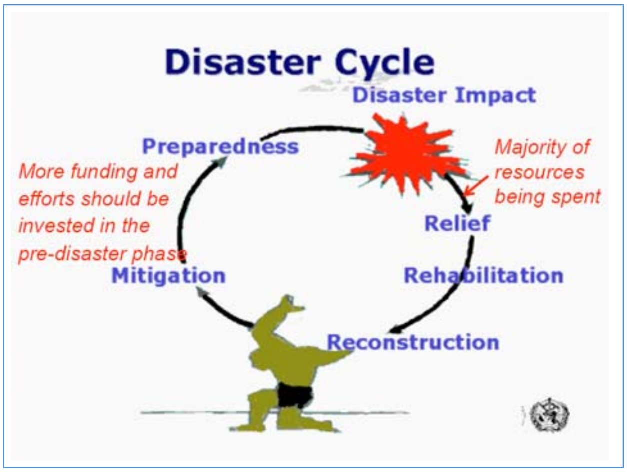

Figure 7 Disaster cycle

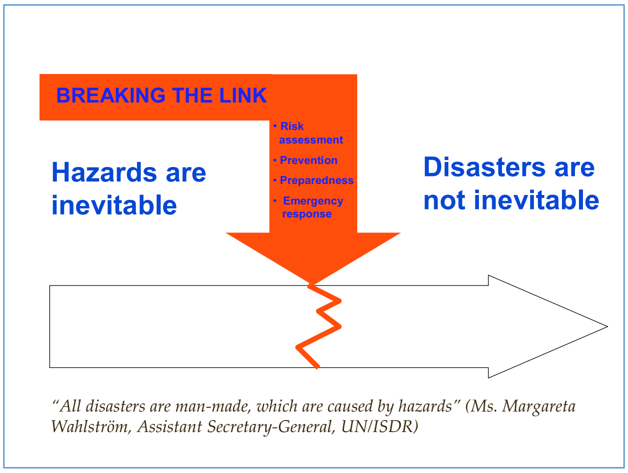

Figure 8 Hazards vs disasters

Disaster risk can be expressed as a combination of hazards, exposure and vulnerability (Figure 9). In terms of hazards, earthquake patterns are relatively static, whereas weather-related hazards may be growing in magnitude due to global climate change. Exposure is increasing due to population growth, migration, urbanization and economic development (Figure 10). Unsafe, poorly built housing, schools, hospitals and lifeline infrastructure all contribute to physical vulnerability.

At the same time, the UN Secretary-General, Ban Ki-moon, has called for a target to halve the loss of lives from disasters by 2015, the closing year of the Hyogo Framework for Action (HFA). Because exposure to risks is increasing, we need to make greater efforts to reduce vulnerability, both physically and socially, in order to significantly reduce disasters.

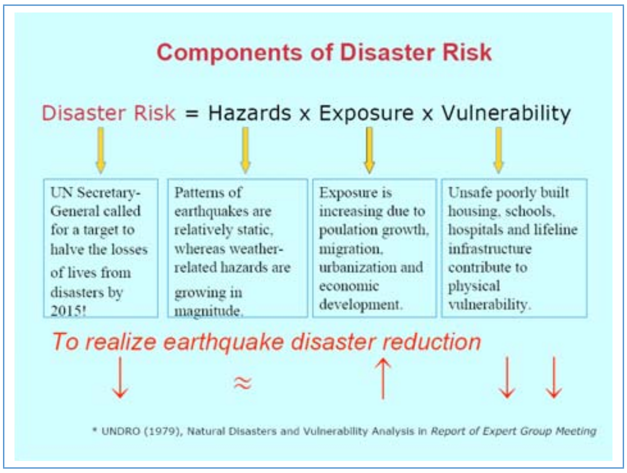

Figure 9 Components of disaster risk UNDRO (1979)

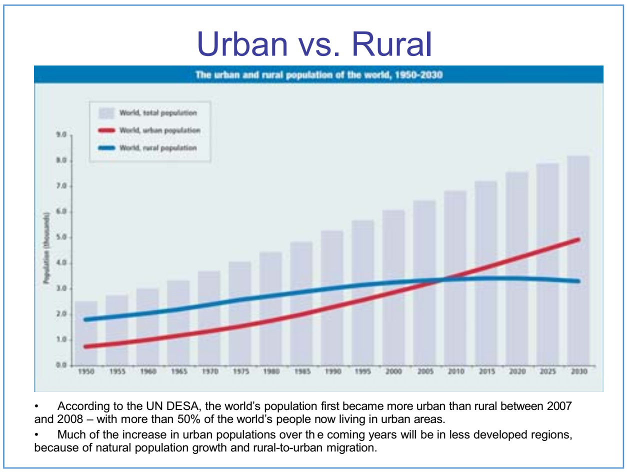

Figure 10 Global urban and rural population (1950–2030)

IPRED: UNESCO'S PROGRAMME FOR EARTHQUAKE DISASTER REDUCTION

For research and expertise on earthquake risk, UNESCO established the International Platform for Reducing Earthquake Disasters (IPRED) in 2008 with the support of the Government of Japan. Its aim is to set up an international network for collaborative research, training and education in seismology and earthquake engineering, and establishing a system for post-earthquake field investigation. The International Institute of Seismology and Earthquake Engineering (IISEE) of Japan acts as the Centre of Excellence for this Platform.

In addition, UNESCO has been jointly carrying out workshops to promote programmes for reducing earthquake losses, in cooperation with the U.S. Geological Survey (USGS) and earthquake science organizations in regions such as the Mediterranean and South Asia. Together, these are known as the Programme on Reducing Earthquake Losses in the Enlarged Mediterranean Region (RELEMR) and the Programme on Reducing Earthquake Losses in the South Asia Region (RELSAR). UNESCO has also established a similar programme in the northeast Asia region. These workshops provide a forum for international scientists and engineers from diverse political contexts to work together under the UNESCO umbrella and discuss regional approaches to improve collaboration on earthquake data exchange and analysis.

IPRED'S BACKGROUND

Buildings, and especially housing, should protect people from natural disasters. When buildings are damaged by earthquakes, the impact on occupants' lives is enormous. Damage to buildings caused by disasters can also seriously hinder relief and recovery efforts. For example, major hospitals and other facilities may be unable to function, roads may be blocked by wreckage, and there may be massive flows of refugees.

In January 2005, the United Nations World Conference on Disaster Reduction (WCDR) was held in Kobe, Japan, and adopted the Hyogo Framework for Action (HFA) 2005–2015: Building the Resilience of Nations and Communities to Disasters. One of the conference sessions discussed improving the safety of buildings and housing as a basic and vital priority for the world's disaster reduction efforts. This led to a proposal for the introduction of a Building Disaster Reduction Network.

Such a network is especially necessary in the field of earthquakes to activate and share data on each country's invaluable experience, as it is difficult for a single country to experience and verify the effects of measures. As Japan has experienced many large earthquakes since ancient times, earthquake disaster reduction has been researched and studied quite extensively there. UNESCO has recognized and supported Japanese efforts and expertise in earthquake risk reduction.

In 1960, the Government of Japan launched international training courses on seismology and earthquake engineering. In 1962, UNESCO participated in a joint venture with the Building Research Institute (BRI) of Japan, and the Government of Japan established the IISEE. Since then, the IISEE has conducted international training courses on seismology and earthquake engineering for researchers and engineers from foreign countries. UNESCO provided financial support for the training courses from 1963 to 1972.

Since 2005, the training has been carried out as the Master Program on Earthquake Disaster Mitigation at the National Graduate Institute for Policy Studies (GRIPS) of Japan. In 2006, UNESCO provided supporting funds and today, the training is also supported by the Japan International Cooperation Agency (JICA). Since 1960, more than 1,400 researchers and engineers have graduated from the course (Figure 11).

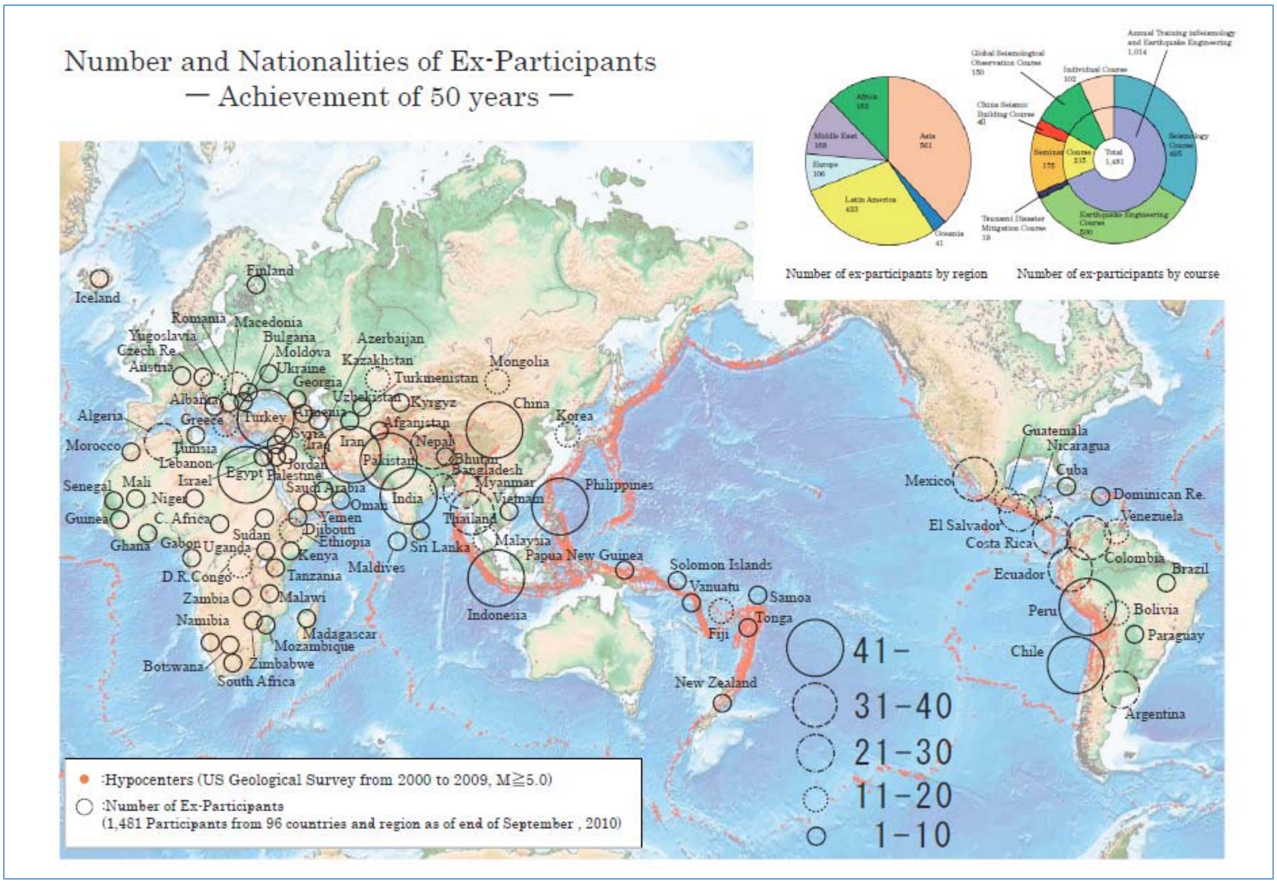

Figure 11 Worldwide alumni of UNESCO-supported IISEE training courses

ESTABLISHMENT OF IPRED (http://www.ipred-iisee.org/)

Against this background, and in order to address policy-relevant issues related to earthquake risk reduction and better prepare for future earthquakes in the world, UNESCO and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan, in cooperation with the Building Research Insitute (BRI) of Japan, agreed to promote and expand an international platform regarding earthquakes, including a research and training platform for earthquake disaster reduction based on seismology and earthquake engineering.

Figure 12 Kickoff meeting (Tokyo, June 2007)

The kickoff meeting for this initiative was held in June 2007 in Japan, jointly organized by UNESCO, MLIT and BRI, and supported by the Japanese National Commission for UNESCO, the Ministry of Foreign Affairs of Japan and other related organizations. The meeting was attended by representatives of UNESCO Headquarters and nine countries (Chile, Egypt, Indonesia, Japan, Kazakhstan, Mexico, Peru, Romania and Turkey), to share experiences from JICA projects regarding earthquake disaster reduction in the past and related organizations (Figure 12).

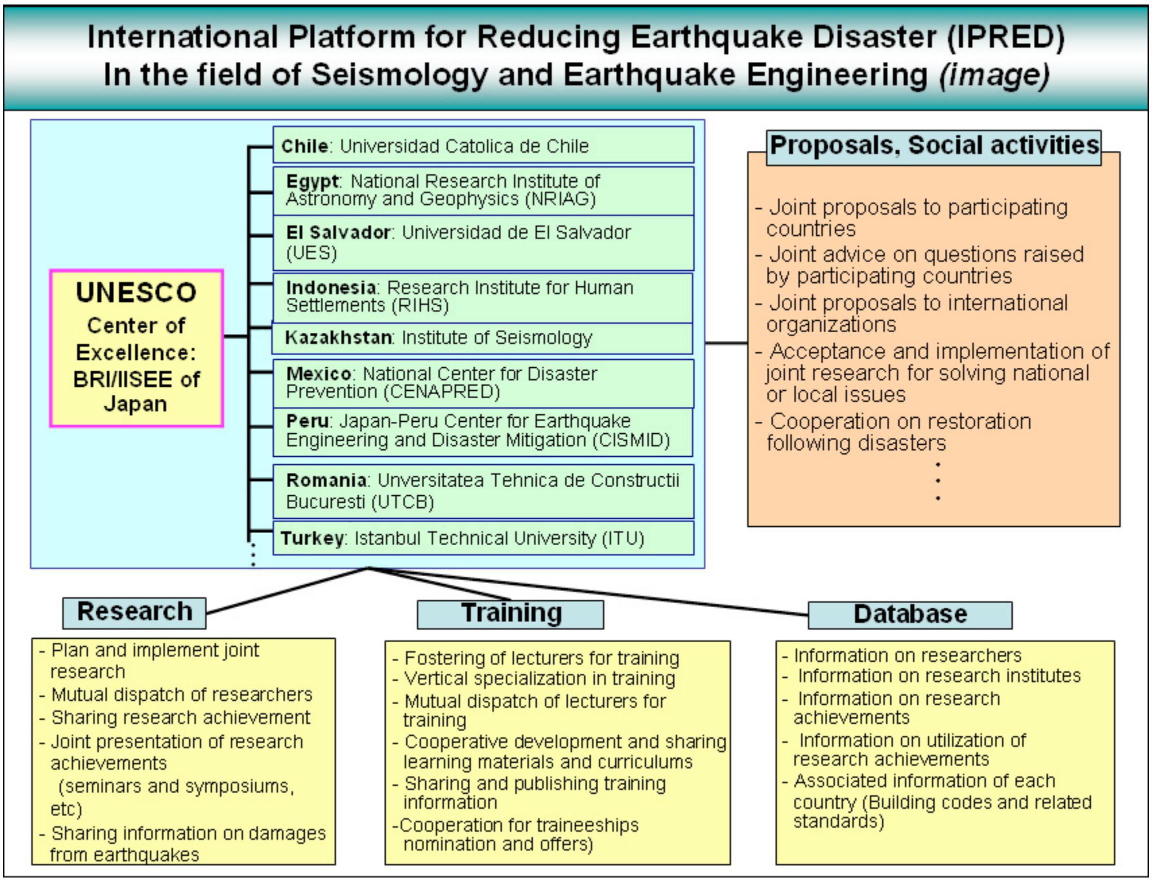

Figure 13 IPRED activities

At the end of the kickoff meeting, participating members adopted resolutions including the establishment of an international platform to promote earthquake risk reduction of buildings. The formal name of this initiative was later agreed as the International Platform for Reducing Earthquake Disasters (IPRED) (Figure 13).

The first IPRED meeting was held in July 2008 at the UNESCO Headquarters in Paris. The meeting was attended by representatives of nine earthquake-prone countries (Chile, Egypt, Indonesia, Japan, Kazakhstan, Mexico, Peru, Romania, and Turkey) as well as a guest expert from a Chinese university and several observers from the Permanent Delegations to UNESCO. At the meeting, quick reports and lessons learned from recent devastating earthquake disasters were shared, and an action plan was discussed. Participants suggested holding the second IPRED session in Istanbul, Turkey, in July 2009, inviting local government and policy-makers to a workshop, and this proposal was welcomed with a general round of applause (Figures 14–17).

Figure 14 Mr Koïchiro Matsuura, former Director-General of UNESCO, launches IPRED

Figure 15 The first IPRED session (Paris, July 2008)

> "Natural disasters, including earthquakes, do not recognize geographical borders. Knowledge about earthquakes must be shared for the benefit of all."
>
> Mr Koïchiro Matsuura, former Director-General of UNESCO, during the first IPRED session

IPRED'S MISSION AND OBJECTIVES

IPRED's mission is to identify gaps and priorities through the sharing of scientific knowledge and experience in the field of seismology and earthquake engineering, and to promote the development of political will and public awareness to ensure better earthquake preparedness and a culture of safety for people around the world.

IPRED's main objectives are as follows:

(a) Exchange information and propose plans for collaborative research, training and education on seismology and earthquake engineering, in order to reduce earthquake disasters, especially linked to buildings and housing
(b) Address policy-relevant issues related to the reduction of earthquake disaster risks and implementation of the Hyogo Framework for Action, including making recommendations on priorities in the International Strategy for Disaster Reduction (ISDR) system

(c) Establish a system to dispatch experts to earthquake-stricken countries to carry out post-earthquake field investigations and draw lessons for future risk reduction, using the worldwide alumni network of IISEE international training
(d) Support and cooperate with the IISEE in its activities including implementation of international training courses on seismology and earthquake engineering aimed at reducing earthquake disasters
(e) Propose and organize specific enquiries in seismology and earthquake engineering to investigate and address priority matters to governments and regional or international communities
(f) Advise IPRED members on scientific and technical issues regarding seismology and earthquake engineering
(g) Assist and coordinate scientific and technical activities within the ISDR system, including initiatives of the ISDR Global Task Force on Building Codes coordinated by UNESCO

IPRED ACTION PLAN

IPRED's action is based on 15 main action points:

1 Develop a database to contribute to field investigations (anti-seismic performance, etc.) (http://www.ipred-iisee.org/database/)
2 Establish a system for post-earthquake field investigations
3 Develop an educational materials database (for e-learning, etc.)
4 Promote international joint research programmes
5 Promote international cooperation with universities
6 Promote the sharing of engineering data on structural testing, soil properties, etc.
7 Promote a ground-motion observation network and data sharing
8 Train trainers through IISEE follow-up training and workshops, etc.
9 Develop the portal website (http://www.ipred-iisee.org/)
10 Establish the IISEE–UNESCO Lecture Notes Series (http://iisee.kenken.go.jp/lna/)
11 Develop microtremor array exploration techniques
12 Disseminate activities through international and/or regional events related to seismology or earthquake engineering
13 Plan international workshops to raise awareness of IPRED
14 Disseminate information through printed materials
15 Translate building codes into other languages

Figure 16 The second IPRED session (Istanbul, July 2009)

Figure 17 Agreement signed between the BRI of Japan and NCSRR of Romania

IPRED POST-EARTHQUAKE FIELD INVESTIGATION

One of IPRED's most important objectives is to establish a system for post-earthquake field investigation. It is recommended that, before major earthquakes occur, UNESCO and IISEE as the IPRED Centre of Excellence prepare a register of names and email addresses of members who may be able to cooperate with and/or participate in post-earthquake field investigations. Initially, it would be a good idea to use the global network of IISEE international training alumni (Figure 18).

Based on the IPRED action plan, UNESCO and IISEE have developed the database to contribute to post-earthquake field investigations through building codes, materials, guidelines, etc. and this database is being upgraded. (http://www.ipred-iisee.org/database/)

When a major earthquake occurs, UNESCO and IISEE should gather information on its magnitude and damage, and dispatch the information to registered members by Internet and/or emails. If a post-earthquake field investigation is deemed necessary, UNESCO and IISEE will promptly establish a field investigation team in cooperation with registered members.

Some key criteria to establish the need for a field investigation would include the following:

(a) Severe damage to many engineered buildings or characteristic damage to non-engineered buildings
(b) Lessons on seismology and/or earthquake engineering regarding plans, designs and construction works can be obtained
(c) No major public safety issues for carrying out a field investigation

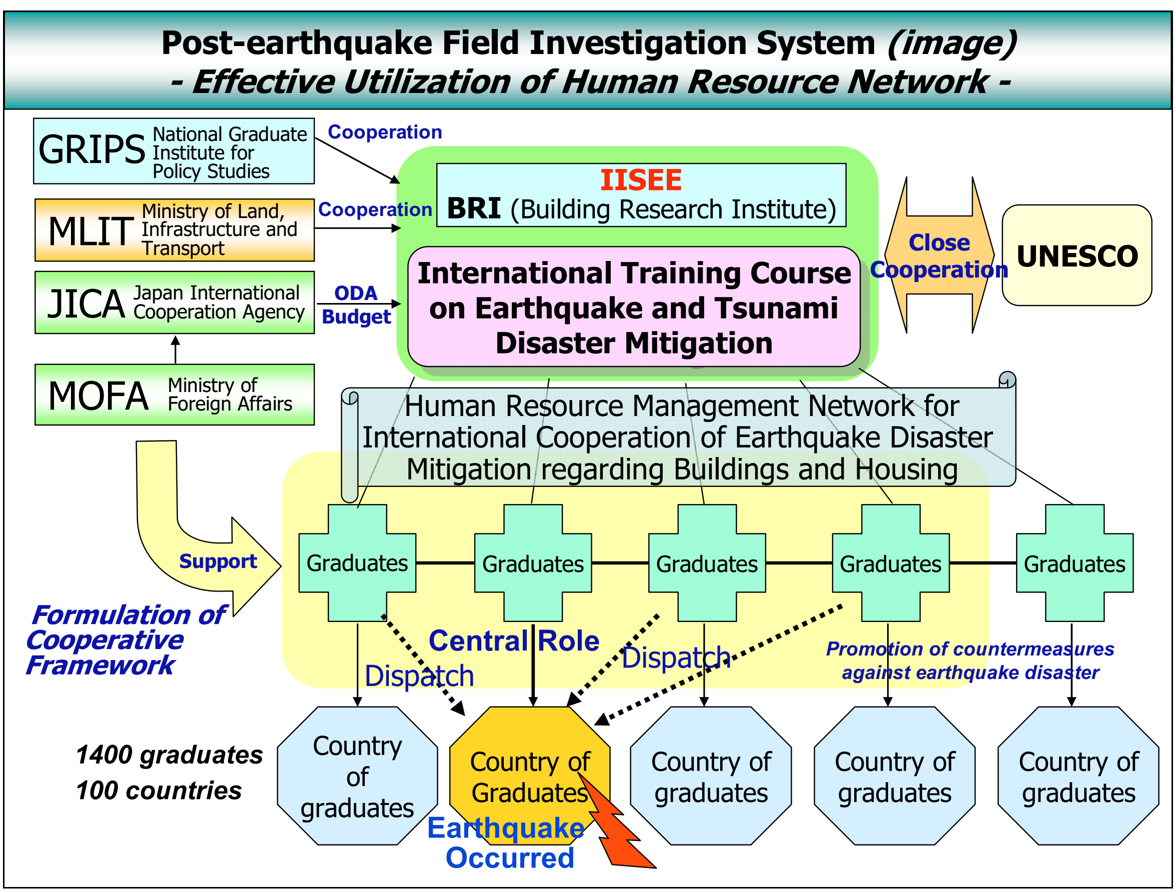

Figure 18 IPRED's post-earthquake field investigation system

It is important to synthetically take into account widely distributed construction methods, languages, customs and livelihoods in earthquake-stricken areas as well as any potential difficulties in carrying out a field investigation, such as humanitarian issues. In order to carry out a field investigation as effectively and efficiently as possible and avoid disturbing victims or rescue teams in the earthquake-stricken area, there should not be too much overlap with field investigation teams dispatched by other organizations.

In order to take effective action, it is also necessary to develop field investigation manuals. The primary aim of field investigations would be to evaluate the overall damage to buildings and record such information for academic/ scientific purposes. It would be difficult to carry out a detailed examination and/or provide advice on seismic retrofitting, etc. for a specific building during these investigations. However, a contribution could be made to the earthquake-stricken area later on, by reporting to local governments on results of the field investigation, advising on a future reconstruction plan, introducing state-of-the-art knowledge and technology, and so on.

After field investigations, UNESCO should post a quick report on its website. Depending on the situation, UNESCO may, for example, plan a meeting on the quick report or publish the field investigation results.

In principle, each member of the investigation team should cover his or her own travel expenses. However, UNESCO will facilitate funding through its own programme and budget or by mobilizing extrabudgetary resources, depending on availability. At the request of the field investigation team, UNESCO will consider supporting all or part of the expenses within the limits of its budget and depending on the situation. UNESCO may also offer convenience to members, including requesting prompt authorization of visas to the affected county and other arrangements with the relevant local organizations.

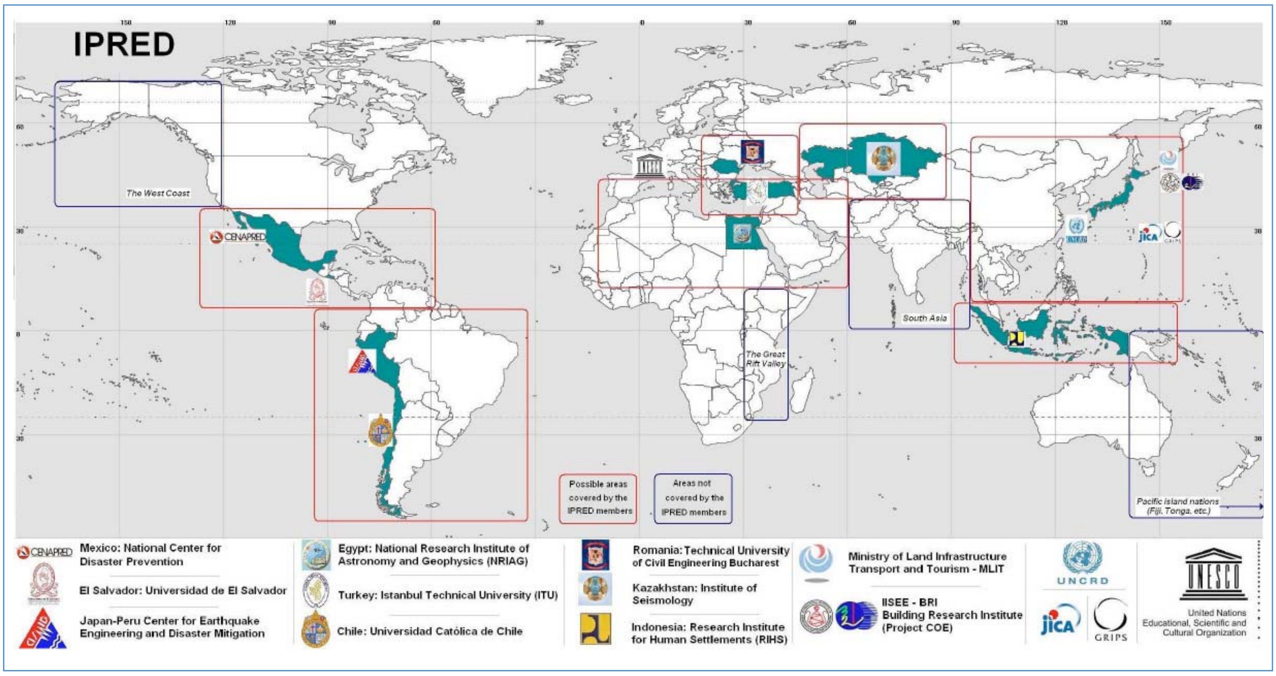

Figure 19 Possible regional network for the IPRED programme

When a foreign government dispatches a field investigation team to the country affected by a major earthquake, it is common procedure for that country's government to first make an official request to the foreign government through its diplomatic establishments. Such a request may not run smoothy, however, in the wake of an earthquake.

On the other hand, there may be no common formal procedure when a non-governmental foreign organization such as an academic society dispatches a field investigation team to a country affected by a major earthquake. It may not be easy for these team members to obtain the relevant visas.

Therefore, UNESCO as a United Nations organ proposes to make prior arrangements with related governments and organizations to facilitate post-earthquake field investigations.

During the third IPRED session in Padang, Indonesia in July 2011, the Letter of Intent (LoI) between the Research Institute for Human Settlements (RIHS) and UNESCO in cooperation with IISEE concerning cooperation for reducing earthquake disaster risks and post-earthquake field investigations was signed during the workshop's closing ceremony. This was a significant first step in cooperation on post-earthquake field investigation, and similar agreements should be signed between UNESCO and each key IPRED member institute or university in cooperation with IISEE (Figures 20–21).

Figure 20 The third IPRED session (Padang, July 2010)

Figure 21 The Letter of Intent signed between RIHS and UNESCO in cooperation with IISEE

EDUCATION FOR DRR AND SUSTAINABLE DEVELOPMENT (INCLUDING SCHOOL SAFETY)

The dramatic increase in human and economic losses from disasters in recent years is alarming (Figures 22–25). In particular, natural disasters often hit hardest some of the world's poorest communities, which are the most poorly placed to protect themselves or recover afterwards. While natural hazards are not a new phenomenon, sadly they tend to attract attention only when they become disasters. Reducing and mitigating disaster risk is still low on many governments' agendas despite the ample available body of knowledge and know-how on assessing natural hazards and reducing their impact.

A major shift in focus is required from disaster response to disaster prevention. More than ever, the implementation of the Hyogo Framework for Action is critical for pursuing a substantial reduction in disaster losses. Operating as it does at the interface between education, science, social sciences, culture and communication, UNESCO is committed to playing a vital role in building a global culture of disaster resilience.

Figure 22 Collapsed junior high school buildings in Yingxiu (© 2008 T. Imamura)

Figure 23 School building (left) raised 2 m by the fault in Bailu (© 2008 T. Imamura)

Figure 24 Heavily damaged hospital surrounded by debris in Hanwang (© 2008 T. Imamura)

Figure 25 Collapsed elementary school buildings in Beichuan (© 2008 T. Imamura)

For decades, UNESCO has been actively engaged in the study of natural hazards and building capacities to mitigate their effects. As an active partner in the International Strategy for Disaster Reduction (ISDR), UNESCO promotes international and regional networks of systems and expertise for the monitoring, exchange and analysis of hazards data, and in particular data related to earthquakes, tsunamis, floods, droughts and landslides.

As a United Nations specialized agency with "education" inscribed in its name, UNESCO is also concerned with education and disaster risk reduction, as well as the protection of educational buildings and cultural monuments and sites in hazard-prone areas. It is an intrinsic element of the UNESCO-led United Nations Decade of Education for Sustainable Development (UN DESD). The decade proposes a vision of education addressing issues related to the environment, democracy, the economy, human rights, culture, parity, etc. through a transdisciplinary approach.

The decade will promote:

- Education that empowers people to commit to sustainability, transforming people into responsible citizens with creative and critical thinking and other skills: oral and written communication, collaboration and cooperation, conflict management, decision-making, problem-solving and planning using appropriate information and communication technologies (ICTs)
- Education that fosters responsible citizens and promotes democracy by allowing individuals and communities to enjoy their rights and fulfill their responsibilities, and to learn to live together in peace and tolerance
- Education at all levels of education systems and in all social contexts (family, school, workplace and community)

Hyogo Framework for Action 2005-2015 – *Building Resilient Communities*

- Policy and Governance;
- Risk identification, assessment, monitoring and early warning;
- Knowledge management and education;
- Reducing underlying risk factors;
- Preparedness for effective response and recovery.

Figure 26 HFA priorities

UN-ISDR
(International Strategy for Disaster Reduction)
Thematic Platform on Knowledge and Education
UNESCO is one of the active agencies

- Creation of a forum to exchange knowledge;
- Dissemination of good practices and examples;
- Mainstreaming of disaster risk reduction into school curricula and school safety.

Figure 27 UN-ISDR Thematic Platform on Knowledge and Education (TPK&E)

UNESCO cannot achieve these objectives alone and acts within a network of UN agencies, inter-governmental groups, and non-governmental or civil society organizations coming together as ISDR. In this sense, UNESCO serves as the convener of the UN multi-stakeholder platform concerned with knowledge and education for disaster reduction (Figures 26–29).

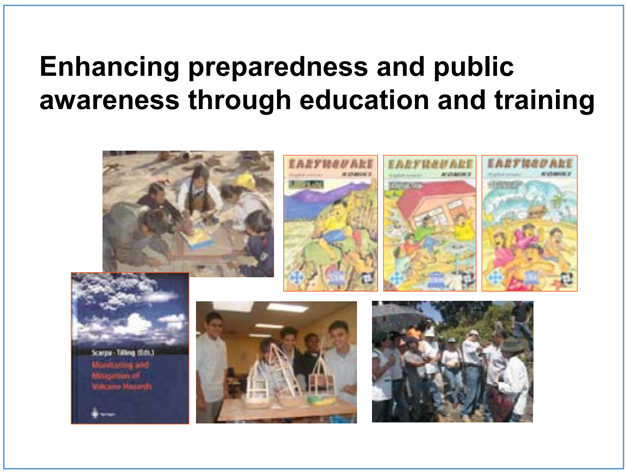

Figure 28 Promotion of education and training

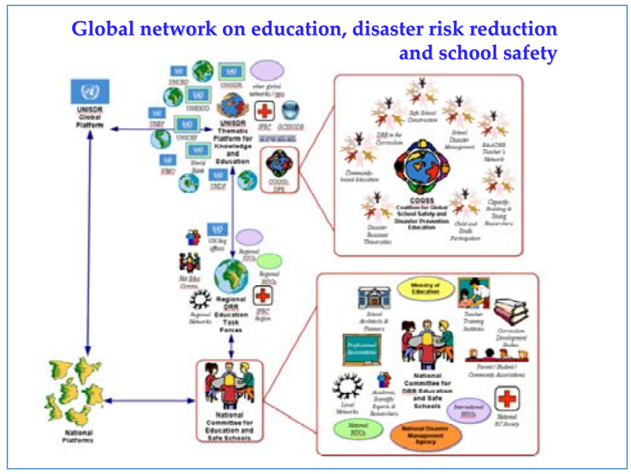

Figure 29 Global network on DRR education and school safety (http://cogssdpe.ning.com/)

GLOBAL PLATFORM FOR DISASTER RISK REDUCTION (GPDRR)

In June 2007, the first session of the Global Platform (GP) for Disaster Risk Reduction was held in Geneva to assess and implement the HFA. The GP takes place every two years, providing a global forum for accelerating worldwide momentum on disaster risk reduction. As the primary gathering for the world's disaster risk community, it brings together governments, UN agencies, international regional organizations and institutions, non-governmental organizations, scientific and academic institutions and the private sector. In line with the United Nations General Assembly (A/RES/62/192), the GP's purpose is to:

(a) Assess progress made in implementing the Hyogo Framework for Action
(b) Enhance awareness of disaster risk reduction
(c) Share experience and best practices
(d) Identify gaps and recommend targeted action to accelerate national and local implementation

During one of the GP side events in 2007, the importance of enforcement, implementation and dissemination of building codes was highlighted (Figure 30). As a result, the introduction of an ISDR Global Task Force on Building Codes was proposed (initially known as the Taskforce Group on Building Codes), with UNESCO offering to act as the secretariat (http://www.ipred-iisee.org/gtfbc/).

Figure 30 GP side event in 2007

Figure 31 GP special event in 2009

The second session of the GP was held in June 2009 in Geneva, witnessing a dramatic increase in political will to manage disaster risk compared to the first session in 2007 (Figures 31–33). Many tools and successful pilot projects exist, but the main challenge is to scale up these actions and systematically modify development programmes and budgeting to reduce risk in all sectors. Crucial aspects to tackle are increasing urban risk and depleted ecosystems, coupled with the role of local governments and local partnerships in addressing these issues and transforming policies and knowledge into concrete actions.

The benchmarks set out in the Chair's summary of the second session in 2009 have served as a basis for the agenda of the third session in May 2011. It focused on five main areas:

1. Urgently harmonizing frameworks for both disaster risk reduction and climate change adaptation in the broader context of poverty reduction and sustainable development
2. Reducing risk at the community and local levels, through collaborative partnerships based on recognition of the mutual dependence of central/local governments and civil society actors, and promotion of the role of women as drivers of action, with special consideration to the roles of children and youths
3. Moving from isolated actions and pilot projects to full implementation of the Hyogo Framework for Action, with the GP proposing targets in specific areas, including national assessments of the safety of existing education and health facilities to be undertaken by 2011, and concrete action plans for safer schools and hospitals to be developed and implemented in all disaster-prone countries by 2015
4. Scaling up action and funding from national budgets and international sources with significant support for targeting the equivalent of 10 per cent of humanitarian relief and recovery expenditure, and at least 1 per cent of all national development and development assistance funding for risk reduction measures, as well as starting to measure the effectiveness of investments in risk reduction
5. Acknowledging the important role of the strategy system in supporting governments and civil society organizations, considering that the planned mid-term review of the Hyogo Framework for Action would require ownership by governments, the close involvement of civil society and strengthened regional capacities for coordination and support

Figure 32 Second GP session

Figure 33 2009 Global Assessment Report on Disaster Risk Reduction

Within the third area, specific targets were proposed as catalysts for reducing the deaths and economic losses brought on by disasters (Figure 34):

1. By 2011, a global structural evaluation of all schools and hospitals should be undertaken, and by 2015 concrete action plans for safer schools and hospitals should be developed and implemented in all disaster-prone countries. Similarly, disaster risk reduction should be included in all school curricula by 2015.
2. By 2015, all major cities in disaster-prone areas should include and enforce disaster risk-reduction measures in their building and land-use codes.

This Chair's Summary was based on the message by the UN Secretary-General, Mr Ban Ki-moon, calling for a target to halve the loss of lives from disasters by 2015, the closing year of the Hyogo Framework for Action.

GLOBAL PLATFORM ENDS WITH CALL TO HALVE DISASTER RELATED DEATHS BY 2015

<<TARGET>>

- By 2011, a global structural evaluation of all schools and hospitals
- By 2015, concrete action plans for safer schools and hospitals developed and implemented in all disaster-prone countries, and DRR included in all school curricula
- By 2015, all major cities in disaster-prone areas to include and enforce DRR measures in their building and land use codes

Figure 34 Target proposed in the Chair's Summary

The next World Campaign (2010-2011) « Making Cities Resilient»

- Building codes may be the weakest link.
- This is not about the technical issues; This is about how the importance of investing for safer buildings is understood and carried out by decision-makers, communities and citizens.

"People check the brake before buying and driving a car; Why not for our houses, schools, hospitals, churches and other buildings to make sure they can withstand potential hazards?" *(Mr. Salvano Briceño, Director of UN/ISDR Secretariat)*

Figure 35 World Campaign for Making Cities Resilient (2010–11)

Under the ISDR system, efforts have been made to raise awareness of and commitment to sustainable development practices as a means to reduce disaster risk and increase the wellbeing and safety of citizens, with "Invest Today for a Safer Tomorrow" as a slogan. The World Campaigns for Safer Schools (2006–07) and Hospitals (2008–09) have been promoted, but many tasks still need to be carried out. The current two-year World Campaign (2010–11) is focused on making cities resilient or raising awareness of the benefits of sustainable urbanization in reducing disaster risk (Figure 35).

The campaign seeks to engage and convince city leaders and local governments to commit to a checklist of *Ten Essentials for Making Cities Resilient* and to work on these together with local organizations, grassroots networks, the private sector and national authorities. UN/ISDR and its partners have developed this non-exhaustive checklist as a starting point for all those wishing to join in the campaign. Equally important is that commitment to these *Ten Essentials* will empower local governments and actors to implement the Hyogo Framework for Action. Making cities more resiliant to disaster requires sustainable urbanization. When successfully implemented, resilient cities help reduce poverty and provide for growth and employment, more social equity, business opportunities, balanced ecosystems, better health and improved education.

The *Ten Essentials* also include the enforcement of building codes as well as DRR education and school safety issues. IPRED should naturally help advocate this initiative, which is perfectly in line with IPRED objectives.

GLOBAL TASK FORCE ON BUILDING CODES (GTFBC)

Coordinated by UNESCO, the GTFBC consists of worldwide experts in the field of building codes and practices. These include UN agencies (UNCRD, UNDP, UNESCO, UN-HABITAT, UNICEF, UN-ISDR, UN-OCHA, UNU, World Bank, etc.), international organizations and non-governmental organizations (ADPC, ADRC, Build Action, COGSS-DPE, DWF, EERI, EMI, IAEE, IAWE, ICC, IFRC, IG-WRDRR, INEE, Plan, RICS, Risk Red, etc.), national governments and institutions, universities, building officials, architects, engineers and seismologists.

Building codes already exist in most disaster-prone countries, but the biggest challenge is how to enforce, implement and disseminate them. The issue is not only technical, but more importantly, how to explain our scientific knowledge so that it is understood by policy-makers and non-scientific communities.

Figure 36 Materials, etc. gathered after the Haiti earthquake

Don't just wait for disaster
By Ban Ki-moon (24 March, 2010)

- No country can afford to ignore the lessons of the earthquakes in Chile and Haiti.
- (Chile) Because stringent earthquake building codes were enforced, much worse casualties were prevented.
- (Haiti) Had nonexistent or unenforced building codes, and very poor preparedness.
- In flood and earthquake-prone areas, the solution is to enact and enforce building regulations.
- The Chile and Haiti earthquakes showed us once again why action before disasters makes all the difference. To prevent natural hazards turning into disasters, we must all act sooner and act smarter.

Figure 37 "Don't just wait for disaster" by the UN Secretary General

As a group of experts in seismology and earthquake engineering, with skills in buildings and housing, IPRED has greatly contributed to GTFBC discussions. After the Haiti earthquake in January 2010, IPRED members contributed to the GTFBC by gathering a number of useful materials, guidelines, etc. to be used for the reconstruction of safer buildings and houses in Haiti, and supported efforts made by the Shelter Cluster in Haiti (Figure 36).

In his article entitled "Don't just wait for disaster" in March 2010, the UN Secretary General, Mr Ban Ki-moon mentioned that no country can afford to ignore the lessons learned from the earthquakes in Chile and Haiti. In Chile, much worse casualties were prevented by stringent earthquake building codes being enforced. On the other hand, Haiti had nonexistent or unenforced building codes and very poor preparedness. In flood and earthquake-prone areas, the solution is to enact and enforce building regulations. The Chile and Haiti earthquakes showed us once again why action before disasters makes all the difference. To prevent natural hazards turning into disasters, we must all act sooner and smarter (Figure 37).

The GTFBC session will continue from the 2009 GP outcome of establishing a global network and general resource database, by setting objectives for mapping existing codes, standards resources and compliance activity, and identifying gaps. The Task Force will advocate the establishment of working groups and action plans for the future.

CONCLUDING REMARKS

Bringing together a group of experts on seismology and earthquake engineering with expertise in buildings and housing, UNESCO's IPRED programme has an important mission and great potential to contribute by promoting objectives including the following:

(a) Exchange information and propose plans for collaborative research, training and education on seismology and earthquake engineering in order to reduce earthquake disasters, especially in terms of buildings and housing
(b) Address policy-relevant issues related to reducing earthquake disaster risk and implementing the Hyogo Framework for Action, including making recommendations on priorities within the International Strategy for Disaster Reduction (ISDR) system
(c) Establish a system to dispatch experts to earthquake-stricken countries to carry out post-earthquake field investigations and learn lessons for future risk reduction through a worldwide network of IISEE international training alumni

Building codes already exist in most disaster-prone countries, but the biggest challenge is how to enforce, implement and disseminate them, as they can save lives. The issue is not only technical but more importantly how to translate our scientific knowledge so that it can be understood by policy-makers and non-scientific communities.

International initiatives such as the World Campaign on Making Cities Resilient (2010–11) are perfectly in line with IPRED objectives. IPRED can and should contribute to the creation of a safer built environment worldwide.

We need to act now and should not just wait for disasters!

ACKNOWLEDGEMENTS

As a project coordinator at UNESCO when the IPRED workshop was held in Padang in July 2010, I wish to extend my heartfelt gratitude to all the participants of the workshop, meeting and field trip, especially my colleagues at the Research Institute for Human Settlements (RIHS), the Ministry of Public Works and the Provincial Government of West Sumatra for their great efforts in organizing this successful event. I would also like to thank the Japan International Cooperation Agency (JICA) for their support on this project.

I would also like to take this opportunity to convey my sincere thanks to the IPRED members and all the Japanese supporters, including the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), the Building Research Institute (BRI), the International Institute of Seismology and Earthquake Engineering (IISEE), the Building Center of Japan (BCJ), the Center for Better Living (CBL), the Japan Building Disaster Prevention Association (JBDPA) and all other colleagues and friends who have kindly offered support and advice for this project.

Finally, I would like to express my sincere gratitude to our Director, Mr Badaoui Rouhban, for his warmhearted guidance and advice throughout my duties in Paris; without his support, the IPRED programme would not have become a reality. I also wish to thank my former UNESCO colleagues, Ms Kristine Tovmasyan, Ms Aïssatou Gakou, Ms Brigitte Sartre and Mr Jair Torres, for their great support and friendship. And of course, I wish to thank Mr Yasuo Katsumi, my successor and best friend, from the bottom of my heart for his efforts in expanding the IPRED programme for the purpose of ensuring better preparation against earthquakes and building a culture of safety for the people around the world.

Figure 38 Participants of the IPRED workshop in Padang in July 2010

AN IISEE–BRI GLOBAL CATALOGUE OF RECENT LARGE EARTHQUAKES: FROM SEISMOLOGISTS TO EARTHQUAKE ENGINEERS

N. Hurukawa and T. Hara

International Institute of Seismology and Earthquake Engineering (IISEE),
Building Research Institute (BRI), Japan
Email: hurukawa@kenken.go.jp, thara@kenken.go.jp

EARTHQUAKE INFORMATION

The International Institute of Seismology and Earthquake Engineering (IISEE) has started a project to determine the following earthquake information for recent large (7.2 Mw) earthquakes worldwide using analytical techniques developed by IISEE staff members and visiting researchers:

1. Centroid moment tensor (CMT)

Centroid moment tensors are determined by analyzing long-period body wave data recorded at Global Seismological Network (GSN) stations.

1.1 Period: 1994 – January 2009
1.2 Analytical method: grid search approach by Hara (2004, 2005)
1.3 Principal Investigator: Tatsuhiko Hara, IISEE (emai: thara@kenken.go.jp)

2. Aftershock distribution and corresponding fault plane

Aftershocks, including a main shock and foreshocks, are relocated using P-wave arrivals from International Seismological Centre (ISC) CD-ROMs. The corresponding fault plane is then determined based on the obtained aftershock distribution (nodal planes are taken from the Global CMT catalogue).

1.1 Period: 1994–2005
1.2 Analytical method: modified joint hypocentre determination method (MJHD. Hurukawa and Imoto, 1992; Hurukawa, 1995; Hurukawa et al., 2008)
1.3 Principal Investigator: Nobuo Hurukawa, IISEE (email: hurukawa@kenken.go.jp)

3. Rupture process

Earthquake rupture processes are determined by analyzing broadband waveform data recorded at GSN stations. The above aftershock analyses are used to set up earthquake fault planes.

1.1 Period: January 1994 – October 2004
1.2 Analytical method: waveform inversion considering covariance components in inversion analyses of densely sampled observed data by Yagi and Fukahata (2008)
1.3 Principal Investigator: Yuji YAGI, Tsukuba University/IISEE visiting researcher (Email: yagi-y@geol.tsukuba.ac.jp)

Please visit the following website:
http://iisee.kenken.go.jp/eqcat/Top_page_en.htm

STRONG GROUND-MOTION SIMULATION

We developed software to perform strong ground motion simulation for seismic bedrock using the stochastic Green function method (Onishi and Horike, 2000). In addition, we are implementing a function to export earthquake source parameters in the IISEE earthquake catalogue to calculate intensities, peak ground velocity (PGV) and peak ground acceleration (PGA)using attenuation relations.

WEB INTERFACE

A database has been created using U.S. Geological Survey (USGS) moment tensor (MT) solutions, Global CMT solutions, and International Seismological Centre (ISC) aftershock distributions, etc. from the IISEE earthquake catalogue. The search page for this catalogue is available at http://iisee.kenken.go.jp/cgi-bin/eqcatalog/eqcatalog2_eng.cgi.

A Keyhole Markup Language (KML) file is provided, showing the earthquakes registered in the catalogue on Google Earth and the corresponding earthquake information.

SPECIAL PAGES

When large and/or damaging earthquakes occur, we post special pages on those events on the IISEE web site, presenting information such as aftershock distributions, tsunami simulations and seismic design codes (http://iisee.kenken.go.jp/quakes.htm).

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SAFETY ISSUES REGARDING RECONSTRUCTED BUILDINGS IN ACEH, INDONESIA

K.Okazaki,[1] K.Pribadi,[2] D.Kusumastuti,[3] T.Boen[4] and S.Ando[5]

[1] Professor, National Graduate Institute for Policy Studies, Japan
Email: okazakik@grips.ac.jp

[2]Associate Professor, Institute of Technology, Bandung, Indonesia
Email: ksuryanto@si.itb.ac.id

[3]Researcher, Institute of Technology, Bandung, Indonesia.
Email: dkusumastuti@si.itb.ac.id

[4]Senior Advisor, World Seismic Safety Initiative, Indonesia
Email: tedboen@cbn.net.id

[5]Director, IISEE, Building Research Institute, Japan
Email: ando@kenken.go.jp

ABSTRACT

The 2004 tsunami and earthquake devastated Aceh, Indonesia. Approximately 125,000 people were killed, 95,000 went missing and more than 600,000 were displaced. Given that Aceh Province is one of most earthquake-prone areas in Indonesia; the goal of rebuilding a safer Aceh should be pursued. This research was conducted in 2006 to investigate current building capacity and practices and analyze the quality of reconstructed buildings, mostly non-engineered houses. The objectives were (1) to investigate and assess the current capacity and building practices of various actors in the ongoing reconstruction process, focusing on the vulnerability of houses, and (2) to develop recommendations for technological interventions to prevent unsafe practices in building construction. Several important findings were obtained from this study. The survey on planning and design aspects shows that improvements are needed for reconstruction efforts to match the needs and demands of communities. The study found that proper seismic design should be ensured to avoid severe damage from future earthquakes, and materials used in reconstruction projects should be improved to meet the minimum standards specified in building codes. In addition, the quality of workmanship should be improved to reduce the vulnerability of structures, and projects should be well managed and supervised to ensure that building components work together together to form an integrated structure.

KEYWORDS

Aceh, reconstruction, houses, earthquake safety

INTRODUCTION

Background

The 26 December 2004 Indian Ocean earthquake followed by a killer tsunami caused terrible losses in the region. In particular, the Nangroe Aceh Darussalem (NAD or Aceh) Province suffered the loss of more than 100,000 lives and the destruction of many economic and social infrastructures, including more than 200,000 houses. In all, more than 400,000 people lost their homes and jobs.

The most serious destruction faced in Aceh was the damage to houses and school buildings, due to the large numbers of buildings affected and the impact on people's lives after the disaster. (Houses reflect people's a standard of living, while and school buildings impact children's education. Reconstruction efforts are underway to repair, rehabilitate and rebuild housing, schools and other infrastructures, in recognition of the extensive support from many local, national and international donors.

As a highlight of the ongoing reconstruction process, the quality of buildings should be considered a major issue, along with the large quantity of structures that need to be built in the region. Given that the geological and seismological conditions of Aceh Province make it one of Indonesia's most earthquake-prone areas, the goal of "Rebuilding a Safer Aceh" should be established to characterize every reconstruction effort in the province.

To improve the future safety of Aceh communities and minimize the vulnerability of newly reconstructed buildings and infrastructures to earthquakes, it is very important to ensure that all building and construction regulations are followed. With the large amount of ongoing reconstruction projects and the limited time frame, the quality of buildings and infrastructures could become a secondary concern, thus compromising the safety of buildings in terms of their earthquake resistance. Improved construction processes may need to be developed and implemented to reduce the vulnerability of newly reconstructed facilities and, more importantly, to avoid a recurrence of building and infrastructure failure. Therefore, current building skills and practices need to be investigated and the quality of the structures analyzed. Based on this analysis, recommendations are put forward for improving the quality of buildings and infrastructures, especially houses and school buildings, to ensure safer communities in the event of earthquakes and tsunamis.

Building damage situation and recovery stage

The destructive earthquake and tsunami left an enormous number of casualties and a vast area of damaged structures and infrastructures in NAD Province and the neighbouring North Sumatra Province. The latest report from Satkorlak Banda Aceh on 2 March 2005 shows that in NAD Province alone, 124,946 people were killed, 94,994 were reported missing and more than 600,000 people were displaced from their homes. It should be pointed out, however, that most of the damage was caused by the impact of the tsunami, the most devastating ever on record. The earthquake itself caused severe damage to buildings that were not designed and constructed in accordance with the prevailing code.

The report of damage to housing and infrastructures also paints a grim picture of destruction. Considering the information on buildings before and after the earthquake for each city or county in the NAD and North Sumatra provinces, almost 40 per cent of buildings were totally or partially damaged, with a staggering 300,000 houses in need of reconstruction and/or rehabilitation.

The need to reconstruct buildings and houses can also be appreciated through the following figures (Source: 6-Month BRR Information Sheet):

- 116,880 housing units were destroyed out of a total of 820,000, while about 152,000 housing units (19 per cent) suffered damage estimated at over 50 per cent of their value. The damage was concentrated within a 3.2–6.4 km zone along the coast, with most of the destruction affecting 80 per cent of the housing stock in Kota Banda Aceh, Aceh Jaya, Aceh Besar, Kota Sabang and Aceh Jaya.
- 2,135 schools were partially or totally damaged and about 2,500 teaching and non-teaching staff were killed by the tsunami. As a result, approximately 150,000 students lost their education facilities.

Infrastructures were also badly damaged by the earthquake and by the tsunami in particular. Water and electricity lines were down and communications were cut, making it difficult to obtain an accurate report of the damage. Transportation was greatly disrupted, most roads in western NAD were destroyed and Malahayati Port in Banda Aceh was severely damaged, as well as Cut Nya Dhien Airport in Meulaboh. The disruption to transportation made speedy humanitarian aid impossible to organize, especially in the first days.

Aid was unable to reach Aceh for two or three days following the earthquake and tsunami. Navy ships carrying medical and humanitarian aid were able to reach Meulaboh, which was isolated during those days. Fortunately, Sultan Iskandar Muda Airport only suffered minor damage, enabling assistance to reach Aceh.

However, in the first few days following the disaster, the only medical unit available, the Army Hospital, became the centre for medical activities but was insufficient to treat all the victims.

Due to the level of devastation in the area, emergency relief activities were the primary concern in immediate period after the disaster. In the first few months, food supplies, healthcare, shelters and temporary housing dominated post-disaster rehabilitation projects. However, some reconstruction projects were also initiated during this period, especially for essential facilities or buildings that had suffered only partial damage.

The Rehabilitation and Reconstruction Agency (BRR)

To manage all rehabilitation and reconstruction efforts in the NAD and North Sumatra provinces, the Indonesian government set up a new agency, the Rehabilitation and Reconstruction Agency (Badan Rekonstruksi dan Rehabilitasi NAD-Nias or BRR) on 16 April 2005. Its mandate was defined by Regulation in Lieu of a Law (Regulation / Perpu) No. 2/2005 issued by the President of the Republic. On 29 April 2005, President Susilo Bambang Yudhoyono signed Presidential Regulation (Perpres) No. 34/2005 detailing the agency's organizational structure and mechanism (BRR Fact Sheet, June 2005).

BRR's mission is to restore livelihoods and strengthen communities in Aceh and Nias by designing and overseeing a coordinated, community-driven reconstruction and development programme implemented according to the highest professional standards. BRR will operate over four years, with a main office located in Banda Aceh and branch offices in Nias and Jakarta. BRR's authority extends to planning, implementing, controlling and evaluating the rehabilitation and reconstruction process, and the agency reports on progress directly to the President of the Republic of Indonesia.

Current situation

The disaster on 26 December 2004, presents authorities with challenges and opportunities for rebuilding a safer Aceh that is more resistant to earthquake hazards. The recovery and reconstruction process provides a second opportunity to build structures with higher seismic performance, and to follow a master plan to meet social and economical objectives.

More than one year after the disaster, progress had been achieved in reconstruction projects, although slower than expected. From about 26,000 planned houses, about 7,000 houses were completed by 2006. School buildings had also been constructed at an almost identical rate to houses. However, in an attempt to carry out reconstruction at the expected pace and reach the target number of buildings, quality control of the newly constructed houses and school buildings seems to have been overlooked.

Similarly, due to inadequate needs assessment before construction, some of the projects seem to fail to comply with the needs and demands of the local community. There have been cases where the number of students in school buildings is far greater than the capacity for which they were concived. In addition, infrastructures have not been rebuilt in line with the construction projects, resulting in houses being located very far from main roads with no means of transportation.

Objectives

The objectives of this research were as follows:

1. Investigate and assess the current capacity and building practices of various actors in the ongoing reconstruction process, including the vulnerability of buildings as a result of inadequate building practices
2. Develop recommendations for technological interventions within the ongoing reconstruction process to prevent unsafe practices in building construction and produce less vulnerable buildings

The research was designed to produce a clear understanding of the current building capacity and practices in ongoing reconstruction projects, together with recommendations for improving the quality of buildings and infrastructures in Aceh.

Scope of work

Based on the objectives of this research, several activities were conducted:

1. A field survey of building practices in Aceh, mainly aimed at ongoing reconstruction projects, and in some cases pre- and post-rehabilitated buildings damaged by the tsunami and earthquake
2. An assessment of the building practices employed by various industry players, including the current systems used in reconstruction projects and regular development projects, from design, procurement and construction to operations and maintenance
3. An analysis of the vulnerability of selected buildings (existing and reconstructed) to understand weaknesses and find ways to improve quality
4. The development of appropriate technological intervention and the means to reduce the vulnerability of buildings and disseminate information on building practices to the relevant stakeholders
5. A workshop to disseminate the survey findings and analytical results (in Banda Aceh)

METHODOLOGY

Survey

The survey was conducted on various reconstruction projects in Banda Aceh and Aceh Besar from 29 January 2006 to 4 February 2006. Due to the limited time frame and the vast reconstruction activities in the area, the survey and assessment were limited to selected school buildings and non-engineered simple public buildings and housings. The buildings were randomly selected and included those constructed by communities, the local government and donors (non-governmental organizations). In addition to buildings in the construction stage, several pre- and post-rehabilitated buildings were observed to better understand building capacity and common construction practices in Aceh. In total, 53 construction projects were visited for the field survey, including housing, school buildings, mosques and other buildings.

The survey was designed to obtain information on ongoing reconstruction projects and building practices in general. Therefore, field testing of building materials was therefore carried out, along with interviews with the various parties involved in the reconstruction process. Documentation was also obtained in the survey, including structural drawings, specifications, pictures and notes. A few samples of building materials were collected for laboratory analysis. Local stakeholders, including workers, contractors, related local government agencies, non-governmental organizations (NGOs) and local community groups, were visited and interviewed to obtain information on building technology capacity, building procurement processes and mechanisms, and traditional building practices and methods. Input was also collected from building owners or future occupants and other interested parties to obtain a comprehensive view of the issues.

Assessment of building quality

The current capacity was assessed using available information from the survey. This assessment involved every aspect of building practices:

- Building design
- Project management
- Materials
- Workmanship
- Infrastructures and supporting facilities
- Policy studies

Building quality in terms of earthquake-resistant design was analyzed based on documentation. Structural plans and specifications were reviewed to ensure that the original documents endorsed seismic building design. Project management aspects, including building technology, procurement processes and tools, were reviewed to verify project efficiency.

These assessments were followed by an analysis of the quality of materials used in the buildings. In addition to the results from field tests, several material samples were tested in the laboratory to assess their properties and structural qualities. The quality of workers was then analyzed to evaluate the adequacy of workmanship for the reconstruction projects. Knowledge of each skill required to construct the buildings, the time taken to complete each type of work, and the quality of the finished products were the main criteria used.

The required environment for reconstruction projects was also reviewed. Infrastructures were investigated, along with other supporting facilities necessary to ensure the smooth running of reconstruction projects and to support communities after project completion. Local and national codes and other policies applying to reconstruction projects were also studied to investigate compliance with regulations.

Based on the results of the field survey and laboratory tests on materials, an analytical study was conducted to examine the structural behavior of buildings. A few buildings from the reconstruction projects were selected to understand weaknesses and find ways to improve building quality. The analysis was conducted using a structural platform, and building performance was examined using calculated force/stress and displacement responses.

From the field observation and structural analysis, an appropriate technological intervention will be developed to reduce the vulnerability of buildings. This intervention will be based on the available capacity, culture, local materials and tools, and also the supporting environment, including common legal and formal procedures. After formulating ways to reduce building vulnerability, the means to disseminate information to the relevant actors will be obtained to ensure that the appropriate technological intervention will be common knowledge for all parties concerned and used in reconstruction projects.

A workshop was conducted in Banda Aceh on 22 February 2006 to communicate the findings from the survey and analytical results. Issues found in the field investigation and analytical studies were highlighted. This workshop was also set up to obtain input from local actors (including local government agencies, NGOs, local community groups, contractors, consultants, universities and other relevant parties) on how to overcome the problems in reconstruction projects.

SURVEY FINDINGS

As explained in the methodology, a survey was carried out to investigate the quality of construction in the reconstruction process. The current building practices in NAD Province was examined, exploring several aspects: planning and design aspects; construction aspects, including procurement methods, materials and workmanship; project management aspects; and the contribution and participation of communities. Based on the results of the field observation and structural analysis, several observations were made regarding the quality of reconstruction projects. These findings are explained below.

Current construction practices in NAD Province

From an engineering perspective, about two thirds of the buildings in NAD are non-engineered buildings and one third are engineered buildings. Non-engineered buildings are buildings that were traditionally constructed with little or no assistance from qualified engineers. Along with traditional houses such as timber houses or other indigenous dwellings, most masonry structures also fall into this category. Engineered buildings are considered to be properly designed and constructed for satisfactory performance under applicable loadings. Most public facilities should fall into this category, including school buildings, government offices, mosques and other essential buildings.

In general, most buildings in Aceh are masonry structures, most commonly one- and two-storey houses, which first caught on in the 1970s and continue to be the most popular choice. The existing buildings can survive earthquakes with little or no damage, provided that they were built properly using good-quality materials and good workmanship (Figure 1). It is interesting to note that masonry structures built in the 1970s or 1980s performed better than those built in the 1990s. The changes may be attributed to new building codes that allow an inelastic response of the structure assuming that it can develop adequate ductility, thus requiring specific detailing. Almost all damaged structures from the 1990s were designed incorrectly, failing to meet the stipulated seismic standards.

Figure 1 Examples of surviving masonry structures

Also included in the survey were some more traditional houses: timber structures or other indigenous dwellings, which performed well under seismic loading. Unfortunately, very few of these existed before the earthquake and most of those remaining were not strong enough to survive the devastating tsunami.

A few buildings dating back to the 1900s or even the 1800s survived, mostly with very little damage. Often called Dutch buildings due to the colonial period in which they were built, their characteristic thick walls and enormous columns enabled them to withstand the impact of the earthquake and tsunami.

The survey showed that the new trend for buildings in NAD is a “Ruko” (“house and shop”), a two-storey building with several units like townhouses (Figure 2). Each unit is two-storeys high and can be used as an office or a shop on the first floor, with an apartment on the second floor. The new trend in NAD also reveals a growing trend for steel structures, especially in Ruko buildings.

Figure 2 Ruko buildings, increasingly popular in Aceh

Planning and design

Planning and design aspects relate to the needs and demands of reconstruction projects. The survey shows that some problems arose due to limited feasibility studies prior to reconstruction projects. Several examples can be given for poor planning and design aspects, such as transition houses being built at the same time as permanent houses, or a lack of infrastructures for housing. It seems that reconstruction projects were poorly matched with the needs and demands of the community, leading to ineffective projects.

The survey also encountered several finished projects that were inhabitable, or examples of communities refusing to live in the proposed areaa. The study revealed several issues raised by communities, besides the poor quality of the buildings. First, communities were uprooted from their villages, as evidenced in attempts to relocate a fishing community to a new location about two kilometres from the coastline. The fishermen refused to be moved because of the importance of easy access to their boats and the sea to their lifestyle. Second, a lack of planning led to a lack of infrastructure, which means no transportation, no services, no electricity and even no water, making houses inhabitable. Another problem was the distance to adjacent neighbourhoods, public facilities and health facilities. Finally, communities objected to the finished buildings because of inadequate communication of correct information.

Housing and school buildings follow typical design structures. Most surveyed school buildings have one or two-storeys. The two-storey schools often fall into the category of engineered buildings while most of the one-storey structures are non-engineered. The houses are mostly what is known as Type 36 houses, which means that the total living area is 36 m2. These are one-storey non-engineered buildings. Type 36 houses were endorsed by the government as replacement houses.

Most buildings are made of burnt brick walls with reinforced concrete columns and beams as structural elements. Roofs are constructed with wood trusses and galvanized iron sheets or roof tiles. These buildings fit in with the local culture and sustainability goals. However, some projects used imported materials and technology in their designs, compromising maintenance and sustainability.

Assessment of small-scale contracting capacity

Construction industry in NAD Province

The construction industry in the NAD Province is not considered as strong as in Java Island or other more developed regions, for various reasons. More than three decades of armed conflict have limited the growth of private sector investment, resulting in a relatively small private construction market. The total construction market is dominated by investments in government infrastructure. Large international investments (in oil and gas processing and related industries) are limited to major contractors, usually from outside the province (Medan or even Jakarta). Many local contractors depend solely on government works, resulting in fierce, and possibly unhealthy, competition between local contractors. The construction market is unsustainable and fluctuating, in particular in a turbulent economic and security context. This situation is not conducive to the development of a healthy construction industry, as enterprises are unwilling to invest in developing their human resources, construction plants and technology. (The construction sector relies heavily on skilled labour and reliable plants.)

The Regional Infrastructure Agency estimated at about 9,000 the number of contractors before the tsunami disaster. An interview with GAPENSI (the largest association of contractors) provided a lower estimate of 3,500 members, (due to company closures, mergers or acquisitions), fulfilling the requirements of the new law on the government procurement system (Keppres or Presidential Decree No 80/2003).

The construction industry is regulated by the regional construction industry development board (LPJKD). Before 2003, the national system of contractor qualification divided contractors into three classes (large = B, medium = M, small = K), and the small-scale contractors (K class) were divided into a further three classes (K1, K2 and K3) based on maximum contract value. The new Presidential Decree (Keppres 80/2003) recognizes only two classes, large and small, and no sub-categories. In practice, however, the old qualification system is still in use. The K1 class may be awarded a government contract of a maximum of Rp1 billion, the K2 class a maximum of Rp500 million and the K3 class a maximum of Rp200 million.

The tsunami disaster worsened the situation due to the following losses:

- Contractors, family members or relatives, causing moral and financial burdens
- Assets (homes, offices, construction plants and equipments, data)
- Skilled labour (managers, technical experts, skilled tradespeople, etc.)
- Financial networks, leading to a drop in capacity and competitiveness

On the other hand, the tsunami has provided a vast opportunity for the construction market, since damaged infrastructures and houses need to be rehabilitated and reconstructed after the emergency response phase. An appropriate policy should be designed to enable contractors to recover, increase their capacity and in the future establish a strong, healthy local construction industry that is competitive enough to share the local, national and even international construction contracts.

Small-scale contractors (SSCs) and small-scale contracting

According to LPJK (Construction Service Development Board) registrations, the total number of SSCs in the Aceh NAD Province reached 2,589 on September 2004. The Aceh Besar District counted 276 small-scale contractors, much fewer than the 600 estimated by the District Public Works Office.

Local SSCs are involved in small or medium infrastructure projects such as roads, small bridge construction and maintenance, small-scale irrigation and maintenance schemes, and residential and non-engineered public facilities (school buildings, government offices, health service centres, etc.), simple urban infrastructures, building maintenance and rehabilitation etc., in the public and private sectors. For larger or more complicated infrastructure projects, a main contractor occasionally subcontracts to SSCs.

A typical SSC employs 3 to 10 permanent staff (managerial and technical), but in NAD Province, many do not have a permanent rosta of qualified, skilled technical personnel. In most cases, they are hired on a project basis, because of uncertainty in obtaining contracts. This situation does not help SSCs to develop, as companies are unable to accumulate experience and knowledge. Another problem faced by SSCs is access to financing (from formal financing institutions) due to the perception of complicated procedures (proposal, supporting letters, collateral etc.).

SSCs generally own very limited equipment, mostly hiring it on a project basis, preferably from the local Public Works Office, which is cheaper than private equipment rental companies.

Some government programmes, both at provincial and district (Kabupaten) levels, are designed specifically to employ small-scale contractors. These projects, mostly for public infrastructure such as rural roads, bridges and irrigation, are divided into contracts worth less than Rp1 billion (mostly between Rp300–500 million) so that only small contractors are involved in the bidding process.

Government procurement system

There are two main types of construction procurement system: private and public. Public sector procurement is governed by Presidential Decree (PD), currently PD No. 80/2003. The regulation prescribes open tender bidding for all public goods and services, with rules for exceptions where a limited tender (based on a shortlist of contractors), direct selection or direct appointment can be used. Both pre-qualification and post-qualification processes can be used for selecting eligible bidders.

In the past, for certain works such as routine infrastructure maintenance, the forced account method was often used. A variance of the forced account method, community contracting by the implementing agency, is now employed widely in many rural development programmes, in particular those that are donor driven. This process is mostly used with a community bottom-up and top-down planning process, where the implementing agency provides a block grant and the community decides what it wants locally. These programmes are becoming very popular, the community sees them as beneficial, and they are more cost effective than outsourced projects. (There are no contractor fees and overheads, government taxes or marketing fees, for example.)

Community contracting can be implemented in three ways:

1. The community procures the services of (local) contractors using its own funds (either from its own fund raising or from donors).
2. The community acquires infrastructure contracts oursourced by government agencies using government funds or World Bank loans, for example.
3. The community works for major contractors, who are required to subcontract part of the work (such as supply of labour or materials) locally.

The second method is most commonly used, for example for Kecamatan Development Programmes (KDPs), where the community contracting scheme provides block grants to village communities (Kelurahan level) in other parts of Indonesia under the forced account mode by the Kabupaten Public Work Office. The third method is now less common, given its ineffectiveness.

Community contracting is not preferred by contractors, who consider that it undermines the construction market. Also construction, even of simple rural infrastructure, requires a good technical understanding of the relevant technology and construction processes, which village communities do not generally have, and quality can therefore be compromised.

Local government capacity

In the post-disaster situation, local government agencies have been disrupted in many affected districts in Aceh and are almost unable to function properly. Employees and family members died or were displaced, and buildings and facilities were destroyed or damaged, all affecting local government services. As an example, the Aceh Besar District's Office of Settlement and Regional Infrastructure (Public Works) lost 28 of its 190 employees in the tsunami disaster. There are 18 engineers (16 with undergraduate degrees and 2 with graduate degrees) in the Office of Public Works, including 6 working for the road division. The Public Works also employs about 20 technicians, including 8 road technicians.

In the past the Public Works procured more equipment through the IBRD/KR3 Kabupaten Road Programme, but most had to be scrapped due to maintenance problems (no spare parts), and some was damaged by the tsunami. The existing equipment is currently used for routine maintenance only, and when available, is often rented by contractors for road construction or improvement projects as it costs about 40 percent less than equipment from private equipment rental companies.

The PW has also a laboratory facility, complete with adequate material and workmanship testing equipment (for aggregate gradation and abrasion testing, concrete testing, proctor testing, marshall testing, field compaction and density testing etc.)

Due to the limited technical capacity of its personnel, the District PW outsources engineering works for its projects, using local engineering consultants for the survey, design and supervision of roadwork projects. It has a limited capacity to design and in particular supervise the projects.

Construction aspects

Procurement method

The current procurement methods used during the reconstruction process in Aceh can be divided into the following categories:

- In-house design and construction by donors and project managers

Donors (mostly non-governmental organizations) produce their own designs and execute construction independently. As there is no system for auditing, the procedure is at the mercy of donors. Those who do not have strong design skills (architectural or structural) risk producing more vulnerable constructions than more knowledgeable donors.

- Contracted process to NGOs

Donors and government agencies may subcontract design and construction to NGOs, where the risks are similar to the previous approach.

- Contracting

Donors (or government agencies) have their own design mechanism (using in-house employees or consultants), and the construction process involves various procurement modes, such as bidding or direct appointment of a local or national contractor. Donors (or the government agencies executing projects) might supervise the construction process through their own engineers and inspectors or hired consultants. In theory, this is the best option as it provides an opportunity for auditing, but in practice, the level of supervision is often inadequate and construction is often of sub-standard quality. There are also many cases of contractors subcontracting all or part of the construction to other parties, possibly down to third or fourth tiers, resulting in sub-standard quality because contractors at the end of the chain do not make large enough margins and have to lower quality to cover their expenses.

Contractors sometimes divide projects into smaller packages (e.g. 2, 5 or even 10 houses in larger projects) and subcontract labour to a group of workers led by a foreman (a “mandor” in Bahasa Indonesia), while supplying materials. In this case, quality can differ from one group to another, depending on the level of supervision provided by the contractor and the owner, as well as the mandor’s experience and skill.

- Construction by communities

Community-based rehabilitation and reconstruction is often carried out by both government agencies and NGOs to reduce fund losses occurring in the contracting process, and to build community participation and capacity. The approach provides partial support to the community (in kind or in cash) to procure materials, while labour is provided by the community itself. In other cases, donors or government agencies provide funds for the community (e.g. a school committee in the case of school buildings) to organize and carry out construction work. While this method can benefit the community directly, it carries risks in terms of design and quality, especially if the community lacks knowledge on how to build earthquake-resistant buildings. If donors do not provide adequate supervision and technical assistance, the result may be vulnerable houses and other buildings.

Materials and workmanship

The materials used are critical to the success of reconstruction projects. The survey shows that some projects were stopped or cancelled due to the unavailability of construction materials, thus making the reconstruction process inefficient. Procurement of construction materials mostly depends on the availability of funding and materials. As donors are usually responsible for funds, project continuity depends on them providing a flow of cash, while the availability of materials depends on the market and, in no small measure, transportation.

Materials found in the area can be divided into two categories: local and imported. Local materials including sand, gravel, bricks and wood were obtained from various places in NAD Province, while imported materials came from other areas, mainly North Sumatra, but also Java or even as far away as Australia, South Africa and Europe. These imported materials were usually chosen by the donors and included, for example, bricks from North Sumatra and Jakarta, cement from West Sumatra, roof tiles from East Java and metal frames from Australia. As long as these imported materials are commonly found in NAD Province and regularly used for building work, maintenance and sustainability can be ensured. However, if the materials involve a new system or a new material that is not available locally, maintenance and sustainability may be a problem in the future.

In the study, houses and school buildings were permanent structures using typical materials (burnt brick confined masonry with sand and Portland cement mortar) and confinements made of reinforced concrete columns and beams (Figure 3). A typical flat footing is usually used for the column foundation of two-storey buildings, while a spread footing is commonly used for one-storey buildings. The roof is also typical, with a metal roof deck being the most popular choice due to its cost, workability and durability.

Post-earthquake house design is somewhat similar to pre-earthquake design, showing little improvement in terms of integrating seismic resistance. Most plans do not clarify important earthquake-resistant structural details, such as the beam-column connection, spacing for stirrups, seismic hoops, lap splices and anchorage, which are therefore left up to workers to improvise. On the other hand, most designs for two-storey school buildings show a conservative approach to seismic loading, emphasized by the large number of columns used in the buildings and the substantial size of structural elements. It should be noted that even with proper drawings, the field observations found materials of different specifications and sizes to those specified in construction plans.


Figure 3 Type 36 house (left) and school building (right)

The beams and columns used in reconstruction projects are reinforced concrete. The quality of the concrete varies by a wide margin. For two-storey buildings, the concrete is of higher quality with an average strength of K-175 (fc' of 14.5 MPa), as expected for engineered buildings. However, the concrete quality for houses is much poorer, averaging K-80 (fc' of 6.5 MPa), compared with an expected strength of at least K-100 (fc' of 8.1 MPa).

The concrete mixture is a major problem for reconstructing houses. The materials used in the mixture were adequate in most cases, but almost no projects used the proper concrete mixture (a ratio of 1 part cement, 2 parts sand and 3 parts gravel). The most common mixture is cement, and sand gravel (sand with some gravel) made from one bag of cement for three carts of sand gravel (a volume ratio of about 1:5.25). No sieving was carried out to comply with the standard grade for concrete mixture and no effort was made to avoid large aggregates getting into the mixture, resulting in a very poor gradation mixture with a high per centage of coarse aggregates. This conclusion was confirmed by laboratory tests (Figure 6).

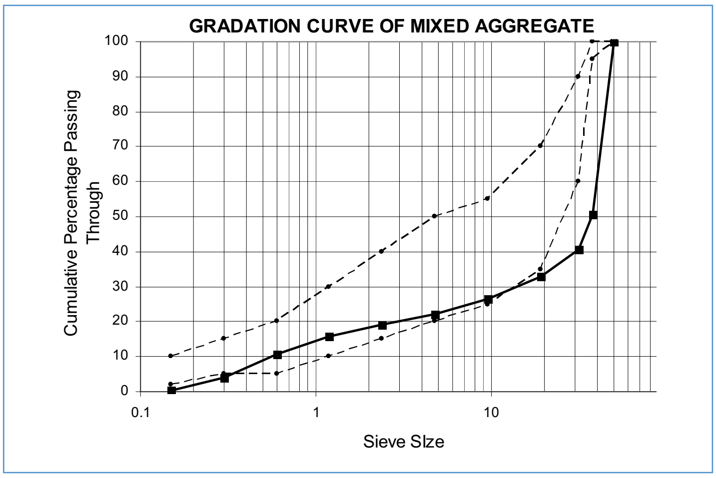

Figure 4 Sieve analysis for sand-gravel mixture

There is also no control over the amount of water used, as long as the mixture is sufficiently liquid to work with, which leads to concrete with excessively high water content and low strength. Proper concrete curing is also uncommon in the region. Considering all these problems, the appalling quality of concrete in some reconstruction projects is hardly surprising (between K-50 to K-60 or fc' of 4.1 to 4.8 MPa).

The reinforcements typically used in the buildings are at most 10 mm diameter for longitudinal plain rebars and 6 mm diameter for stirrups. (8 mm and 4 mm diameters were found in some buildings, as shown in Figure 7.) The Indonesian seismic code stipulates minimum diameters of 12 mm for deformed bars used as column longitudinal reinforcements, 10 mm for deformed bars used as beam longitudinal reinforcements, and 8 mm for plain bars used as stirrups in earthquake resistant buildings. Therefore, most of the reinforcements found in the field survey violated the building codes (Figure 7). Even worse, reinforcements that claimed to meet seismic demands did not in reality.

Figure 5 The use of a 4 mm stirrup (left), large spacing of stirrups (centre) and no seismic hook (right)

The required seismic hook, provided by a 135° bend in stirrups, was found in only a small number of projects. Stirrup spacing also posed a problem, measuring an average of 200–250 mm, compared with the maximum spacing of 150 mm required by the code. Laboratory tests confirmed the sub-standard strength of materials (Table 2). All these facts indicate that the bending and shear strength of structural elements could be much lower than expected.

Type of reinforcement	Average yield strength (kg/mm2)	Standard yield strength (kg/mm2)
BjTP 24	29.56	39
BjTP 30	43.95	49

Table 1 Tensile tests of steel reinforcements

Figure 6 Melting bricks (left) and large brick spacing (right)

With the exception of a few projects, the quality of bricks used in the region is very low (Figure 8). The minimum quality stipulated by the Indonesian code is Class III, which relates to a minimum brick strength of 25 kg/cm2. Most bricks fall below this level and could not be tested for strength as they disintegrates when soaked with water. Mortar quality is also questionable, in terms of average strength (most only reaching K-60 or fc' of 4.8 MPa), and the wide variations observed. No standard appears to have been followed to mix mortar, leaving the matter up to workers' judgment. Brick laying is also a major problem, with excessive amounts of mortar being applied between bricks (with a spacing of more than 15 mm) and bricks not being installed in a straight line, due to minimum leveling (Figure 6).

The poor gradation of sand used (Figure 7) is much coarser than required, leading to poor brick spacing. The common mortar mixture found in the area was 1 bag of cement for 3 carts of sand, or a 1:5.5 volume ratio, compared to the recommended 1:3 ratio. Altogether, these factors contribute to poor-quality walls and partitions, reducing building strength.

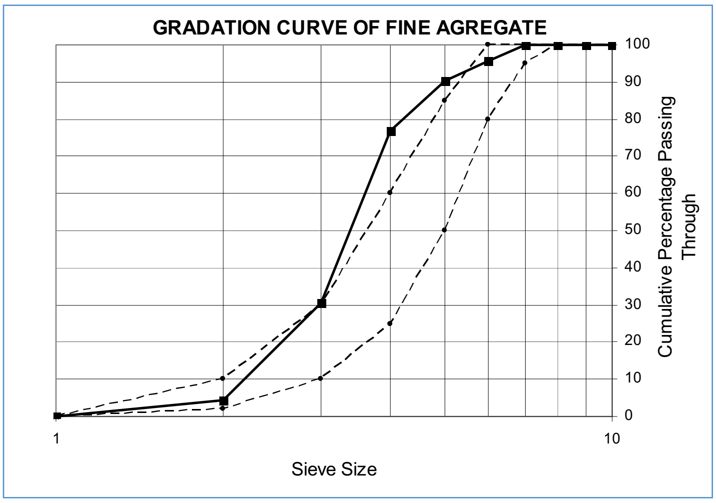

Figure 7 Sieve analysis for sand

Buildings are also lacking in structural integrity, due to insufficient connections between each structural component. For example, in one of the projects surveyed, beam-column connections did not comply with the requirements laid out in the codes, and no wall anchorage was provided to the columns and ring beams, leading walls to collapse during construction in one of the project surveyed (Figure 8).

Figure 8 Wall collapse before completion

Workers and tools

While poor quality materials produce poor structural quality, poor quality workmanship amplifies the problems found in reconstruction problems. Given the amount of building work being carried out, trained and qualified workers are scarce in the region. Most projects demonstrated that workers were inadequately trained for the job, given, for example the lack of a sieving process for concrete ingredients, seismic hooks for stirrups, curing for concrete, and soaking of bricks before laying, while the water content of concrete mixture was high to facilitate pouring (Figure 19). All these problems arose from the absence of awareness of building quality issues. Workers simply did what seemed easiest with no concern for quality because they were not equipped with knowledge of proper construction methods or basic concepts of building quality.

Figure 9 Poor workmanship (left) and a tilted column resulting from poor workmanship (right)

The survey found workers coming from different parts of the country: Aceh Province, neighbouring North Sumatra Province or even further afield (West Sumatra, South Sumatra and Lampung) and many come from Java Island (West, Central and East Java). Workers' skills vary with their experience, but workers from as far as East Java have demonstrated better skills than those from Aceh or North Sumatra. Moreover, better skilled workers from Java Island are willing to work longer hours with lower wages than their local colleagues. Workers from other provinces come on their own initiative and find jobs easily in Aceh reconstruction, and some workers are brought by contractors from other areas (Medan, Jakarta and even Surabaya).

Since many of the construction sites use conventional building technology (confined masonry with reinforced concrete frames), no special equipment or tools are needed. Ordinary concrete mixers are used for concrete and mortar on larger project sites, while manual mixing tools are used for small-scale work. Other required equipment includes hand tools such as saws, hammers, spades, hoes, chisels, mortar trowels, bar bending tools and wrenches.

In addition, the tools used by workers sometimes need to be improved or used correctly. For example, wrenches for bending re-bars should be large enough to bend 10 mm diameter re-bars easily. Another example is concrete mixers, which stand unusued on some sites because workers prefer to hand-mix the concrete closer to the building under construction. The correct use of tools can improve the quality of building work, as well as productivity.

Project management and supervision

Investigation shows that there are two types of reconstruction projects for houses. The first is the project method, in which NGOs or other donors assign the construction project to a contractor. The second is community-driven reconstruction, in which NGOs or other donors provide full or partial funding while building is managed by the owner or other actors chosen by the owner. Each method has advantages and disadvantages. The project method is prone to subcontracting, where the appointed contractor sells the project to a third party, and in some cases, this subcontractor further subcontracts. Projects are subcontracted two to three times on average and up to four to five times in some cases, with each party making a margin on the original cost of the building. This means that the funds for actual construction are much smaller than intended. On the other hand, the community-driven method is affected by the lack of qualified construction workers. With each worker free to choose the most profitable projects due to a high demand and low supply, owners sometimes require four or five groups of workers to finish the project, leading to varying building quality and integrity depending on the quality of workers finishing the job.

The survey also showed that quality control was not carried out due to the difficulty of finding qualified supervisors. For this reason, daily inspections are difficult (and would be ineffective if carried out) and for some projects, inspections were made weekly, bi-weekly or even monthly. Considering that 15–30 days are usually required to build a house, such inspections would not make much impact. Therefore, proper construction methods could not be enforced, and structural quality could not be ensured.

Unfortunately, the building permit system, which can be seen as one of the mechanisms for ensuring building quality, has also been suspended due to an inability to handle the massive construction projects being carried out in the area. Currently, houses and other facilities damaged by the earthquake and tsunami can be repaired or reconstructed without a building permit. In this way, no control has been exercised over these buildings.

Building ownership

The survey explains that the survivors of the earthquake and tsunami in NAD received aid for rebuilding houses or other community buildings based on their own reporting. In theory, the process is relatively simple. Each survivor reports on the damage to his or her house to the head of the village (the “Keuchik”) or other village officials. The official then relays this information to the city or district Public Works (PW) agencies, and the agencies notify BRR of the request. After sorting through the designated beneficiaries, BRR contacts a donor or NGO to support the reconstruction project. In turn, the donor contacts each beneficiary directly to verify needs and to gather information from the community so that his or her requests are taken into account in the reconstruction project. Once a project is completed, the beneficiary can process the building permit or certificate of proof of ownership from the city or district agencies.

In practice, the process is more problematic. In most cases, survivors have been unable to prove ownership of their land or homes because certificates were lost or damaged in the tsunami, and they have therefore been unable to claim aid for rebuilding their properties. The village structural command was also badly disrupted by the death of some employees, leaving villagers without guidance on how to obtain this assistance. Donors have also tended to build in specific locations that have received significant media coverage, and that are highly visible or more familiar to them, thus excluding other areas. Government agencies and BRR have also encountered problems with checking whether each survivor only received a single unit of housing for his or her family. There are cases of people ending up without a home while others obtained two or more units.

STRUCTURAL ANALYSIS

Based on the results of field survey and material testing, structural analyses were performed on selected buildings. A typical house funded by donors was selected for the analytical study, mainly due to the availability of comprehensive documentation and technical information. The house is a Type 45 house, referring to a 45m2 single-storey stone building. All structural elements were typical of houses in Aceh.

The survey found that this house had a good structural capacity with materials and construction workers of adequate quality. Its design followed the available building codes and standards, using local materials and technology. Therefore, analyses were expected to confirm that the house would perform satisfactorily under various loading conditions.

For structural analysis, the house was modeled as a reinforced masonry structure. All structural components including columns, beams, roof and walls were modeled as frame and shell elements. Material properties for these materials were taken from the results of the field survey and material testing. Various loading conditions, including dead load, live load, seismic and wind loads, were considered for the analysis.

In general, the results show that satisfactory structural responses, provided that the structure is built according to the structural plan and specifications.

RECOMMENDATIONS

The field investigation and structural analysis reveals a clear lack of quality assurance in reconstruction projects. All parties involved in reconstruction activities should remember that the main objective is to rebuild a safer Aceh to protect against future hazards. With this in mind, reconstruction projects should go beyond numbers, focusing not only on quantity but the quality of required buildings. Therefore, several aspects of construction work are in dire need of improvements. Recommendations for each aspect will be discussed below.

Planning and design aspects

Planned reconstruction projects should be communicated to the relevant community and involve their input. The authority should explain their programmes to the community and disseminate the local master plan to build community awareness and ensure proper planning.

The field survey revealed that most reconstruction efforts were based on immediate needs and spontaneous requests from victims. Very few feasibility studies were conducted prior to reconstruction projects and no master plans were used for sites. Thus, site plans sometimes clashed with the master plan for the area, affecting social or economic interests. Environmental issues also impact safety, as shown by some planned sites located on riverbanks or at the foot of hills, making these houses prone to flooding or landslides.

Construction should be in line with infrastructure. Site plans should therefore include drainage, access roads, provisions for sanitary and water supply, electricity, etc., as well as supporting facilities such as public buildings and health facilities. Therefore, better planning that matches the city or area master plan is necessary before conducting reconstruction projects.

Building design must respect codes and standards to ensure satisfactory performance under various loads, including earthquakes. Adequate dimensions for structural elements and proper detailing will ensure buildings have sufficient capacity for applicable (i.e. seismic) loading conditions.

The use of local materials and technology will ensure building maintenance and sustainability. (“Local” means materials and technology that are commonly used and easy to find in Aceh but not necessarily obtained in the neighbourhood). The use of local materials and technology will also enhance community participation in reconstruction efforts.

Construction aspects

Material supplies

The availability of materials is the main procurement issue in reconstruction projects. For projects to run smoothly, it is necessary to avoid at all costs a situation where materials become unavailable during construction, so the use of “local” materials helps ensure project continuity. For special materials or pre-cast elements, contractors should set up their own workshops to ensure a steady flow of supplies.

Other problems found in the field were related to funding, especially the increasing price of materials and labour, and high related costs such as transportation. High demand and low supply of materials and qualified workers drove prices up, while the hike in gasoline prices recently led to an increase in related costs. The authority needs to consider other options for securing the supply of construction materials in Aceh, such as obtaining materials from neighbouring provinces or other sources. Another reason for exploring materials from outside Aceh is to limit environmental damage linked to the heavy exploration of Aceh’s natural resources. For example, high demand for timber for wooden buildings could endanger Aceh’s pristine tropical forest.

For these reasons, the sourcing of materials for reconstruction projects should be planned carefully to avoid any suspension or cancellation during construction. The availability and cost of materials are crucial in reconstruction projects.

Quality control

Performance evaluation of a sample of buildings reveals a need to improve all aspects of construction. In addition to the quality of materials, the quality of workmanship makes a significant contribution to poor building performance. Several common mistakes are described below, along with technical recommendations for improving building quality.

Foundations

Good foundations require good quality materials and the proper organization of building works. The foundation installation process should therefore be carefully executed to avoid common mistakes.

Structural elements

Structural elements such as beams and columns require good workmanship to ensure good quality. Most beams and columns are made of reinforced concrete, the quality of which depends on the mixture used. Materials used to make concrete should pass sieve analysis before mixing. Sand or fine aggregates should pass a 5 mm sieve size, and gravel or coarse aggregates should pass a 40 mm sieve size.

Another common mistake found in the survey was a high water content in the mixture to facilitate work through a liquid texture. Figure 10 shows concrete mixtures with two different levels of water content. With a high water content, the concrete mixture is more liquid and more workable but produces low-strength concrete. A concrete mixture with low water content is more solid and less workable but produces higher-strength concrete.

The survey found that construction workers rarely following the curing procedure for freshly poured concrete (i.e. wetting the concrete element during the setting and hardening process, which takes at least three to four weeks). This incorrect curing leads to a reduction in concrete strength, since the evaporation rate is very high in Aceh's hot climate and this process means there is insufficient water to mature the cast concrete elements. Builders are strongly advised to cure concrete elements properly by wetting them adequately.

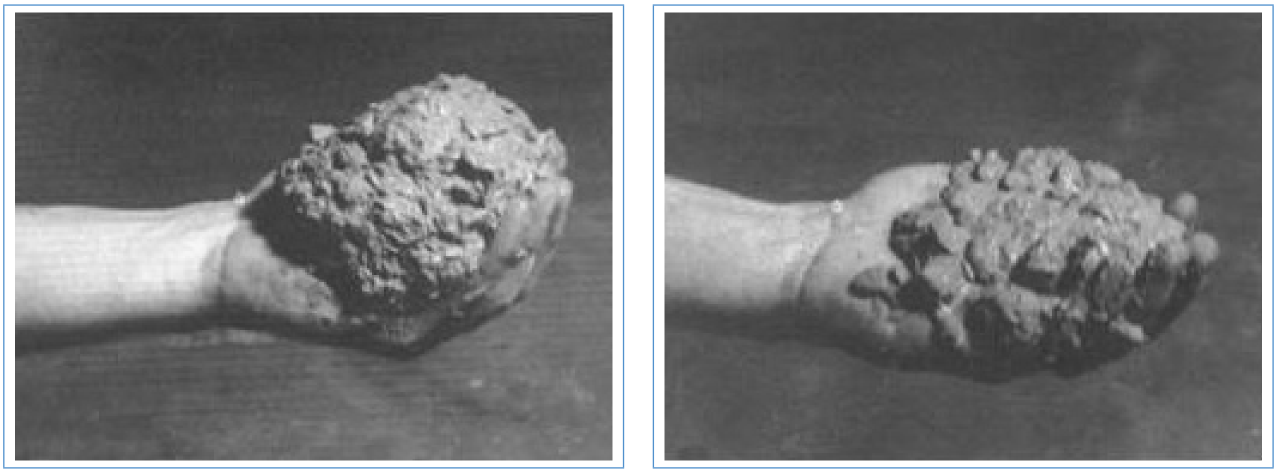

Figure 10 Correct concrete mixture (left) and wrong mixture (right)

Concrete mixtures should also follow a volume ratio of 1 part cement, 2 parts sand and 3 parts gravel. For mortar, the volume ratio should be one part cement to three parts sand. These mixtures should produce good quality concrete and mortar. Table 3 presents a step-by-step illustrated guide to concrete making.

In addition to reinforcing structural elements, earthquake-resistant design demands correct detailing to produce the required lateral capacity (i.e. the building should be inelastic under seismic loading). The codes stipulate minimum dimensions for longitudinal and transverse reinforcements, spacing for stirrups, development length, anchorage, seismic hoops, etc. Extra attention should be paid to the detailing of beam-column-connections or joints, since joints are expected to survive even if damage occurs to other structural elements connected to this element.

1. Walls

Masonry walls and partitions add structural rigidity and integrity to buildings. As bricks are commonly used for walls and partitions, correct brick laying is key to achieving the required strength and performance. Several possible brick arrangements are shown in Figure 11. Bricks should be arranged with clear mortar-filled spaces of less than 15 mm on all sides and in straight line, levelled at every two layers. Walls should be anchored to structural elements such as columns and beams through reinforcements to enable all elements to act together as one unit under external loads. Buildings can therefore be modeled as reinforced masonry, with beams and columns providing reinforcement for stone or brick walls.

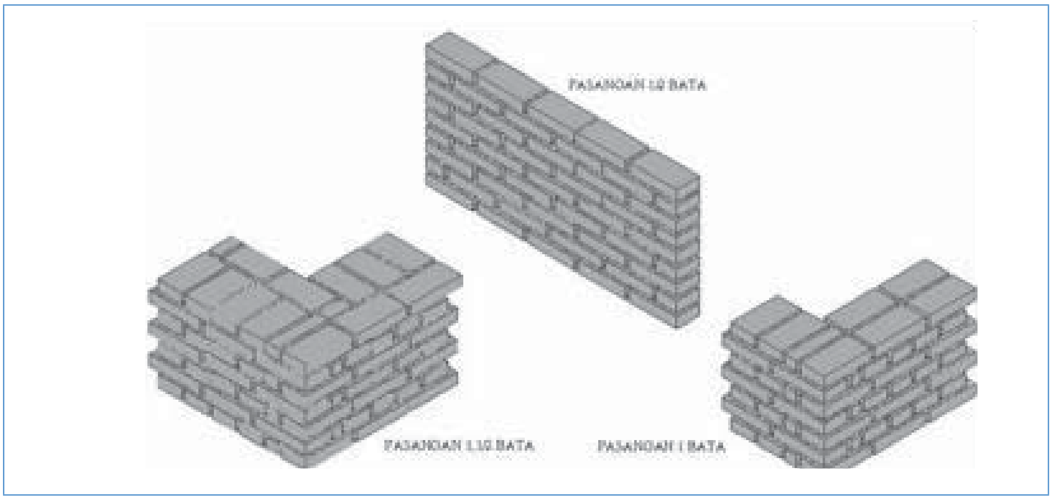

Figure 11 Appropriate brick arrangements

Workers on masonry wall constructions must be correctly supervised. They should be told to wet bricks properly before laying them and to cure masonry walls and mortar properly, wetting walls periodically to prevent them from drying too quickly.

2. Roofing

Wood structures are also impacted by the quality of labour. Poor workmanship leads to poor-quality elements, which make buildings more vulnerable to earthquake loading. Although buildings are commonly designed as permanent structures with reinforced concrete members, wood structures remain the most popular choice for roofing. Therefore, detailing and connections should follow the requirements set out in building codes and standards to ensure good structural performance.

Workers

As mentioned earlier, poorly skilled labourers contribute to poor building performance. In the research, very few workers had adequate construction skills and knowledge, although the high number of reconstruction projects requires more and more qualified workers. Currently, insufficient skilled labour is available to conduct the reconstruction activities.

To resolve this problem, the authority should conduct a widespread practical training programme for a large number of workers, and in particular site supervisors. The training should take a hands-on approach, covering building quality and every aspect of construction work, such as brick laying, concrete mixing and placing, bar bending, etc. Participants should have the opportunity to work with the correct tools and acquire knowledge of the appropriate construction methods and basic concepts of building quality.

In this training, participants can learn how to carry out various types of construction work. After the training, participants will be expected to use the techniques learnt in the workshops and share them with their coworkers to help spread the appropriate building methods. This massive training programme could meet the very high demand for qualified workers within a short time.

Each donor should also help improve the quality of labourers by conducting in-house training for each reconstruction project. Donors can coordinate with the authority to organize such training.

Project management and supervision

Project management and supervision are key elements for conducting efficient and effective reconstruction projects. Methods for reconstruction projects should be improved so that funding is used only as intended. Contractors should be selected carefully to ensure they do not subcontract to minimize overhead costs. Donors and owners should also check the qualifications of contractors and/or workers to ensure project continuity and quality. The authority should implement ratings and qualifications to ensure that contractors work according to their skills. For example, small-scale contractors would not be able to bid for large reconstruction projects that would require qualifications they do not have. Contractors should also be equipped with qualified supervisors and workers so they can work as intended and produce buildings with satisfactory structural performance.

To improve quality control for buildings, the small number of skilled supervisors should be increased to meet the high demand, and the authority should provide them with an extensive practical training programme. This training should include knowledge of construction work and building quality, taking a hands-on approach. Supervisors need to be familiar with every aspect of construction work, such as brick laying, concrete mixing, etc, and they should be able to teach the correct techniques to workers. Participants should also have the opportunity to work with the correct tools. In this way, they would be equipped with a knowledge of correct construction methods and basic notions of building quality for supervising building work properly.

Donors should also help improve quality control on their projects. In addition to inspections by the authority, donors should carry out their own supervision to ensure the quality of their projects. To this end, each donor should conduct in-house training for supervisors on each reconstruction project. Donors can coordinate with the authority to organize the training.

The building permit system should be re-established by the authority to enforce building codes, ensure the use of correct construction techniques and produce better quality, higher-performance buildings.

Implementing quality control for reconstruction projects

In line with the objective of rebuilding a safer Aceh to withstand future hazards, buildings from existing reconstruction projects should be checked to ensure they perform satisfactorily, including under seismic loading. It is recommended that the authority hire a third-party auditor to check the quality of reconstruction projects. The auditor should conduct a field survey and material/component testing if necessary. Based on this investigation and valid structural analysis, the auditor should submit a report to the authority on the quality of buildings. If the auditor concludes that they fail to perform satisfactorily under applicable loads, retrofitting should be recommended.

It should be noted, however, that building design should not have to withstand a tsunami of the same magnitude as as the recent disaster. The reason is that the 26 December 2004 tsunami was an event unlikely to recur during a building's lifetime. Therefore, buildings should be designed to perform satisfactorily under the loading combinations stipulated in the appropriate building codes.

In terms of planning, support facilities and infrastructures should be built immediately so that communities can start relocating to buildings that have already been completed. If a site plan does not fit the local master plan, the authority should update its master plan to take into account the site's social and economic interests. If the location is deemed unsuitable for housing, the authority should consider relocating the community.

To communicate on rebuilding a safer Aceh, it is recommended that the authority produce guidelines for reconstruction projects. These guidelines should explain how to carry out construction projects using the appropriate codes and methods, providing instructions and examples. The risks related to unsafe buildings should also be emphasized. Such guidelines would help raise community awareness of the need to improve building quality.

WORKSHOP RECOMMENDATIONS

A one-day workshop for this study was conducted on 22 February 2006 to share findings from the survey and preliminary analyses, obtain input or more information from the relevant parties, and resolve problems encountered in the reconstruction process.

During the workshop, the findings from the field survey, material tests and structural analyses were revealed to the audience. Based on these facts, several possible solutions were highlighted, as follows:

- Community awareness of building safety should be raised to engage the community in improving building quality.
- Communication and coordination between donors, communities and government agencies should be reinforced to enable society to participate in the reconstruction process.
- Building codes and standards should be enforced, and each of the parties involved in construction projects should understand their roles.
- Internal quality control systems should be set up by the relevant parties, such as owners, consultants, contractors, donors or government agencies. If necessary, each party should have its own supervisor per project to ensure building quality.
- The authority should ensure the spread of appropriate building methods.
- Before reconstruction projects are implemented, feasibility studies should be carried out, integrating input from community members to ensure their needs are met.

- Workers and supervisors should be trained to ensure the use of correct construction method for high-quality buildings.
- Building guidelines should be produced to promote the adoption of appropriate construction methods.

CONCLUSIONS

A study was conducted to assess the current capacity and building practices of various actors in the ongoing reconstruction process in NAD Province and the vulnerability of buildings resulting from inadequate building practices. Different methods were used, including a field survey, laboratory testing of materials, structural analyses, and a one-day workshop. School buildings and houses were chosen as the main target for quality control, due to their significant role in everyday life and the large number of construction projects involving them.

Several important conclusions were made from the investigation of structural quality. Planning and design aspects reveal a need for improvements so that community needs and demands are met by the planned reconstruction efforts. Seismic design features should also be integrated to lessen the damage from future earthquakes. In addition, building materials should be improved to pass the minimum standards specified in the building codes. The quality of construction work should also be improved to reduce the vulnerability of buildings through appropriate building techniques. Projects require sound management and supervision to ensure that each building component contributes to a good-quality structure, especially in terms of earthquake resistance.

The workshop confirmed these problems in reconstruction projects and suggested several possible solutions, including raising community awareness of building safety, enforcing building codes and appropriate construction methods, ensuring internal quality controls by each party involved the construction project, and improving the skills and knowledge of workers and supervisors.

This study shows that there must be a change in focus from quantity to quality in order to achieve the objective of rebuilding a safer Aceh that can withstand earthquake hazards.

EARTHQUAKE AND TSUNAMI PHENOMENA IN SOUTHERN JAVA

Johnny Rakhman[1] and Azhar Pangarso L.[2]

Research Institute for Human Settlements, Agency for Research and Development
Ministry of Public Works, Indonesia
[1]Email: jrakhman2000@yahoo.com
[2]Email: azhar_pl@yahoo.co.id

ABSTRACT

Southern Java is a tsunami- and earthquake-prone area, as observed over the last decade, in which there have been several severe earthquakes that have caused the loss of lives and property. Notably, the Pangandaran earthquake and tsunami on 17 July 2006 caused 659 casualties and damaged most of the buildings along the shore, measuring 6.8 on the Richter scale, with a hypocentre 20 km deep, 150 km from Pangandaran at 9.4 (S) latitude and 107.2 (E) longitude. The tectonic earthquake in Tasikmalaya on 2 September 2009 caused 79 casualties and severely damaged thousands of residential buildings, measuring 7.3 on the Richter scale, with a 49 km deep hypocentre, 142 km South West of Tasikmalaya at 7.7 (S) latitude and 107 (E) longitude. Another tectonic earthquake struck Tasikmalaya on 26 June 2010, measuring 5.8 on the Richter scale, with a hypocentre 96.8 km deep, 80 km south of Tasikmalaya on the Hindia Ocean. These earthquake and tsunami events have become important topics of research on every aspect of damage, to both residential and public buildings, aimed at producing standards for earthquake-resistant buildings.

KEYWORDS

Tectonic earthquake, tsunami, casualties, earthquake damage, building standards.

INTRODUCTION

The Pangandaran earthquake and tsunami occurred on 17 July 2006, measuring 6.8 on the Richter scale, with a 30 km deep hypocentre, 150 km from Pangandaran in Ciamis District at 9.4 (S) latitude and 107.2 (E) longitude. The tsunami wave, which reached about 5 m high, caused 659 casualties and damaged most of the buildings along the shore (only 50–500 m from the sea), including social and public facilities. Pangandaran Beach in West Java is a well-known tourist spot.

Another tectonic earthquake occurred in Southern Java on 2 September 2009 at 14.55 GMT +07.00, measuing 7.3 on the Richter scale, with a 49 km deep hypocentre 130 km southwest of Tasikmalaya at 7.7 (S) latitude and 107 (E) longitude. This disaster caused 79 casualties and damage to thousands of houses from Curug village to Sagaranten (3,199 buildings in the city and the Sukabumi district in West Java, including 1,240 houses experiencing light damage and 1,959 heavy damage). Damage was also inflicted on important buildings, such as government buildings; the Sukabumi City hall, whose walls received cracks; 400 houses and schools; and religious buildings. The main reasons for this damage were sub-standard building materials and non-engineered buildings.

DAMAGE TYPE

The following aspects generally led to earthquake damage in residential buildings:

Building material quality

Sand: Generally, sand mined from the local river is used in concrete mixes, along with cement and split stone. As the sand contains a high intensity of mud, the resulting concrete is of weak strength. Based on an observation of debris, this concrete lacks PC to the extent that it is grayish in colour, and the various concentration of chemicals lowers its quality.

Split stone: The split stone used in concrete does not meet existing standards, having a rounded surface and being larger than the 5 cm river stones still commonly used. According to the standards for concrete mix, the ideal aggregate gradation is a 1–2 cm diameter.

Reinforcement bars: The use of reinforcement bar, especially as the main reinforcement, was still using small-diameter (10 mm) steel, which does not meet standards, meaning that the building is unable to bear the load of its capacity (Figure 1), making a buckled column and beam damage unavoidable.

Figure 1 Column component after collapsing during the aftershock

Structural system capacity

The correct structural system laid out in the reinforced concrete standard applies the appropriate structural design and analysis to every building. This standard requires a firm joint between the beam and column, so that it will not break, especially when it is subjected to shear load. However, many buildings, especially residential, have not followed the correct standards, leading to collapse and various types of damage.

Generally, two types of structural system have been applied by the local community. The first is unframed supporting walls made of bricks 3/4–1 brick deep, while the second is supporting walls framed with beam columns made of reinforced concrete.

Roofing for both systems follows the Joglo structural system commonly found in the Jogja tradition. The roofing is not well secured to walls and therefore becomes a weak point as lateral force such as an earthquake increases the moment of inertia of the supporting wall.

Brick masonry is commonly used in foundations for the typical supporting wall system. However, river-stone masonry foundations are used in the wall and frame system. Line-spread footing foundations are used in both systems. The joint between walls and foundations is not anchored.

Unframed-wall houses typically suffer heavy damage or collapse due to:

(a) The heavy weight of brick walls, which causes sudden collapse (Figure 2)
(b) Heavy Joglo roofing made of clay tiles, which increases the moment of inertia to lateral seismic force (Figure 3)
(c) No serration connection between wall joints, at neither the corner nor the middle of walls
(d) No anchorage between the roof and walls
(e) No anchorage between walls and foundations
(f) Joglo wooden roofing being too heavy for the building
(g) Weak sand mortar for the brick masonry
(h) No wall bracing in the confined masonry system

The light to heavy damage typically suffered by framed-wall houses is caused by:

(a) A wall area exceeding the 12 m2 stipulated in the standard for reinforced concrete beam-column framed walls or the 6 m2 for wooden framed walls
(b) No anchorage between walls and columns
(c) Insufficient lap connection between the reinforcement bar in the column reinforcement and the beam reinforcement, and in beam-to-beam reinforcement, both at the corner and in the middle of joints
(d) Reinforced concrete practical columns that lack a reinforced concrete ring beam

CONCLUSION

An assessment of building damage leads to the following conclusions:

1. Generally, the extent of earthquake damage varies, due to poor quality building materials and methods, a failure to respect earthquake-resistance standards, and a lack of lateral earthquake force supporting systems (e.g. the basic rule that a building should be in simple geometry to minimize the impact of an earthquake).
2. Poor quality concrete results from poor quality ingredients that violate concrete-mixing standards.
3. Poor quality buildings results from errors in reinforcement detailing, such as miscalculated reinforcement capacity, stirrups spaced wider than 300 mm apart and/or having a diameter under 10 mm, and other detailing errors in joints.
4. Unjointed roof

RECOMMENDATION

For buildings to comply with existing standards, an analysis of building design and construction processes, as well as supervision of construction work, should be conducted by professionals who understand buildings and earthquake engineering. The construction of each building in Java Island should follow the Indonesia Building Code SNI 03-1726-2002 for the design of earthquake-resistant buildings.

Figure 2 Houses collapsed after the Jogjakarta earthquake

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ENHANCEMENT OF EARTHQUAKE AND TSUNAMI DISASTER MITIGATION TECHNOLOGY IN PERU

F. Rios[1] and C. Zavala[2]

[1]Associate Researcher, Planning and Disaster Mitigation Department,
Japan Peru Center for Earthquake Engineering Research and Disaster Mitigation (CISMID),
Faculty of Civil Engineering, National University of Engineering (UNI), Peru
Email: frv1805@hotmail.com

[2]Director of the Japan Peru Center for Earthquake Engineering Research and Disaster Mitigation (CISMID), Faculty of Civil Engineering, National University of Engineering (UNI), Peru
Email: czavala@amauta.rcp.net.pe

ABSTRACT

The relationship between Peruvian and Japanese researchers in the field of earthquake engineering and disaster mitigation was initiated many years ago. In 1986, the Peru–Japan Seismic Investigation and Mitigation Center (CISMID) was created, officially linking the National Engineering University (UNI) in Lima with prestigious research institutes in Japan. Thus in 2008, collaboration began between Chiba University and UNI in the area of natural disaster prevention through the Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru project within the Science and Technology Research Partnership for Sustainable Development (SATREPS) research programme under the joint sponsorship of Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA). The significance of this joint research between Peru and Japan can be summarized in four points: 1) Japanese science and technology contributing to disaster mitigation in Peru, 2) providing research fields to Japanese geoscience and earthquake engineering, 3) the contribution to international tele-tsunami research for subduction-zone earthquakes, and 4) the promotion of disaster mitigation and capacity building by sharing knowledge from international joint research.

KEYWORDS

CISMID, disaster risk reduction, earthquake, tsunami, joint research.

INTRODUCTION

Peru is located in the Pacific Ring of Fire, one of the world's prominent seismic zones given the earthquakes of great magnitude that have occurred there, resulting in many deaths and great material losses throughout its history. In this century, there have been two major earthquakes on the coast of Peru that caused great destruction and were accompanied by tsunamis hitting coastal towns.

In this context, on January 2010, Japan and Peru signed a comprehensive joint research agreement for the Enhancement of Earthquake and Tsunami Disaster Mitigation in Peru, led by Chiba University and the National Engineering University of Lima. The objective of this project is to conduct comprehensive research into earthquake and tsunami disaster mitigation in Peru, considering regional characteristics, through strong collaboration between Peruvian and Japanese researchers studying Peru. Several activities were developed in the first year of the project, focusing on Lima Metropolitan City as an initial priority. In the future, the research should extend to other Peruvian cities located in seismic areas.

BACKGROUND TO PERU'S SEISMIC HISTORY

Seismic history up to the twentieth century

Peru is located in the Ring of Fire, almost at the meeting of two tectonic plates, the South American and Nazca plates, which, as experts explained, move to produce an effect called subduction, which in recent years has led to a large number of highly destructive earthquakes in the western part of Peruvian territory. Local and regional earthquakes are caused by local faults. These earthquakes are of lesser magnitude, but occur very near the surface and have great destructive power.

The most destructive earthquake in Peru's history occurred in May 1970, causing about 70,000 casualties, deaths or missing people, mostly in the department of Ancash. Lima has a long history of earthquakes, the largest of which occured in 1746. Only 25 of the city's 3,000 houses remained. In the port of Callao, due to the tsunami following the quake, a total of 4,000 people survived only 200. In 1940, another major earthquake, which measured 8.2 on the Richter scale, led to 179 deaths and 3,500 casualties.

The earthquakes occurring in ancient Peru, dating almost from the Spanish conquest, represent a history of destruction, death and other effects. The long, rugged territory, low-density population, lack of communication means, the concerns of conquerors for garnering support in these new lands, and civil unrest, were all linked to the rudimentary nature of scientific knowledge at the time and the inability to secure more information or make what would today be called a geographic seismic catalogue. The available data is incomplete and scattered between previously unpublished or poorly known works in the religious annals, or stories of famous travelers visiting this part of the continent. The historian Don Jose Toribio Polo (1904), who analyzed all these sources and others, believed there were more than 2,500 tremors on Peruvian territory from the conquest until the late nineteenth century, and warned that, for various reasons, many earthquakes were not recorded from 1600 to 1700.

The damage was extensive because buildings were unable to withstand the violent ground motion. Built using regional materials and according to climatic conditions, the prevailing constructions featured adobe and thatch on the coast, and stone in the highlands and Arequipa City, where they were built from sillar.

In the mid-seventeenth century, Lima, the main metropolis of South America, acquired and developed a peculiar physiognomy. Its straight streets, brick and adobe buildings with wooden balconies, and 70 temples and towers were a source of pride. The 1687 earthquake destroyed this architectural beauty, which was later rebuilt by the Viceroy Melchor de Navarra and Roca, only to be destroyed again by the great earthquake of 1746, accompanied by a tsunami that devastated the main port of Callao.

During this period, other emerging Peruvian cities were destroyed by tremendous earthquakes: Arequipa in 1582, 1600 and 1784; the imperial city of Cuzco in 1650; and Trujillo in 1619 and 1725. Several earthquakes occurred during the nineteenth century, of which of one the most intense occurred in 1868, devastating Arequipa, Tacna and Arica. This was followed by a tsunami that ended shocked the entire Pacific Ocean, reaching the remote beaches of Japan, New Zealand and Australia.

In the twentieth century, earthquakes notable for the intensity and devastation they caused struck Huancabamba Piura (1912), Caravelí (1913), Chachapoyas (1928), Lima (1940), Nazca (1942), Quiches, Ancash (1946), Satipo (1947), Cuzco (1950), Tumbes (1953), Arequipa (1958–1960), Lima (1966), Chimbote and Callejon de Huaylas (1970) and Lima (1974).

Major earthquakes in the twenty-first century

Two major earthquakes hit the Peruvian territory in this century.

First, the southern Peru earthquake of 2001 had a magnitude of 8.4 and occurred at 20:33 UTC (15:33 local time) on Saturday, 23 June 2001, at 16.26 (S) latitude and 73.64 (W) longitude. Affecting the Peruvian departments of Arequipa, Moquegua and Tacna, this earthquake was Peru's most devastating since the 1970 catastrophe in Ancash.

The earthquake left a death toll of 240 people, including 26 who died as a result of the tsunami, which also caused the disappearance of 70 people. The relatively low death toll was partly due to the tsunami occurring outside the main tourist season and also at low tide. Approximately 320,000 people were affected by the earthquake, 17,500 houses were destroyed and 35,550 were damaged around the cities of Arequipa, Camana, Moquegua and Tacna. The quake was felt with great intensity in northern Chile, where it caused three deaths. In Bolivia, the earthquake caused panic in La Paz and El Alto, as well as damage to many homes in the provinces of La Paz and Oruro.

Second, the Peru earthquake of 2007 occurred on 15 August 2007 at 23.40. UTC (18:40 local time), lasting about 175 seconds (2 minutes 55 seconds). Its epicentre was located off the coast of central Peru, 40 km west of Chincha Alta and 150 km southwest of Lima, and its hypocentre was 39 kilometers deep. This earthquake was one of the most violent to have occurred in Peru in recent years and the most powerful in terms of intensity and duration (Figures 1–2), but not the most catastrophic, since the 1970 earthquake caused thousands of deaths.

The earthquake, which scored a 7.9 seismic moment magnitude or VI-IX on the Mercalli scale, left 513 dead and almost 2.291 injured. In addition, 76,000 houses were totally destroyed or uninhabitable, affecting 431,000 people. The worst affected areas were the provinces of Pisco, Ica, Chincha, Cañete, Yauyos, Huaytará and Castrovirreyna. The destructive magnitude of the earthquake also caused extensive damage to infrastructure that provided basic services to the population, such as water, sanitation, education, healthcare and communications.

Figure 1 Map of Peru and main cities

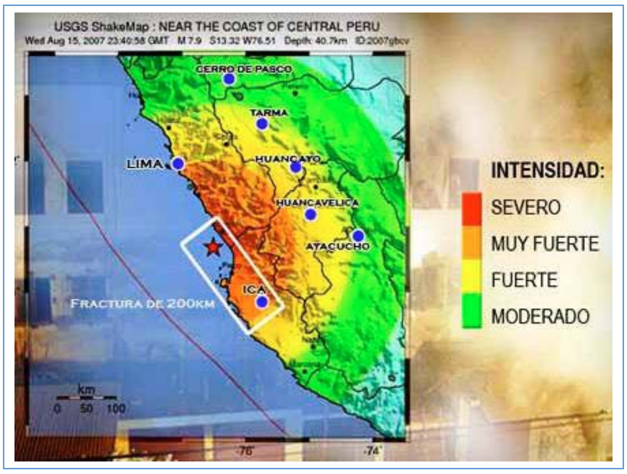

Figure 2 Intensity map of Pisco earthquake, (15 August 2007)

ORGANIZATIONAL STRUCTURE OF THE PROJECT

The relationship between Peruvian and Japanese researchers in the field of earthquake engineering and disaster mitigation was initiated many years ago. In 1986, the Peru–Japan Seismic Investigation and Mitigation Center (CISMID) was created, officially linking the National Engineering University (UNI) in Lima with prestigious research institutes in Japan. Thus in 2008 collaboration began between Chiba University (under the leadership of Prof. Fumio Yamazaki) and UNI (under the leadership of Prof. Carlos Zavala) in the area of natural disaster prevention through the Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru project within the Science and Technology Research Partnership for Sustainable Development (SATREPS) research programme under the joint sponsorship of Japan Science and Technology Agency (JST) and the Japan International Cooperation Agency (JICA).

The significance of this joint research between Peru and Japan can be summarized in four points: 1) Japanese science and technology contributing to disaster mitigation in Peru, 2) providing research fields to Japanese geoscience and earthquake engineering, 3) the contribution to international tele-tsunami research for subduction-zone earthquakes, and 4) the promotion of disaster mitigation and capacity building by sharing knowledge from international joint research.

The joint research is focusing on five main research topics (Figure 3): 1) strong-motion prediction and development of seismic microzonation, 2) the development of tsunami countermeasures based on numerical simulations, 3) enhancing the seismic resistance of buildings based on structural experiments and field investigations, 4) the development of a spatial information database using remote sensing technology and earthquake damage assessment for scenario earthquakes, and 5) the development of an earthquake and tsunami disaster mitigation plan and its implementation in society.

Five groups of Japanese and Peruvian researchers have been formed to work on the following topics:

- G1: Seismology and geotechnical engineering (source and soil response)
- G2: Tsunami (size, impact and countermeasures)
- G3: Buildings (current state and enhancement of building resistance)
- G4: Damage assessment (geo-spatial inventory, damage assessment methodologies and earthquake scenario simulations)
- G5: Planning (development of disaster mitigation plans)

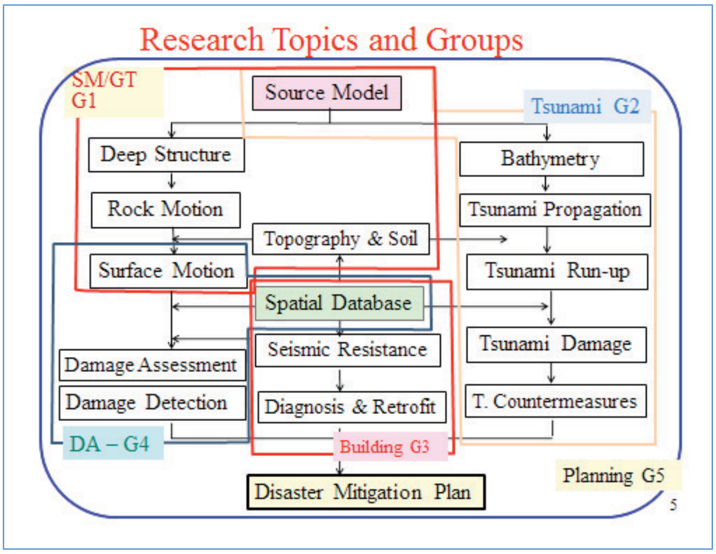

Figure 3 Research topics and project items

The Peruvian contingent is led by the Japan–Peru Center for Earthquake Engineering Research and Disaster Mitigation (CISMID) of the Faculty of Civil Engineering of the National University of Engineering of Lima, and includes the National Institute of Civil Defense (INDECI), the Institute of Geophysics of Peru (IGP), the National University of San Marcos (UNMSM), the Ministry of Culture (MCUL), the Ministry of Housing (MVCS), the Directorate of Navigation and Hydrography of the Navy of Peru (DHN), and the Private University of Tacna (UP Tacna). (See Figure 4.)

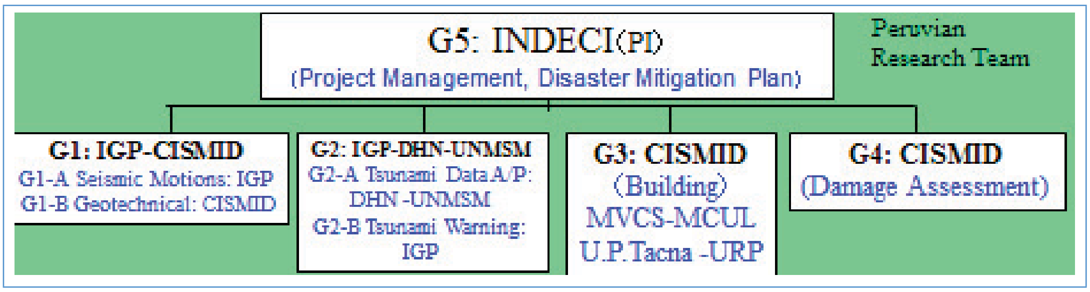

Figure 4 Peruvians institutions participating in the project on various topics

The following seven outputs are listed in the master plan agreed on January 2010:

1. Identification of scenarios of large-magnitude inter-plate earthquakes that could cause the most significant losses in Peru (G1, G2)
2. Preparation of geographical information for the study areas (G4)
3. Estimated tsunami disaster losses in study areas by scenario earthquake, and development of mitigation technologies (G2)
4. Simulation of strong motion and ground failure in study areas by scenario earthquake simulated (G1)
5. Estimation of earthquake disaster losses in study areas by scenario earthquake and development of mitigation technologies (G4)
6. Development of technologies for evaluating seismic resistance and structural retrofitting, adapting to the features of Peruvian buildings (G3)
7. Promotion of earthquake/tsunami disaster mitigation in the study areas (G5)

Activities developed during 2010 and the beginning of 2011

1. G1: Seismology and geotechnical engineering (source and soil response)

- A training course was developed on evaluation technologies for seismology (G1) and tsunamis (G2) (IGP-DHN-UNMSM-UNI), and knowledge was exchanged on the evaluation of seismic sources, seismic hazards and tsunami evaluation (Figure 5).
- Equipment was received (CV 374AV2 sensor network, GEODAS-15 HS equipment and a Network Seismocorder CV-575). A linear arrangement was performed in Puente Piedra, La Molina, Villa El Salvador, San Martin de Porres, and the Callao districts of Lima City. In addition, generation waves and signal acquisition were performed (Figure 6).

Figure 5 Training course on evaluation technologies for seismology.

Figure 6 A linear arrangement setting a distance between sensors of 0.5–2.0 m in Reserva Park, Lima

2. G2: Tsunami (size, impact and counter measures)

- A training course for Peruvian researchers to estimate inundation patterns and tsunami parameters (Figure 7)
- A long-term training course for DHN staff at Tohoku University
- Coordination meetings with Japanese experts

Figure 7 Training course for CISMID, DHN and UNMSM researchers to estimate inundation patterns and tsunami parameters

3. G3: Buildings (current state and enhancement of building resistance)

- An inspection of damage caused by the 27 February 2010 earthquake in affected cities in southern Chile, involving a joint team of researchers from Peru and Japan
- A course on the behavior of concrete elements by a Japanese expert at CISMID (Figure 8)
- The Japanese G3 mission visited Lima and Tacna buildings. (Tacna City in southern Peru will be the second city studied in the project.) (see Figure 9)

Figure 8 Course on behavior of concrete elements by Prof. Shunsuke Sugano at CISMID

Figure 9 Japanese Mission visiting the Private University of Tacna G4: damage assessment (geo-spatial inventory, damage assessment methodologies and earthquake scenario simulations)

- Development of a building inventory and a geo-spatial database
- Damage simulations (earthquakes and tsunamis)
- Seismic risk assessment for earthquake scenarios
- Damage assessment methodologies and web-based system for data dissemination (Figure 10)

Figure 10 Different types of land use, La Molina district, Lima (2010) – measuring the social vulnerability of residents from satellite images used to infer the quality of housing

4. G5: Planning (development of disaster mitigation plans)

- In March 2010, the first Japan–Peru workshop was held with reknowned researchers from Japan and Peru, along with researchers from Ecuador, Mexico and Colombia. More than 400 people attended the plenary session (Figure 11).

The project was presented to the Natural Disaster Committee of the Peruvian Congress (Figure 12).

Figure 11 Workshop sessions

Figure 12 Peruvian Congress Disaster Mitigation Seminar

CONCLUSIONS

Given its location on the Pacific Ring of Fire, Peru has a long history of destructive earthquakes, which have left thousands dead and caused significant material damage. Recent earthquakes have occurred in coastal areas, followed by tsunamis that hit coastal towns.

Since 2010, recognized Peruvian institutions and universities involved in the field of earthquake engineering and disaster mitigation, under the leadership of CISMID of the National Engineering University in Lima, have collaborated with prestigious institutions in Japan on the project aimed at the Enhancement of Earthquake and Tsunami Disaster Mitigation Technology in Peru.

This project sponsored by JICA and JST will enable Japanese science and technology to contribute to disaster mitigation in Peru, provide research fields to Japanese geoscience and earthquake engineering, contribute to international tele-tsunami research for subduction-zone earthquakes, and promote disaster mitigation and capacity building through sharing knowledge from international joint research.

During its first year, the project carried out various activities in each of the working groups focusing on various research topics, working in the main districts of Lima. In the coming years, the research will extend to two more cities in the country.

ACKNOWLEDGMENTS

The authors extend their gratitude to the Director of CISMID, who allowed the author's participation in the 2010 IPRED meeting in Padang, Indonesia. We also thank the professors of the University of Chiba, and researchers from other Japanese institutions and universities who have participated in the project, as well as the JST and JICA for contributing to the development of earthquake engineering and disaster prevention in Peru.

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ANALYSIS OF SEISMIC EFFECTS IN ALMATY BASED ON STRONG MOTION NETWORK DATA

T. Abakanov[1] and N. Silacheva[2]

[1]Director for the Institute of Seismology, Ministry of Education and Sciences, Kazakhstan.
Email: seismolog@topmail.kz

[2]Leading Researcher at the Laboratory of Engineering Seismology
and Earthquake Engineering, Institute of Seismology,
Ministry of Education and Sciences, Kazakhstan.
Email: silacheva_nat@mail.ru

ABSTRACT

Data acquired over 10 years by the digital strong motion observation network in Almaty, the most earthquake prone megalopolis of Kazakhstan, has made it possible to create a ground motion database, indicating ground motion parameters for very deep sedimentary basins and providing material for city zoning based on these parameters and soil spectral characteristics. This paper presents the ground motion parameters, with directions for their use in seismic risk mitigation.

KEYWORDS

Strong motion network, database, attenuation relations, seismic hazard assessment, spectral ratio

INTRODUCTION

Strong motion network records provide information on real ground motion parameters in specific conditions and enable the modeling of seismic effects during likely future earthquakes, providing the basic data for earthquake engineering and seismic risk mitigation.

The first digital strong motion network was deployed in Kazakhstan in 2000 within the scope of international scientific and technical cooperation with Japan. Fifteen sets of ALTUS–ETNA accelerometers were installed in the most earthquake prone megalopolis of Kazakhstan, Almaty, and its surrounding region. Figure 1 shows the station layout against Pz-basement depth isolines (Shatsilov, 1989) and the system of intra- and inter-block faults in the city. Over 10 years, the network has produced statistically uniform data in terms of the local geological and soil conditions forming the local spectral features of ground motions, revealing areas characterized by higher ground shaking and enabling the creation of a ground motion database. It is difficult to overstate the importance of this database for engineering seismology calculations, seismic hazard assessment and microzonation in Almaty and the whole southeast of Kazakhstan.

296 records (×3 components) from 43 earthquakes with an epicentral distance of 10–340 km were obtained during the network operation period. The strongest earthquake occurred on 14 February 2005 at the China–Kyrgyzstan border 260 km from Almaty and measured 5.9 Ms, while the closest one occurred on 19 June 2002 at <2 Ms and an epicentral distance of 9–26 km. Maximum accelerations were recorded during the close 29 December 2006 earthquake (3.7 Ms, Rep=46 km) on the VRG site (55.9 cm/s2) and during the stronger but more remote 1 December 2003 Narynkol earthquake (5.7 Ms, Rep=300 km) on the ARZ (35.6 cm/s2) and SLH (30.3 cm/s2) sites.

The data is processed using the Kinemetrics Strong Motion Analyst programme. Waveforms are kept as Altus series EVT files for acceleration, and ASCII files for acceleration, velocity and displacement. Processing results are entered into the databank, which contains a catalogue of registered earthquake source parameters, main and spectral parameters of records, an album of local characteristics of ground-motion observation sites (description, stratigraphic columns, P and S wave velocities, and density). For the strongest events, a bulletin is compiled including earthquake and observation points, graphic waveforms, Fourier amplitude spectra and response spectra. The ground-motion database is kept on Microsoft Access software.

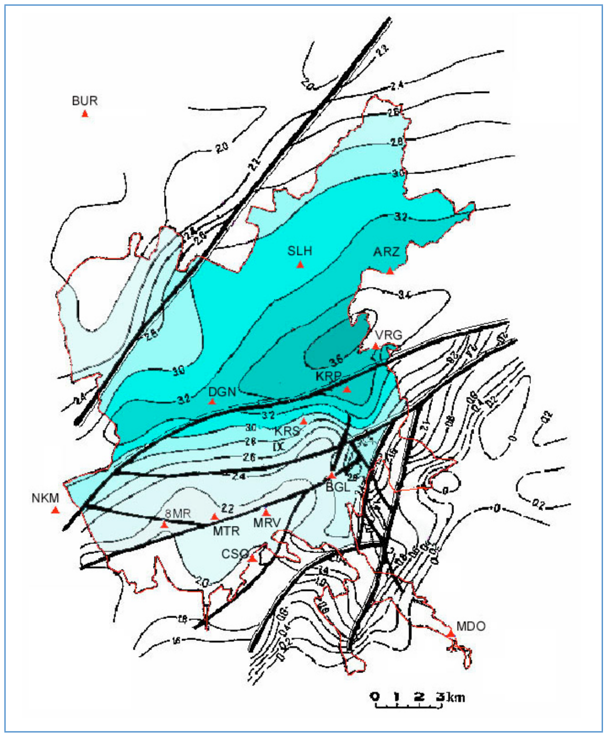


Figure 1 Location of digital strong motion stations in Almaty territory along the Paleozoic basement depth isolines and fault system (modified from Shatsilov, 1989)

DISTRIBUTION OF GROUND MOTION PARAMETERS DURING REAL EVENTS

Table 1 shows the distribution of maximal acceleration amplitudes over the city for 10 events, while Figure 2 describes the epicentres of these earthquakes.

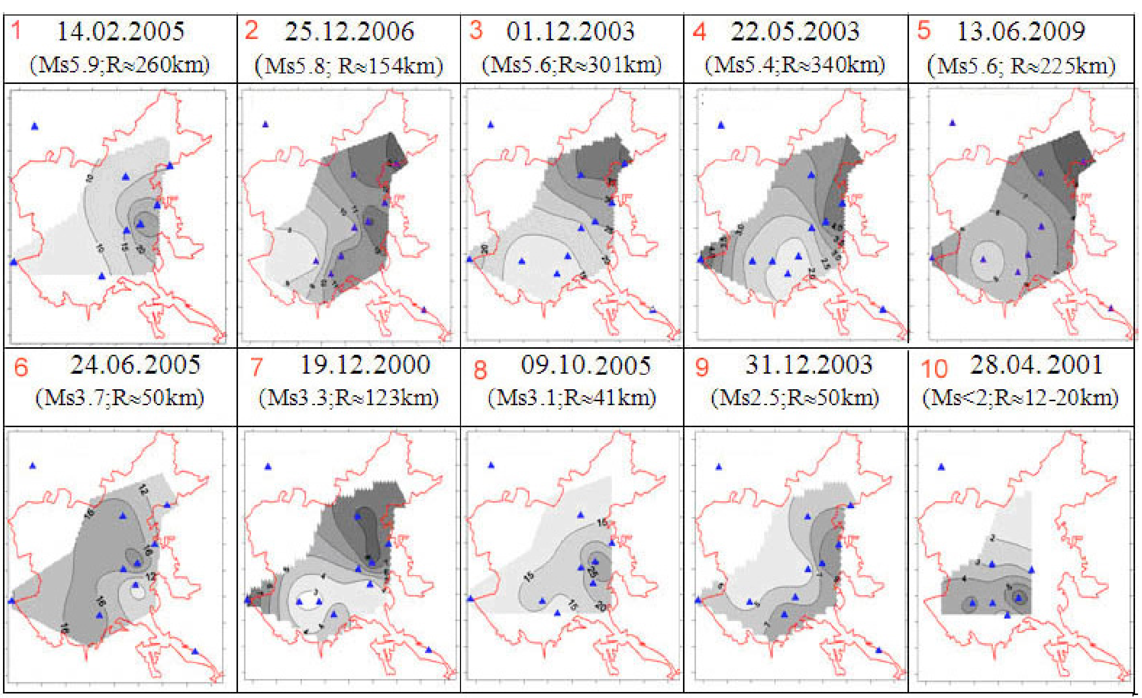


Table 1 Distribution of maximum acceleration amplitudes over the city

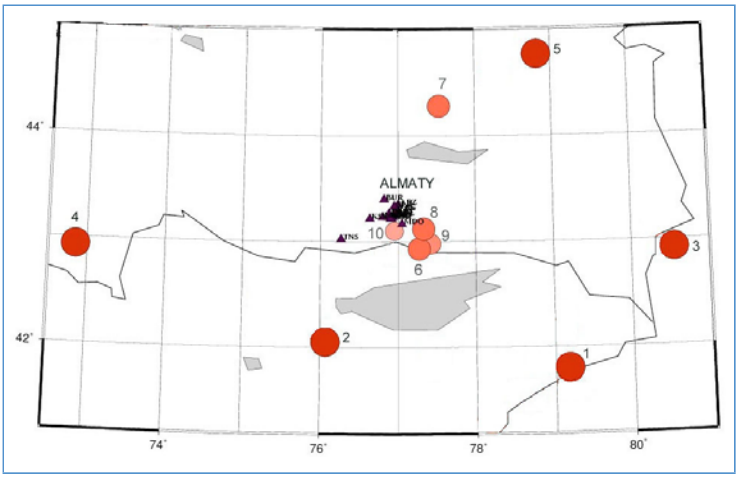


Figure 2 Location of epicentres for which spatial distribution of waveform parameters were obtained

For most recorded earthquakes, the acceleration amplitudes match the total thickness of sedimentary cover, but this pattern changes for nearby events (Figure 1), depending on the angle of waves approaching the sedimentary cover bottom, as well as the wave route in the sedimentary cover (soil type, fault zones, etc). During remote events, waves travel in the basement, then approach the sedimentary cover sub-vertically under a station, whose site conditions determine ground motion amplification. In this case, the general pattern of acceleration distribution is similar for different events. During nearby events, the sub-surface geology vibrates the entire way from an earthquake source to the observation site. Thus sufficiently remote earthquakes with an epicentral distance of at least 100 km should be chosen to study the seismic properties of soils in the city. At the same time, the fault system should be taken into account for city microzonation, and microzonation should take into account the system of faults that are not seismogenerative but when combined with the basin geometry can significantly change a ground motion pattern during earthquakes. The city's most seismically dangerous seismogenerative zones are also located nearby, less than 10 km away (the ≤8 Ms Zailiyskaya zone) and 30 km southeastward (the Kungeiskaya >8 Ms zone).

The lefthand side of Table 2 contains accelerograms (horizontal components) for five events recorded by the stations located in different engineering-geological conditions. In each case, the component with the highest peak acceleration is chosen. The earthquakes are listed from left to right in order of magnitude. Although the 1 December 2003 earthquake in Narynkol was of a smaller magnitude than the 14 May 2005 earthquake (Ms 5.7 vs 5.9) with an epicentre located further from the observation sites, the accelerations recorded in Almaty during this event were on average 2.2 times higher than those recorded during the second earthquake (Table 2). Table 2 shows the depth of the Paleozoic basement (sedimentary cover thickness) at the observation sites in descending order and the waveform differences caused by features of earthquakes and site conditions. The influence of the sedimentary layer and its dynamic characteristics is one of the most important factors determining seismic effects. Usually waveforms obtained in different site conditions differ even within the scope of an event (e.g. Nakamura, 2000) and each site displays typical waveforms during different events.

In this research, the territory is rather local and peculiarities bound with different events are more expressed. Even here, however, waveforms of the only station located on rock (MDO) are similar for different events, but differ from other station waveforms. Close events have much higher frequency waveforms than stronger, more remote earthquakes. Changing dynamics of acceleration predominant periods can be traced on response spectra placed on the righthand side of Table 2. It includes response spectra (ξ=5 per cent) for horizontal accelerations normalized to their maximal values. The spectra of the earthquake on 14 May 2005 (5.9 Ms; Rep≈260km) with maximal Ms have maximal predominant periods. The spectra of the Narynkolskoye earthquake on 1 December 2003 (5.6 Ms; Rep≈301km) are characterized by significantly higher acceleration levels and shorter predominant periods than the spectra of the Lugovskoe earthquake on 22 May 2003 (5.4 Ms; Rep≈340km). In general, the lower the magnitude, the narrower and higher the frequency of the spectra. In the case of remote events, the wave varies in spectral content when going through an absorbing medium, becomes lower frequency and attenuates more slowly. Other features of the obtained spectra can be explained by local site conditions, as well as by secondary and casual factors, so vibrations in a site can often have unexpected deviations from the average pattern observed over a large area.

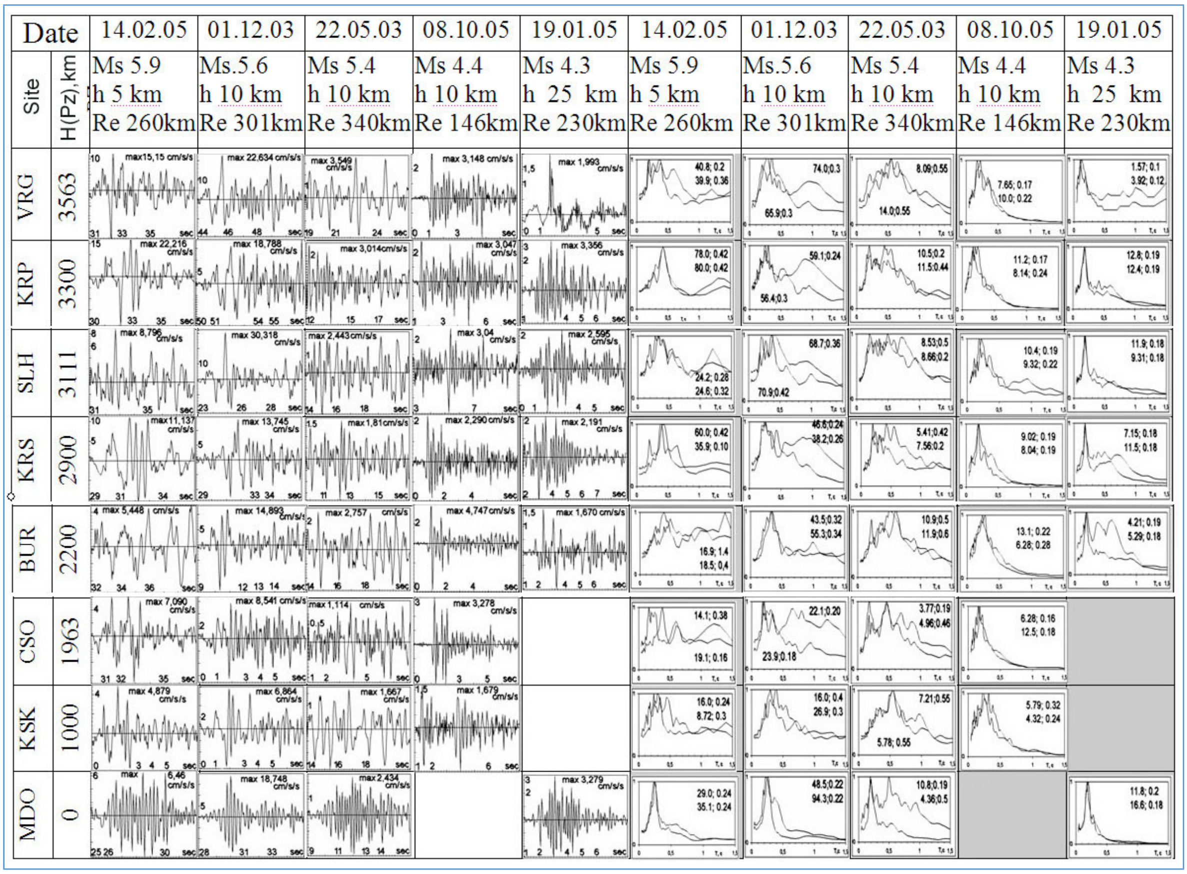


Figure 3a Acceleration waveforms recorded by different stations of the city's strong motion network, and corresponding normalized response spectra

Figure 3a shows predominant periods of Fourier spectra plotted compared with magnitude and distance for the data obtained by the network. A scattering of values is observed within separate events due to differences in site conditions and in separate events, with different source spectra and wave routes. However, the maximum differences are due probably to the influence of basin peculiarities in Almaty. Even for magnitude 4 (3.6–4.5) the predominant peaks in some cases correspond to surface waves with much larger periods than body waves. For magnitude 5 the number of peaks due to surface waves considerably increases and becomes dominant for magnitude 6. At this magnitude, both surface waves produced by the basin geometry and numerous faults inside the basin, and surface waves coming to the basin from outside are observed, supported by considerable amplification of vertical components as well as by H/V spectral ratio analysis for the MDO station and the new TNS station located on rock. In all magnitude groups, the periods increase with magnitude and distance. It is early, however, to speak about predictive relations that take into account all the complication factors, when the maximum periods may refer to different wave types. The distribution of predominant periods over the city territory shows longer periods in the areas with thicker sedimentary cover.

Figure 3b shows the dependence of the effective duration on the estimated magnitude and distance for the available data set. Duration was determined as the time required to build up from 5–95 per cent the integral:

$$\int_0^T \sum_{i=1}^{3} a^2 dt$$

where T is the total record duration, a – acceleration and i – the record component. Major records were obtained on soft soil that induced large data scattering. At distances exceeding 100 km, a decrease in duration with distance is observed for all magnitude groups. Further acquisition of data for the entire range of distances and magnitudes will produce statistically significant attenuation relations for effective duration in the future.

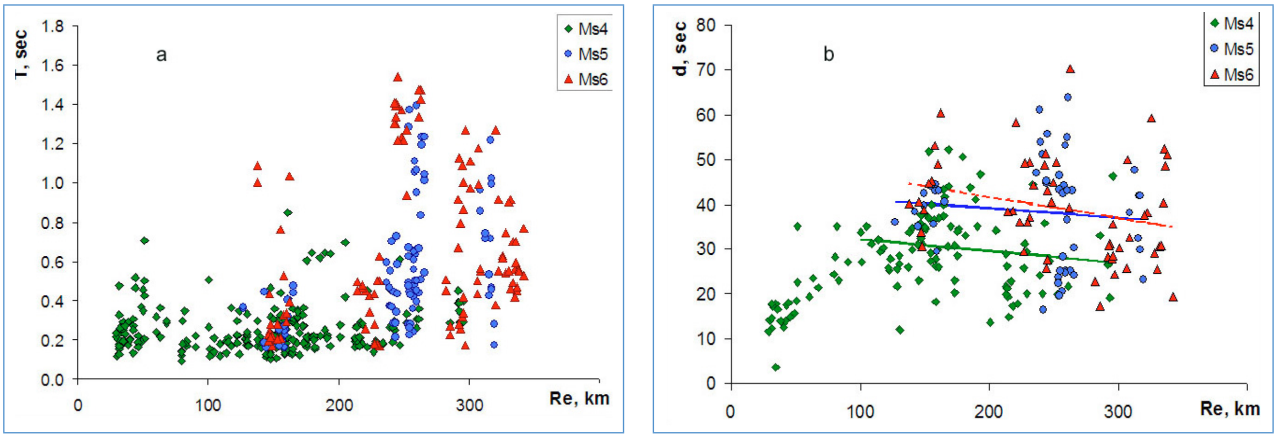


Figure 3b Changes in predominant period (a) and effective duration (b) with magnitude and distance

GROUPING OF STATIONS ACCORDING TO GROUND MOTION PARAMETERS

The stations were divided into three groups characterized by different recorded seismic effects, based on the spatial distribution analysis of recorded and calculated parameters (amplitudes, periods and duration) in conjunction with structure (topography) of the sedimentary cover within the city territory, surface stratigraphy in sites and velocity and density characteristics of soils (Figure 4).

The first group of stations were set up over areas with maximal Paleozoic basement sinking. The sedimentary cover under them is 2.5–3.5 km thick. Soils here are classed as II-III category (buildings, etc., 2006). In the upper 20 m section under the stations of the first group, Vs-velocities vary considerably within the range of 0.2–0.6 km/s (Figure 4a) and ground densities within the range of 1.6–2.4 g/cm^3 (Figure 4b), due to the layered structure of soils in the piedmont plain. Station parameters in the second group differ only in the 4 metre subsurface layer underlaid by the same type of bouldery-shingle debris cones with similar characteristics: 0.60–0.62 km/s and 2.20–2.22 g/cm^3 for Vs and ρ respectively. These stations are located on 2.0–2.4 km thick bouldery-shingle strata of mountain river debris cones. Soils are placed in the second group, where the KSK station has slightly different velocity and density characteristics of debris cone grounds: 0.76 km/s and 2.12 g/cm3. The MDO station located on rock is placed in the third group. In MDO Vs=2.9 km/s, ρ=3.15 g/cm^3.

The level and form of response spectra confirm that the obtained division and station groups are clearly distinguishable in the plotted proportion of spectral levels for different cinematic parameters. (An example for the Lugovskoe earthquake is given in Figure 5.)

Possible coincidences are checked for each event in terms of the differences between accelerations recorded at different stations and those expected from city microzoning. For the same purpose, the research examines whether the response spectra of the events recorded in the city fit into the range of periods covered by the Kazakhstan building code's response spectra for corresponding soil categories. Figure 6 shows acceleration response spectra normalized by maximal amplitude of ground vibration for the VRG station located in the area of maximal thickness of sedimentary cover and for the MDO station located on rock; the spectra are given against the background of the BC β-curves (designed spectra) for corresponding soil categories.

An analysis of sets of individual normalized response spectra enables soil category to be determined for sites, as well as the influence of the source, route and site condition on their form. In general, the obtained pattern of maximal acceleration distribution during an earthquake fits with the operating seismic microzoning map of Almaty with the exception of some local discrepancies.

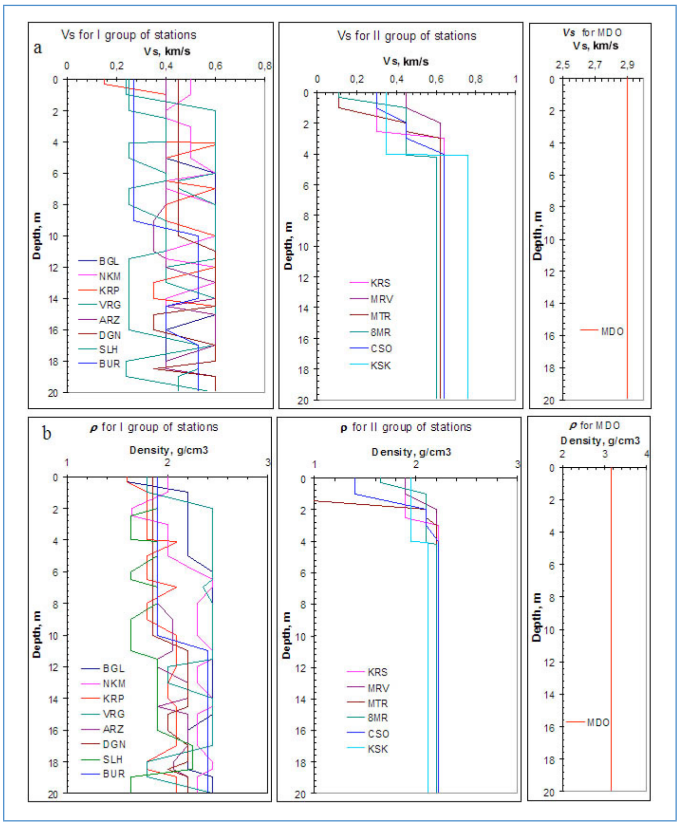


Figure 4 Variations in velocity Vs (a) and ground density (b) with depth in the upper 20 m layer under the station groups

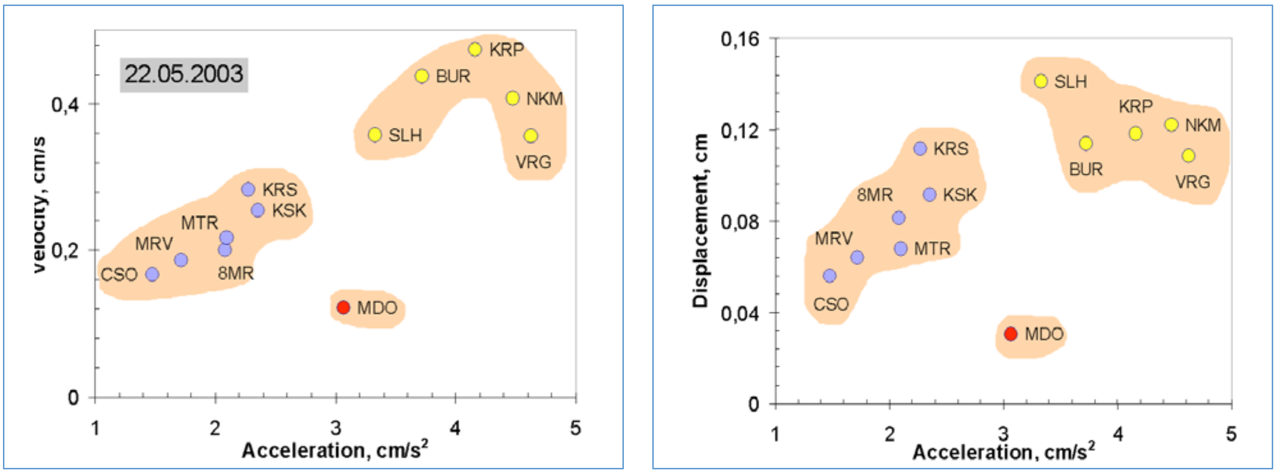


Figure 5 Relation between maximal spectral accelerations, velocities and displacements for the 22 February 2003 Lugovskoe earthquake

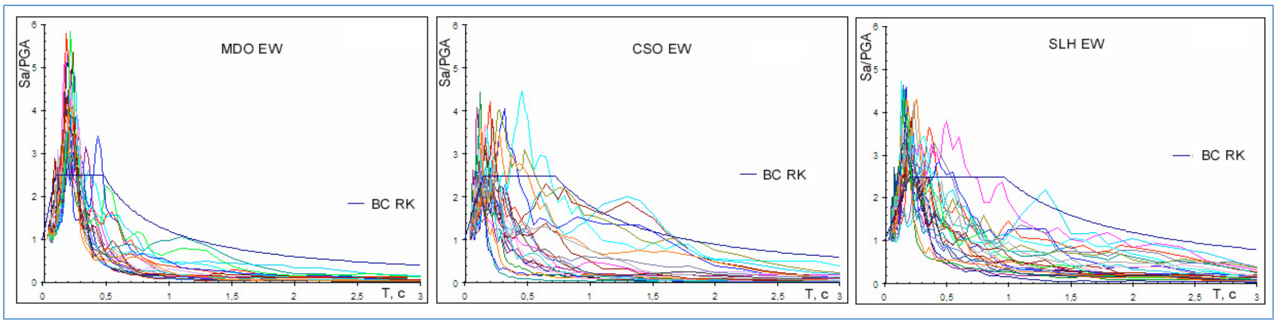


Figure 6 Acceleration response spectra normalized by maximal amplitude of ground motions for the MDO (I category), CSO (II) and SLH (III) stations

ATTENUATION RELATIONS AND PSHA

Although the collected strong motion accelerograms do not cover the range of magnitudes and distances required for the development of independent attenuation relations for ground motion peak parameters, they are very useful for choosing and adaptating world relations for areas with similar characteristics. Figure 7 shows the peak ground acceleration (PGA) attenuation model (Campbell и Bozorgnia, 2006) for rock corrected with network data for Almaty conditions.

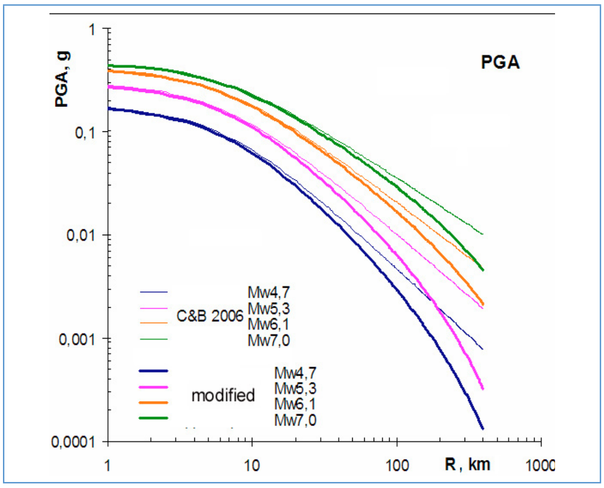


Figure 7 Campbell and Bozorgnia's (2006) PGA attenuation model for basement modified with network data

To obtain our own regional relations, an attempt was made to use strong-motion data together with data from other seismological networks in Kazakhstan (records of earlier local and regional analogue networks and records of regional network of digital velocigraphs). Such an approach enables PGA and peak ground velocity (PGV) attenuation relations to be obtaned in southeastern Kazakhstan for prediction ground motions in seismic hazard assessment and microzonation. As an example, Figure 8 shows the PGV attenuation model for Category II soil, based on complex data for the 6 Ms group, together with observed peak velocities, a corresponding residual distribution and a histogram.

Attenuation relations obtained for earthquake-prone areas of Kazakhstan are an important part of seismic hazard assessment. They are used to obtain spatial distribution of peak ground acceleration in the territory of some administrative districts and Almaty City. As an example, Figure 9 shows probabilistic seismic hazard maps in PGA for the territory of Almatinskaya Oblast. Calculations are made for the bedrock level (Vs≥1,500 m/s) without considering the influence of sedimentary cover (Silacheva, 2010).

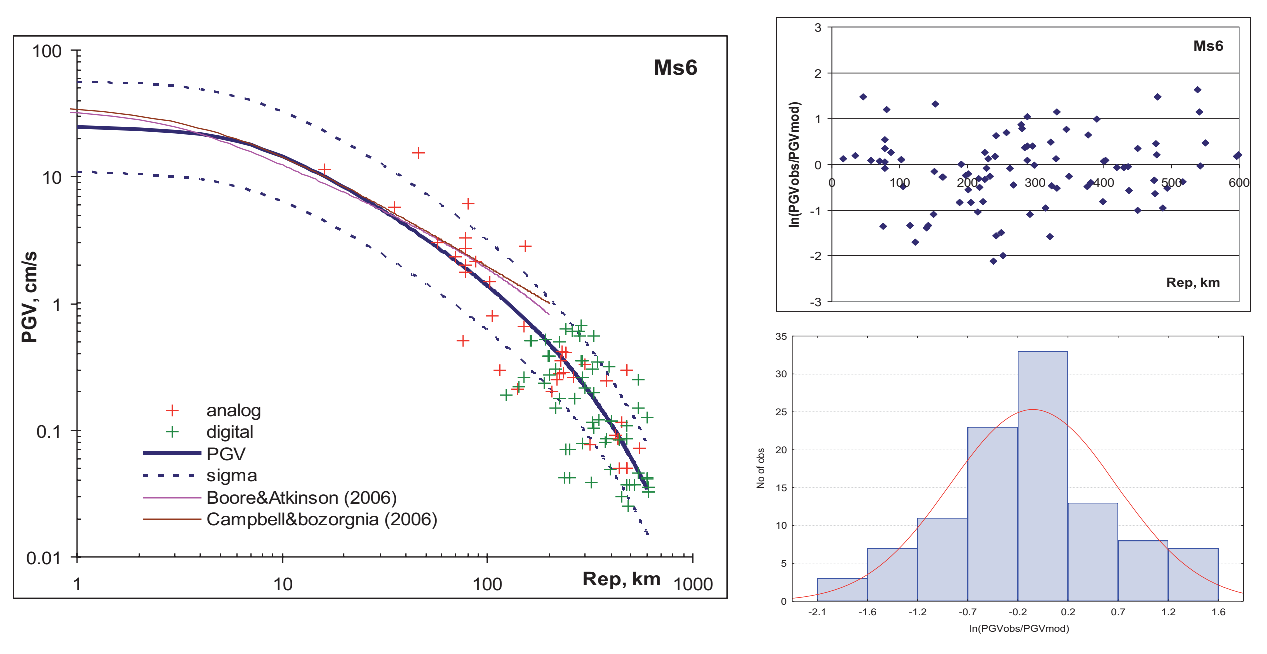
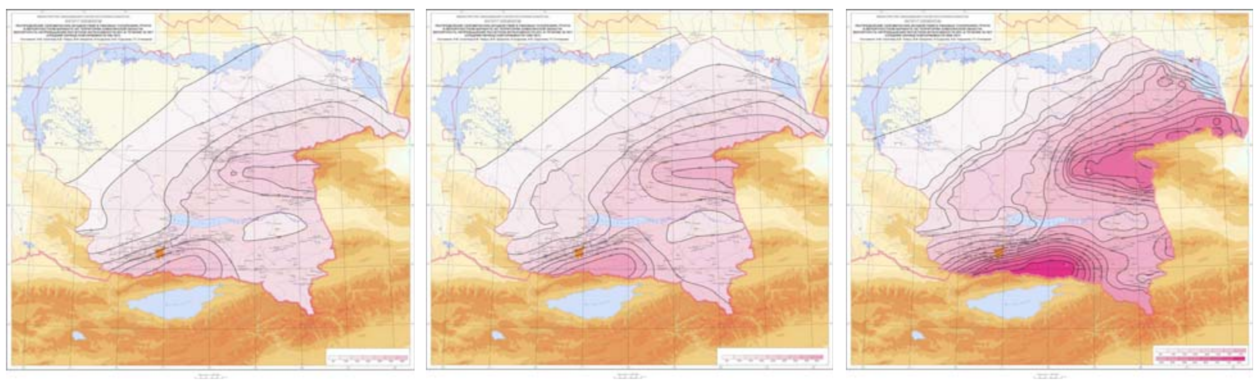


Figure 8 PGV attenuation model for 6 Ms and corresponding residual distribution and histogram

SPECTRAL RATIOS

Spectral analysis of network records enables empirical transfer functions to be obtained in the area of strong motion stations, and the city territory to be zoned with respect to the spectral characteristics of soils. For each station, the average spectral ratios of the Fourier spectra horizontal component over vertical are calculated and the average standard spectral ratios are obtained with relation to the reference MDO station located on the bedrock outcrop within the city. As an example, Figure 10a shows plots for the VRG station. The need to use both techniques is due to the imperfection of MDO as a reference station and the peculiarities of the basin in which Almaty is located (in the centre). From one side, the H/V ratio for MDO, averaged over all available events, shows amplification at frequencies of about 2–6 Hz (Figure 10b), probably due to topographic conditions or weathering of the upper rock layers. From the other site, in major cases both horizontal and vertical components of records are also amplified, changing the pattern of local amplification given by the H/V method. For all cases, there are complicated spectral ratios with amplification within the range of 0.2–3 Hz. The general level of amplification increases at the stations located on debris cones compared to the stations over the deepest part of the basin. A complicated form of empirical transfer functions and considerable amplification of vertical components may indicate the existence of 2D–3D effects in the Almaty area.



(a) (b) (c)

Figure 9 Peak ground acceleration maps for the Almatinskaya Oblast territory
The probability of intensity not exceeding calucations is:
(a) 90 per cent (b) 95 per cent and (c) 99 per cent, within 50 years

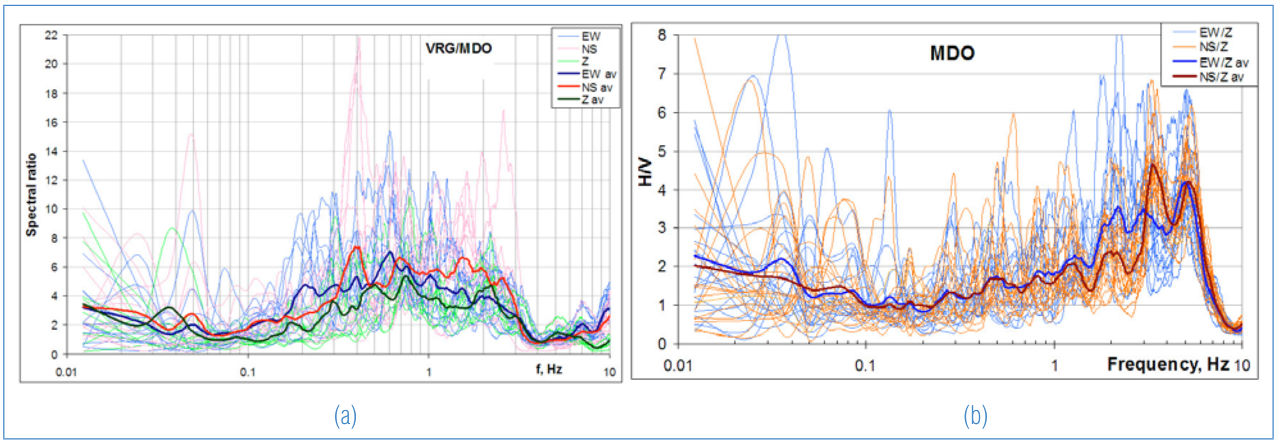


Figure 10 Spectral ratios (a) standard for the VRG station with respect to the MDO station, (b) H/V for the MDO station

CONCLUSIONS

A digital strong-motion database, the only of its kind in the region, has revealed the characteristics and distribution peculiarities of the main ground-motion parameters in Almaty. An analysis of spatial distribution of ground motion parameters in conjunction with the sedimentary basin structure in the city, surface stratigraphy, and the velocity and density characteristics of the ground at observation sites has enabled the stations to be divided into three groups with different recorded seismic effects in order to zone the city territory.

The network data is used to choose world attenuation relations and to adapt them to the conditions in Almaty and southeastern Kazakhstan, as well as to obtain original models for PGA and PGV attenuation. Spectral analysis of the network data has enabled empirical transfer functions to be obtained at the strong motion sites, to estimate possible amplification and to zone city territory according to the spectral characteristics of soils. Research along these lines is ongoing, although the strong motion network has already made a clear contribution to seismic effect prediction and seismic risk mitigation.

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GENERATION OF STRONG EARTHQUAKE ACCELEROGRAMS FOR INTERNAL LAYERS OF ANISOTROPIC MASSIF AS APPLIED TO UNDERGROUND STRUCTURE STABILITY ANALYSIS

T. Abakanov,[1] R. Baimakhan[2] and A. Abakanov[3]

[1]Director, Institute of Seismology, Ministry of Education and Sciences, Kazakhstan.
Email: seismolog@topmail.kz

[2] Main Researcher, Laboratory of Engineering Seismology
and Earthquake Engineering, Institute of Seismology,
Ministry of Education and Sciences, Kazakhstan.
Email: rysbek@ok.kz

[3]Engineer for Laboratory of Seismic Resistance of High-Rise Buildings,
Kazakh Research Institute and Experimental Design on
Earthquake Engineering and Architecture (KazNIISSA),
Agency for Construction and Housing, Kazakhstan.
Email: aseke@22mail.ru

ABSTRACT

This article describes a new algorithm, used as a basis for generating synthetic accelerograms of strong earthquakes, first for the land surface, and then for internal layers of anisotropic massif with an inclined layered structure, as applied to a seismic stability analysis of underground structure. To generate the layer-by-layer accelerograms in the internal layers of the massif, formulas were determined for the coefficient of variation with respect to accelerogram values on the land surface. Formulas were integrated for the coefficient of seismic wave amplification in the earth's crust at the transition from the rock bottom to the upper sedimentary mass. These formulas directly include the mechanical and physical properties of layers and were also therefore integrated for the anisotropic massif.

KEYWORDS

Disaster risk reduction, accelerograms of strong earthquakes.

INTRODUCTION

Seismic stability is no less important for underground structures than for above-grade buildings and structures. The seismically active zones of the earth include entire countries (Armenia, Chile, Japan, Romania and the Philippines), large cities (Ashgabat, Los Angeles, Mexico, San Francisco and Tashkent) and mineral deposits (in Kyrgyz Ala-Too, the Kazakhstani and Russian parts of Gorny Altai, the polymetallic Udokan in Russia's Chitinskaya Oblast, and in North America). In some countries, the underground space is developed intensively for the national economy and special or military purposes, while in large cities, many communal facilities are located underground, with an extensive network of communal and traffic tunnels (including metro tunnels on several floors). Here, mineral deposits are developed mainly using the underground method, by laying an extensive network of mine openings (horizontal, inclined or vertical, and temporary or permanent), creating capacious shaft insets and openings for operating powered or large-scale equipment and mechanisms.

Many specific issues regarding the seismic stability of underground structures were not studied as they should have been. Thus, for example, microseismic zoning of the territory is based on the surface layer of subsoil, while for underground structures, such zoning should also be based on subsoil depth. At different depths, the seismic properties of subsoil vary even within homogeneous formations, as well as heterogeneous, usually bedded formations.

The specific seismic effect on underground structural elements is merely the result of seismic waves transformed in the crust from the blocked structure on their way from the earthquake source. Each new earthquake changes the region's seismicity, reflecting the intensity of shaking, the frequency and origin of the new earthquake source. There is therefore no sense in focusing on records of previous strong earthquakes, even if they are available for new construction sites. It is better to develop synthetic accelerograms, taking into account verified data on the mechanical and physical properties of the earth in the construction area. Such accelerograms should also be developed for the internal layers of the massif, to measure the seismic stability of underground structures. This is no easy matter, especially if the massif has a heterogeneous composition and inclined layered structure. In nature, both subsoil and rocks most often have an anisotropic structure. It is necessary therefore to first develop an algorithm and create methodology for generating synthetic accelerograms of such complex sites.

1. THEORY AND METHODOLOGY

1.1 Generation of artificial accelerograms for free land surfaces during strong earthquakes

Below is the standard basic algorithm for synthetic accelerogram generation according to Eisenberg (1972), which has been developed in the works of Abakanov (2000) and Baimakhan (2000). In the present research, for incomplete seismological data, the following non-steady multiplicative random process is proposed as the most convenient mathematical model of motions:

$$x(t) = \begin{cases} \overline{A}(t,\overline{T}_i)\sigma(\overline{T}_i)\overline{\phi}(t,\overline{T}_i), & t \geq 0, \\ 0, & t \prec 0, \end{cases} \tag{1a}$$

Where standardized envelope line; mean square acceleration value; standardized steady Gaussian process; dominant process period ; time. Peak acceleration amplitude may be calculated by macroseismic formulas as follows:

$$C_I = 5 \cdot 10^{0.61M - p\lg x + Q}, \quad a_{\max} = \frac{C_I}{\sqrt{T}}, \quad I = bM + \nu \lg x + c, \tag{1b}$$

where - constants subject to determination from the seismological conditions of the region or territory: magnitude, attenuation factors, and other constants of macroseismic field; - hypocentral distance; - intensity; peak acceleration amplitude; - dominant ground vibration period. Using specific values of we generate an accelerogram for level 9-, 10- earthquakes using the formula as follows:

$$a(t,\overline{T}) = \overline{A}(t,\overline{T}_i)\sigma(\overline{T}_i)\overline{\phi}(t,T_i) \tag{1c}$$

Parameters integrated into (1a) are calculated using the following formulas:

$$\bar{A}\left(t,\vec{T}_i\right)=\frac{\bar{T}_i t}{20\pi}\exp\left(1-\frac{\bar{T}_i t}{20\pi}\right),\ \sigma_i^2\left(\bar{T}_i\right)=\frac{C_i}{18\pi}T_i^2,\ \bar{\phi}\left(t,\bar{T}_i\right)=\exp\left[\left(-\alpha\left(\bar{T}_i\right)\right)\left|r\right|\right]\cos\left(\bar{T}_i,r\right). \tag{1d}$$

where α – parameter characterizing the rate of decay of the correlation between ordinates of the random process at the increase in difference of these values arguments r.

1.2 Generation of layer-by-layer earthquake accelerograms for multilayer earth cover (generalization of Kanai's formula)

Previously it was believed that the acceleration level of subsoil decreases with depth, but this theory has been disproved. On the contrary, at some depths, the acceleration level may be even higher than on the land surface. This is evident from Japanese records of accelerograms of the same area during five different earthquakes, provided by Tsuchida et al. (1978) and shown in Figure 1.

A paper by Okamoto (1973) contains a formula for the semianalytical method by Kanai (1962), which provides the value of acceleration on the ground surface if acceleration on the surface of the rock foundation is known, as follows:

$$G\,(T)=1+\left\{\left[\frac{1+K}{1-K}\left\{1-\left(\frac{T}{T_G}\right)^2\right\}\right]^2+\left(\frac{0.3}{\sqrt{T_G}}\cdot\frac{T}{T_G}\right)^2\right\}^{-0.5} \tag{1e}$$

where $K=\rho_1 c_1/\rho_2 c_2$ – seismic impedances ratio; $G(T)$ – acceleration factor; T – period of arriving seismic wave; T_G – dominant period of surface layer motions; ρ_1,ρ_2,c_1,c_2 – density and speed of wave propagation in two layers.

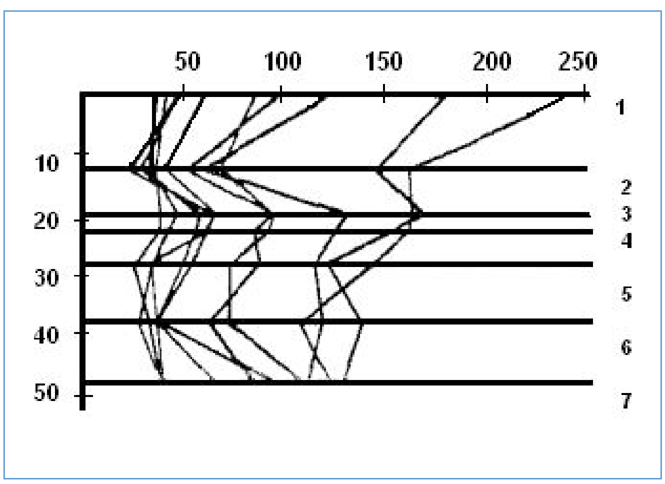

Figure 1 Change in surface accelerations (0–250 cm/s2) by depth (0–50 m) for different layers (1: sand, 2: silty clay, 3: sand, 4: clay, 5: gravel with lam, 6: higging, and 7: rocky)

Kanai's approach received further development in a paper by Aitaliyev and Baimakhan (2000). First, it was applied to the inverse problem (i.e. to obtain acceleration values at any depth, on the assumption of known values at the ground surface). Second, explicit expressions were obtained allowing the effects to be described, as shown in Figure 1.

Our approach can be summed up as follows. The earth's crust consists of several layers and the lowest underlying stratum is not necessarily rocky. Layer thickness is denoted by h_i, where $i = 1,2,3....$ – layer numbers. Within their thickness, the layers will be considered as homogeneous and isotopic, but generally anisotropic.

The speed of propagation in the horizontal plane of inclined layered anisotropic earth of the longitudinal and two quasishear waves (instead of one shear wave of isotopic layer) is calculated using the formulas developed by Yerzhanov et al. (1980) as follows:

$$V_P = \left\{\rho^{-1}\left\{\frac{E_1(n-\gamma_2^2)\cos^4\alpha}{(1+\gamma_1)\left[n(1+\gamma_1)-2\gamma_2^2\right]}+2\left[\frac{E_1\gamma_1}{n(1-\gamma_1)-2\gamma_2^2}+2G_2\right]\sin^2\alpha\cos^2\alpha+\frac{E_1(1-\gamma_1)}{n(1-\gamma_1)-2\gamma_2^2}\sin^4\alpha\right\}\right\}^{0,5},$$

$$V_{SV} = \left\{\rho^{-1}\left[G_2+\left(\frac{E_1(n-\gamma_2^2+1-\gamma_1)}{(1+\gamma_1)\left[n(1+\gamma_1)-2\gamma_2^2\right]}-\frac{2E_1\gamma_2}{n(1-\gamma_1)-2\gamma_2^2}-4G_2\right)\sin^2\alpha\cos^2\alpha\right]\right\}^{0,5},$$

$$V_{SH} = \left\{\rho^{-1}\left[G_2\sin^2\alpha+\frac{E_1}{2(1-\gamma_1)}\cos^2\alpha\right]\right\}^{0,5}. \quad (1f)$$

where $E_1, E_2, \gamma_1, \gamma_2, G_2, \rho$ – elastic constants, Poison's ratios, rigidity and density modulus; $\alpha = \varphi + \beta$; φ – angle of plane of isotropy with respect to horizontal axis Ox in rectangular coordinate system; β – angle between wave normal and axis Ox.

The paper by Baimakhan (2003) obtained expressions for the speed of elastic wave propagation in transtropic massif with normal $\bar{n} = \bar{n}\{\cos\alpha, \cos\beta, \cos\gamma\}$ in an arbitrary direction within inclined layered transtropic earth as follows:

$$V_p = \sqrt{\left(2\sqrt{-p/3}\cos(\delta/3)-b/3\right)/\rho},$$

$$V_{SH} = \sqrt{\left(-2\sqrt{-p/3}\cos((\delta+\pi)/3)-b/3\right)/\rho},$$

$$V_{SV} = \sqrt{\left(-2\sqrt{-p/3}\cos((\delta-\pi)/3)-b/3\right)/\rho} \quad (1g)$$

where $\delta = \arccos\left(-0.5q(-p/3)^{-3/2}\right)$, ρ – earth density, α, β, γ – angles between wave normal and rectangular axes $OXYZ$, $p = -b^2/3 + c$, $q = 2(b/3)^3 - bc/3 + d$, $b = -(A + E + Q)$, A, E, Q – parameters connected with elastic ratio of anisotropic massif. Compared with isotropic earth, two quasishear waves appear here. It should be noted that expressions of speed (1g) are the most general formula for any elastic earth. In particular, if we put $E_1 = E_2, \gamma_1 = \gamma_2, G_2 = G, V_{SV} = V_{SH}$, then from (1g) we go to the expression $V_P = (E(1-\nu))/(\rho(1+\nu)(1-2\nu))^{0.5}$, $V_S = (E/(\rho 2(1+\nu)))^{0,5}$, i.e. we obtain the known formulas for the isotropic earth, where E – Young modulus, ν – Poisson ratio, and ρ – isotropic earth density.

If three components of the accelogram above ground are known, then to obtain their changed values with the true vertical depth down, similarly (1g), the following formulas will be written for them:

$$G_{P_i}(T_{P_i}) = 1 + \frac{1+K_{P_i}}{1-K_{P_i}}(1 - \left(\frac{T_{P_{i-1}}}{T_{P_i}}\right)^2) + q\left(\frac{T_{P_i}}{T_{P_{i-1}}}\right)^2, G_{SV_i}(T_{SV_i}) = 1 + \frac{1+K_{SV_i}}{1-K_{SV_i}}(1 - \left(\frac{T_{SV_{i-1}}}{T_{SV_i}}\right)^2) + q\left(\frac{T_{SV_i}}{T_{SV_{i-1}}}\right)^2,$$

$$G_{SH_i}(T_{SH_i}) = 1 + \frac{1+K_{SH_i}}{1-K_{SH_i}}(1 - \left(\frac{T_{SH_{i-1}}}{T_{SH_i}}\right)^2) + q\left(\frac{T_{SH_i}}{T_{SH_{i-1}}}\right)^2, \quad \text{(q=0.09);} \tag{1h}$$

$$T_{P_i} = \frac{h_i}{V_{P,h_i}}, \quad K_{P_i} = \frac{\rho_{h_{i-1}} V_{P_{i-1}}}{\rho_{h_i} V_{P_i}}, \quad T_{SV_i} = \frac{h_i}{V_{SV,h_i}}, \quad K_{SV_i} = \frac{\rho_{h_{i-1}} V_{SV_{i-1}}}{\rho_{h_i} V_{SV_i}}, \quad T_{SH_i} = \frac{h_i}{V_{SH,h_i}}, \quad K_{SH_i} = \frac{\rho_{h_{i-1}} V_{SH_{i-1}}}{\rho_{h_i} V_{SH_i}}. \tag{1i}$$

Based on the known values of the accelerogram above ground of transtropic massif their values with the depth down will be obtained by dividing them by the coefficient of variation:

$$\ddot{a}_{P_{hi}}(t) = \ddot{a}_{P,h_{i-1}} / G_{P_i}(T_{P_i}), \quad \ddot{a}_{SV_{hi}}(t) = \ddot{a}_{SV_{hi-1}} / G_{SV_i}(T_{SV_i}), \quad \ddot{a}_{SH_{hi}}(t) = \ddot{a}_{SH_{hi-1}} / G_{SH_i}(T_{SH_i}). \tag{1k}$$

2. RESULTS

2.1 Generation of a synthetic accelerogram for the surface and internal layers of anisotropic massif.

To take an example, a metro station has an arched form and twin running tunnels laid at a depth of 50 m (Figure 2). Its geometrical dimensions measure H 125 m, W 45 m and L 160 m for the equilibration region, H 9 m, W 22 m and L 100 m for the stations, and H 2 m and W 2 m for the running tunnels.

The above region is broken by eight-node isoparametric prismatic elements with eight additional internal integration points at 3,508 spacial elements with a total of 4,687 nodes. The mechanical-and-physical properties of the massif are as follows:

$$E_1 = 1.028 \cdot 10^4 \, Mna, \quad \nu_1 = 0.31, \quad \nu_2 = 0.10, \quad E_2 = 0.292 \cdot 10^4 \, Mna, \quad G_2 = 0.11 \cdot 10^4 \, Mna \; \gamma = 2.2 m / м^3.$$

The materials for the station and the lining of the running tunnels:

$$E^{lining} = 2{,}5 \cdot 10^4 \, Mna, \quad \nu^{lining} = 0{,}25, \quad \gamma^{обделки} = 2{,}5 m / м^3.$$

The values of the angle of plane of isotropy:

$$\varphi = 30^0, \; \beta = 0$$

Using the foregoing formulas (1g)–(1k) for the anisotropic massif, synthetic accelerograms will be generated, as shown in Figure 2.

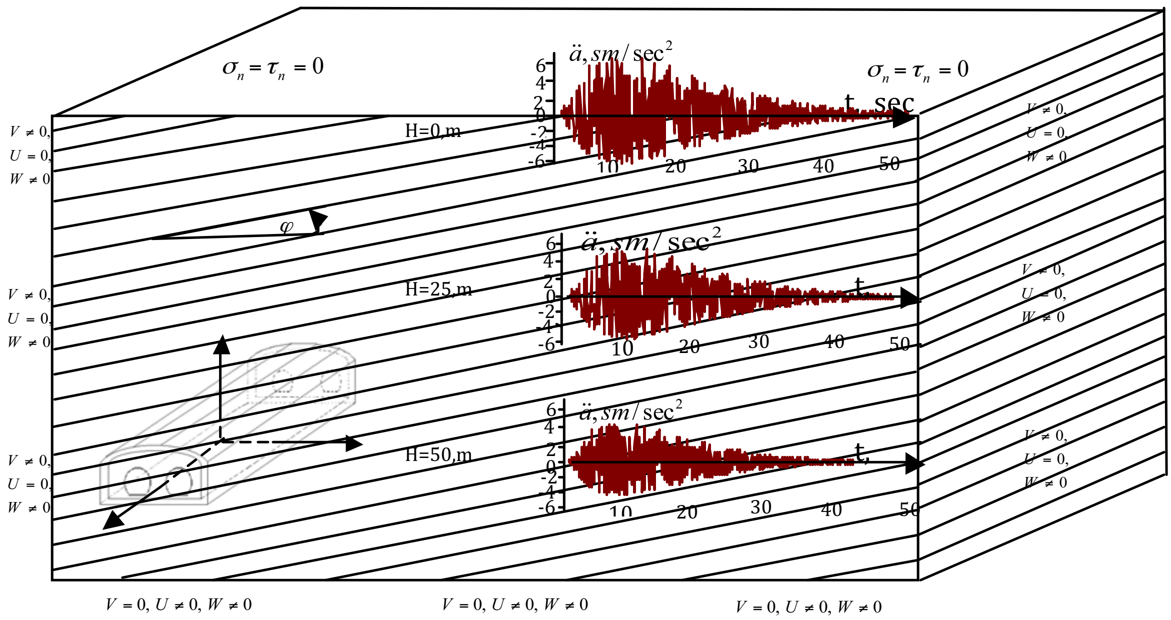

Figure 2 Equilibration region of a complex system of underground structures and synthetic accelerogram of a strong earthquake (intensity I = 10) for the rock massif from the surface to a depth of 50 m

The accelerograms generated for internal layers of the rock massif can now be analysed. Apart from cracking up to the land surface, the continuity of internal layers of the massif remains unaffected, so the same values should be obtained at all points within the massif. This is shown by the accelerogram at all depths up to 50 m (Figure 2). The underground structure will be laid depending on the depth in the rock massif. For the calculation of seismic boundary stress, respective accelerograms can be selected from the sets as an ixternal action. Figure 3 shows the seismic boundary stress diagram for the stationary and running tunnels.

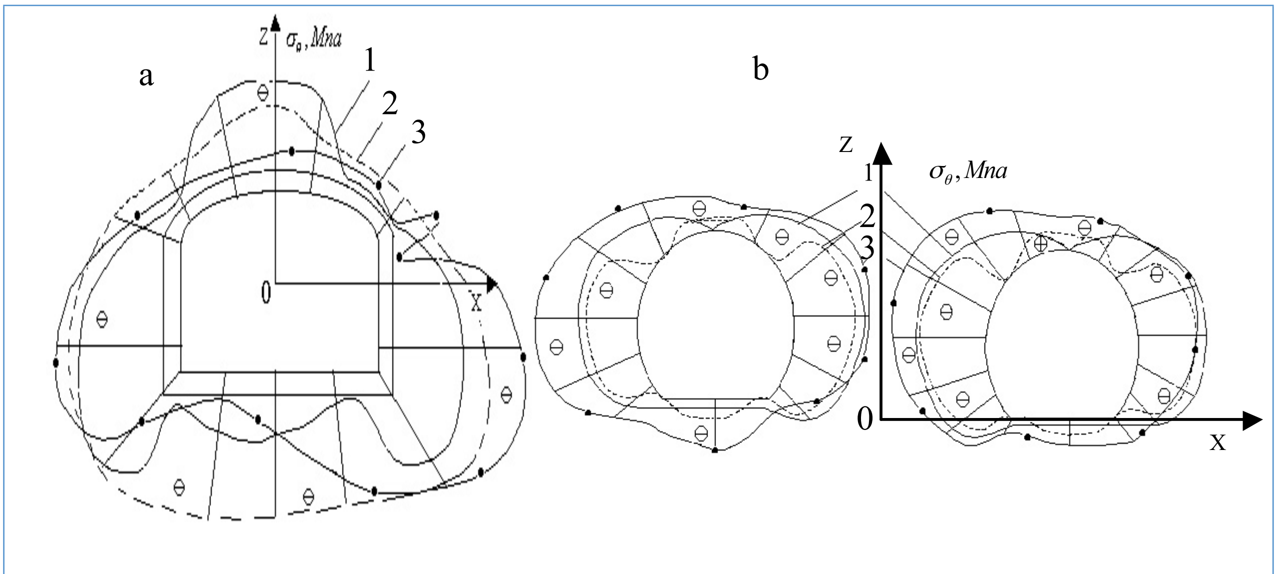

Figure 3 Diagrams of seismic boundary stresses of tunnels at different points of nonstationary seismic effect of 10-point earthquake: a) metro station with twin running tunnels; b) station section 22 metres from the exposed face; c) running tunnels section 35 m from the station. Curves correspond to: 1) static loading from the weights of upper massif layers yH, where y – bulk weights of the massif; 2) and 3) the time of seismic effect 18.244 s and 35.132 s as per accelerogram

CONCLUSIONS

Under a static load, the basic stress concentration is applied to certain areas of roofing and the station's underlier. The seismic load diagram, although complex, shows certain consistent patterns. In addition to the corner areas, lateral areas also experience the greatest seismic load. The same is true of the main line tunnels. The results of the present study enable elements of underground structures to be strengthened, and the disastrous effects of natural events such as earthquakes to be mitigated.

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HAZARD POTENTIAL IN PADANG'S POST-LIQUEFACTION AREA

Silvia F. Herina[1] and Paulus P.Rahardjo[2]

[1]Senior Researcher, Research Institute for Human Settlements
Agency for Research and Development, Ministry of Public Works, Indonesia
Email: silvia_herina@yahoo.com

[2]Professor, Geotechnical Specialist
Parahyangan Catholic University, Bandung, Indonesia
Email: pprahardjo@yahoo.com

ABSTRACT

On 30 September 2009 an earthquake occurred in Padang, destroying much of its infrastructure and buildings. Damage to buildings was due to not only a lack of appropriate construction systems, but also soil conditions, especially in areas dominated by layers of sandy soil. When exposed to this kind of ground shaking, soil can experience melting or liquefaction, which can cause building failure and differential settlement. A key concern is that liquefaction may recur at locations that have already experienced it, as indicated in studies, although more research is required to confirm this. To avert the disasters caused by the earthquake, all societies must gain a proper understanding of prevention, requiring effective exchange of information on construction systems and awareness raising among experts.

KEYWORDS

Padang, liquefaction, earthquake, differential settlement.

INTRODUCTION

A 7.6 Mw tectonic earthquake hit Padang on 30 September 2009, with an epicentre position at 0.725 (S) and 99.856 (E) and a depth of 80 km. Considerable infrastructure and buildings were destroyed in locations such as at Anai Valley and the Malalak and Tanah Datar districts, while large landslides occurred in the Mount Laweh and Tandikat subdistricts, as well as the Padang Pariaman district.

In the Padang Pariaman area, at least 75 per cent of buildings were damaged, mostly due to improper construction systems, and partly due to a differential settlement or deformation caused by liquefaction of soil. More than 20 locations showed signs of liquefaction, including in the western part of the UNP campus and housing Air Tawar, Perumnas Air Tawar, behind the Hajj Lapai area, along Jl.Gereja, Don Bosco High School area, Jl. Asahan, Gedung Wanita GOR Agus Salim, and the Kodam complex near Siteba market.

One of the detectable triggers for liquefaction is shallow groundwater and loose soil. In general, liquefaction can be interpreted as a condition where the soil flow exceeds the shear strength of deposits required to maintain the equilibrium of deposits. When deposits of saturated sand experience vibration during an earthquake, pore water pressure builds up, causing a reduction in soil stiffness and strength, which can ultimately lead to collapse. Pore water pressure is then dissipated in part directly to the soil surface accompanied by changes in volume, and then appears as a settlement in the soil.

In theory, liquefaction can be described in terms of soil particles. Before experiencing vibration, soil particles are in contact, so that all the forces acting on the deposit can be channelled entirely through these contacts, and the soil's shear strength is capable of supporting the existing load on the soil surface.

(a) (b)

Figure 1 Liquefaction: (a) soil settlement at Jl.Gereja, and (b) sand ejected from the fissure floor in the residential complex at the National University of Padang

(a) (b)

Figure 2 Liquefaction: (a) deformation of the soil layer due to the river wall breaking, Jl. Gereja, and (b) differential settlement of subgrade foundations

(a) (b)

Figure 3 Liquefaction: (a) lateral movement causing a road to crack, Jl. Samudera, and (b) sand from the bottom of a road experiencing landslides, Jl. Samudera

When the soil deposit begins to change shape through vibration, the particles move apart, and the vertical force that was channelled through the contact surface moves through the pore water. Because there is no contact between soil particles, soil shear strength is lost and the soil behaves like a liquid. After liquefaction and after the pore water flows out of the soil, contact between the particles is said to be stable again. The position of the particles changes,with a reduction in volume as large as the volume of pore water flowing out.

In practice, however, the above conditions are more complex, as diverse forms of particles with different grain sizes can cause only some of the points of contact between the particles to move apart and back again during and after a shear force. This can lead to a recurrence of liquefaction in the event of a new shock.

PADANG GEOLOGIST

In general, the geology formation of the town of Padang and the surrounding area consists of sedimentary rocks, volcanic intrusive rocks and alluvial deposits. In parts that have slightly sloping morphology or low-lying areas, such as Minangkabau International Airport (S. Prawiradisastra et al, BPPT), most deposits are alluvial: loose deposits, composed of silt, sand and gravel.

Level land to the south and east of Padang Municipality is extensive multicycle alluvial, composed and fluvio-volcanic deposits consolidated with lava, volcanic tuff and andesite, generally covered by a layer of Pleistocene coarse sand 5–10 m thick. Along the coast of Padang in a north-south direction, there are deposits of silty sand with a thickness of 1.5–6 m.

Fluvio-volcanic rocks, tuff, pumice and andesite and more common in the hilly residential area. Most of the hills are formed by the Samangko active fault (Dwikorita et al, UGM). At the time of the earthquake, many avalanche slopes were in the fault lines.

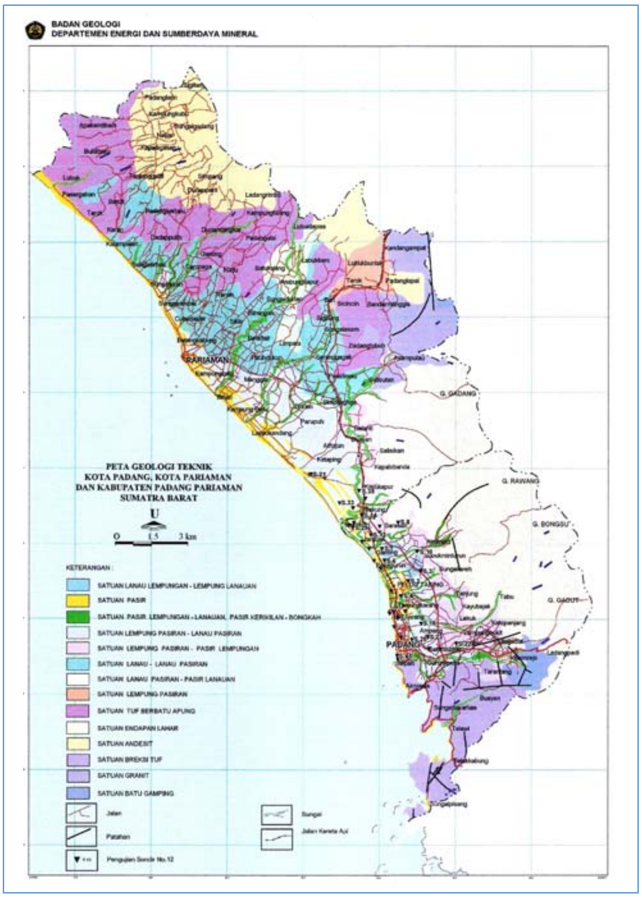

Figure 4 Geotechnical map of Padang

POST-LIQUEFACTION HAZARD

Map of liquefaction potential

After the quake of a magnitude of more than 6 Mw in Padang in 1979, the Sub Directorate of Engineering Geology performed liquefaction zoning (1996/1997), using the simplified procedure of Seed and Idriss (1971), and calculated the critical acceleration amax as follows:

$$0.65x\ r_d \times {}^{a.h}/_{\alpha} \times a_{max} = (r_{dc} / r_{\alpha})\ D_{50} \times D_r /50 \times C_r \times r_0$$

Note :

r_d	stress reduction coefficient
a_{max}	critical acceleration
r_{dc}	stress cycle deviation
r_{α}	ambient pressure in triaxial compression stress
D_r	relative density
C_r	correction factor in triaxial

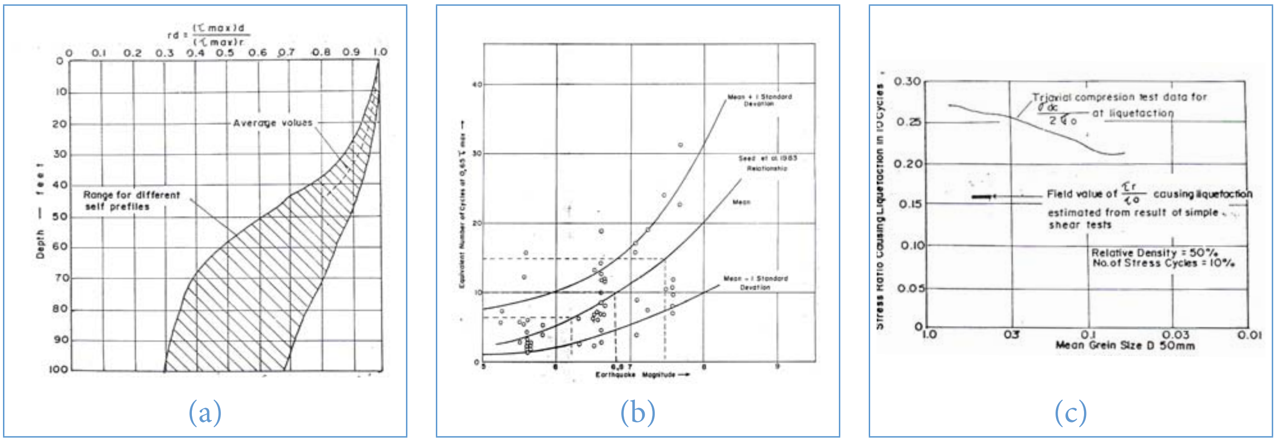

Figure 5 (a) Stress reduction coefficient, (b) equivalent number of uniform stress cycles, and (c) stress conditions causing liquefaction of sand in 10 cycles

Some values of critical ground accelerations and liquefaction potential are summarized in Table 1:

No.	Locations	Depth of soil layer (cm)	Critical acceleration (a_{max})	Liquefaction potential
1.	Air Pecah	190	0.0694	High
2.	Tanjung Aur	250	0.0461	High
3.	Jl. Bypass	200	0.1645	Moderate
4.	Kubu	100	0.3027	Very low
5.	Padang Sarai	225	0.0833	High
6.	Padang Sarai	250	0.1855	Moderate
7.	Muara	200	0.2281	Low
8.	Ganting	200	0.1733	Moderate
9.	Tabing	200	0.2884	Low
10.	Air Tawar	200	0.1869	Moderate
11.	Ulak Karang	140	0.01	High
12.	Jl. Sudirman	240	0.0671	High
13.	Jl. R.Saleh	240	0.2147	Low
14.	Pasar Alai Baru	500	0.0537	High
15.	Jl.Sudirman	100	0.7131	Very low

Note: a_{max} < 0.10 g: high potential, 0.20 g > a_{max} > 0.10 g: moderate, 0.30 g > a_{max} > 0.20 g: low potential, a_{max} > 0.30 g: very low potential

Table 1 Value of critical ground accelerations

When the earthquake struck on 30 September 2009, liquefaction occurred at most of the areas predicted to have liquefaction potential, such as Air Tawar, Ulak Karang and Alai Markets. Jl. Raden Saleh experienced moderate liquefaction, although its liquefaction potential had been considered low.

After the 30 September earthquake, the Geological Agency conducted soil tests and made a zoning map of liquefaction potential in the vicinity of the city and along the west coast of Padang Pariaman. The mapping results indicate that some areas of Padang City and its region that have a high potential for liquefaction, such as Ulak Karang. Tabing and Ganting showed moderate results, while Kubu is among the very low potential areas (Figure 6). These results were very close to the mapping that existed before the earthquake in 1997. For example, the previous map shows Padang and Ulak Karang as having high liquefaction potential, Ganting moderate potential, and Kubu very low potential.

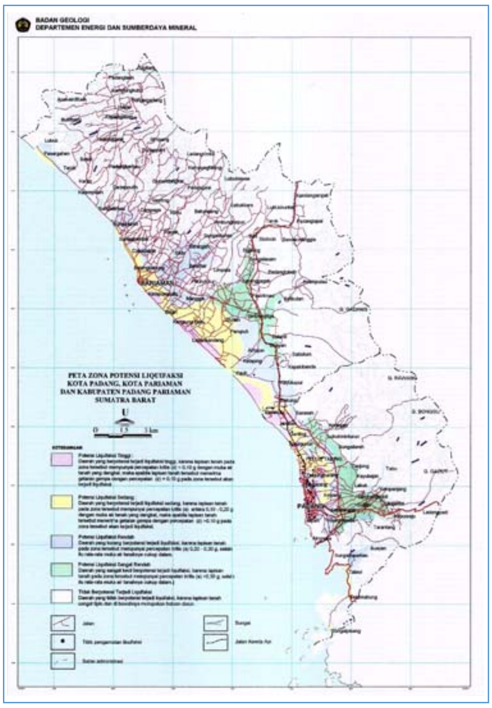

Figure 6 Liquefaction hazard map

Settlement

When saturated sand deposits experience fast shaking, water is trapped inside and pore water pressure rises, which can cause collapse and land subsidence. Fine-grained deposits suffer only minor liquefaction, so the study of liquefaction has generally focused on sand or sandy soil.

A team from Parahyangan Catholic University conducted field testing using the cone penetration test with pore pressure measurement (CPTU) in the area of Don Bosco High School, Frater Junior High School, St.Leo Convent and GOR Prayoga. This area features considerable liquefaction. Figure 7 shows the test results, identifying soil behaviour type and liquefaction potential using the Robertson Chart (1990) and the plot ratio of frictional resistance vs the tip cone pole. The settlement of sand or sandy soil types, which tend to liquefy, was evaluated using the method developed by Zhang et al. (2002).

$$\mathbf{S = \sum_{i=1}^{j} e\ \varepsilon vi\ .\ \Delta zi}$$

Note:

s	liquefaction settlement
$\varepsilon\nu$i	volumetric strain post liquefaction soil at layer i
Δzi	depth of soil at layer i
j	amount of soil layers

The predicted settlement was 20 cm at Don Bosco Senior High School, Frater Junior High School and GOR Prayoga, while the visible settlement was approximately 34 cm at St. Leo Convent.

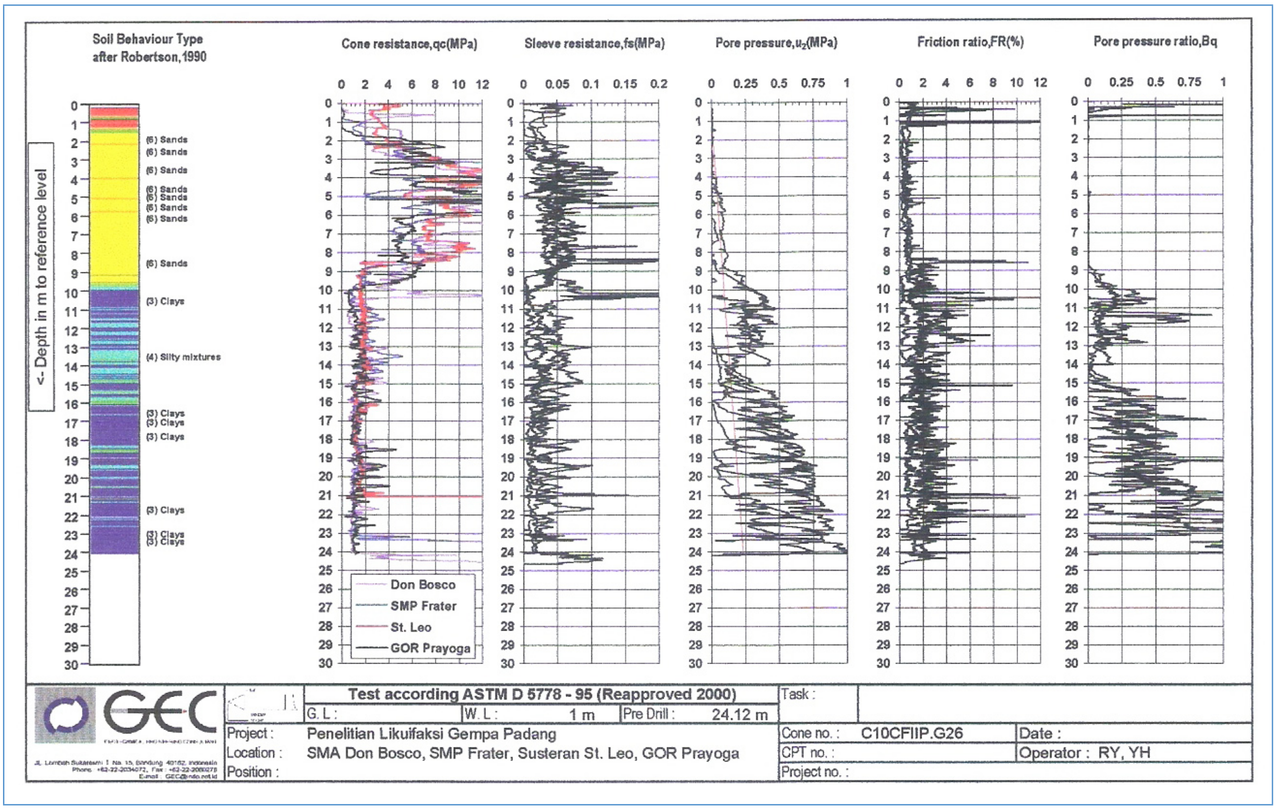

Figure 7 CPTU test results

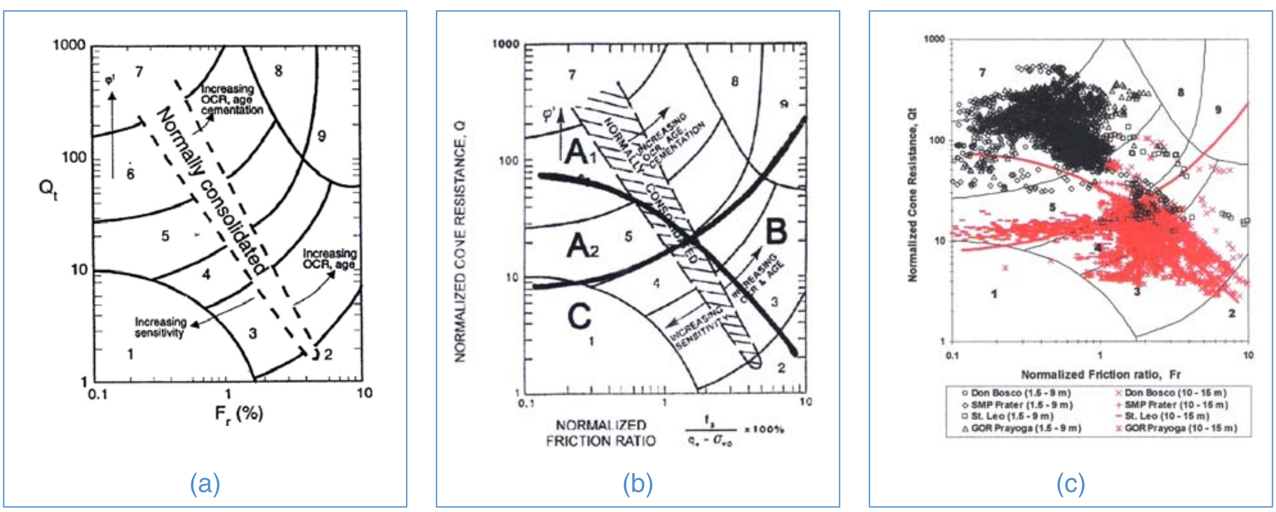

Figure 8 Robertson Chart (Robertson, 1990): (a) soil behaviour, (b) liquefaction identification, and (c) plotting data

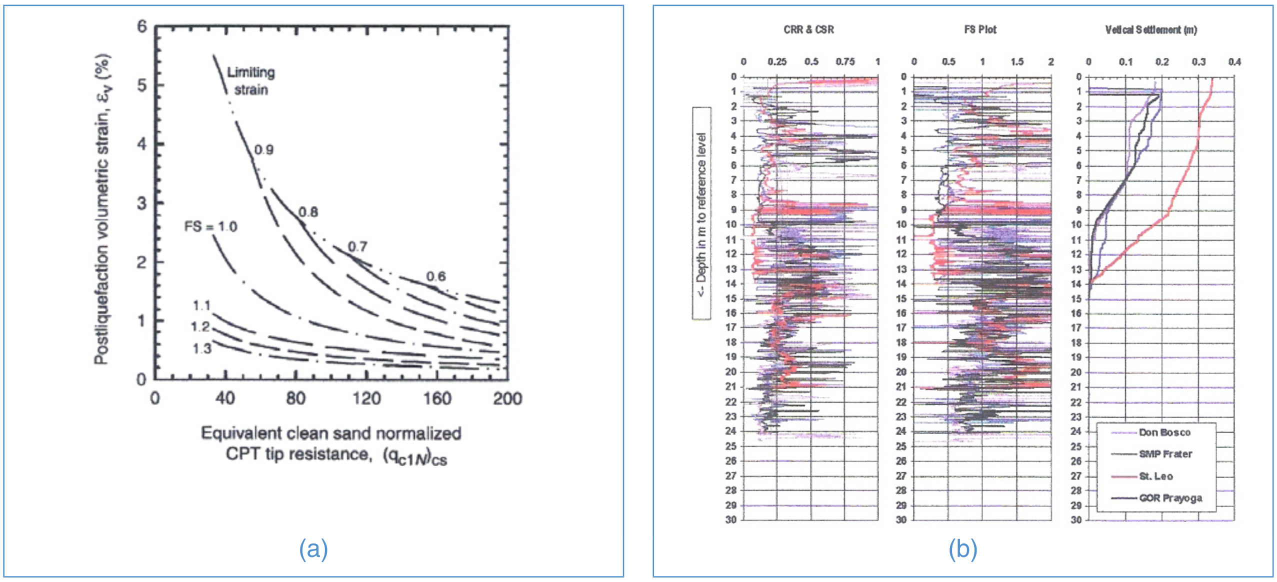

Figure 9 Chart (Zhang et. Al, 2002) and settlement evaluation: a) relation of volumetric strain post liquefaction and normalization cone tip, and b) the result of settlement calculations

Liquefaction type potential

Liquefaction can recur at the same location. In general, two types of liquefaction can occur in Padang and West Sumatra, at locations that consist of loose sand, highly contractive, uniformly graded or fine grain flow. Soil collapse due to liquefaction is usually due to a sudden change, rapid soil development, and fairly large deformation of material between soils.

On slopes or on gently sloping terrain adjacent to a sea or river, spreading or cyclic lateral mobility can occur. This phenomenon appears to be a hardening strain, which can cause large permanent deformation. Cyclic mobility can occur because of the upward water flow caused by the induction of seismic vibrations in the pore water. Failure due to liquefaction still occurs after vibration in the ground stops. This liquefaction occurs when the static shear stress is smaller than the shear strength of liquefied soil. The opposite of flow liquefaction, deformation produced by cyclic movement is controlled by cyclic and static shear stress.

In the special case of this movement, a landslide can occur. If the static horizontal shear stress is very small and lateral deformation does not occur, an irregular movement of soil will happen, resulting in differences in level ground liquefaction. This type of liquefaction depends on the time required by soil water to reach equilibrium. The characteristics of common failures include a fairly large vertical decrease in volume, flooding in low areas, and the occurrence of sand boils. In contrast to flow liquefaction, cyclic movement is not an obvious symptom at the start of the movement, as strain and deformation can accumulate. The magnitude depends on the static shear stress and duration of ground motion. A short duration probably causes only a small deformation, to the slopes with a long duration of ground motion; cyclic movements can cause great damage as a result of extensive soil deformation.

CONCLUSIONS

1. Liquefaction tends to occur in the same places and may therefore recur in areas that have already experienced it.
2. Post-liquefaction soil deformation can occur, and this should be taken into account for public and other important buildings.
3. More intensive research should be carried out for a better understanding of liquefaction behavior in Padang and its surrounding area.

4. A mapping of earthquake hazards and microzoning should be prepared for Padang Municipality and its surrounding area.
5. To mitigate the risk of disaster caused by the earthquake or other hazards, all communities must be involved, enabling the exchange of information on the system and greater awareness among experts.

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LESSONS LEARNED FROM THE RECENT MW 8.8 EARTHQUAKE IN CHILE ON FEBRUARY 27, 2010

R. Alvarez[1] and L. Vergara[2]

[1]Manager of Structural Engineering Area, DICTUC S.A,
Professor of Structural and Geotechnical Engineering Department,
Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Macul, Santiago, Chile
Email: ralvarez@dictuc.cl

[2]Structural and Geotechnical Engineering Department,
Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Macul, Santiago, Chile
Email: luvergar@uc.cl

ABSTRACT

On 27 February 2010 one of the world's largest earthquakes ever recorded struck Chile. While the vast majority of the buildings performed well, many cities were destroyed by the quake and the subsequent tsunami that ravaged coasts.

The present study explains the Chilean experience of facing a major earthquake, how the relevant organizations operated, and the evident lack of a pre determined emergency plan of action.

Furthermore, this paper shows the typical observed building failures due to non-regulatory designs, soil mechanics and the effects of the tsunami, and the good performance of buildings with seismic isolation systems.

Finally, this paper considers the lessons to be learned from the Chilean experience.

KEYWORDS

Chile, earthquake, tsunami, structural inspections, tectonic plates, structural damage, soil mechanics, seismic isolation.

INTRODUCTION

The 27 February 2010 earthquake is one of the largest registered telluric movements in human history, affecting almost the entire Chilean population and causing severe damage to fields, cities, ports, industries and public buildings, much of which was due to the post-quake tsunami that devastated the Chilean centre-south waterfront area.

The quake struck early in the morning at 3:34 local time (6:34 UTC), with a moment magnitude of 8.8 Mw and a duration of more than 120 s.

The earthquake was caused by the continued subduction of the Nazca Plate beneath the South American Plate, over which the mainland of Chile lies. Because of this phenomenon, the rupture zone was 600 km long, affecting more than 70 per cent of the country's population (more than 16 million people).

The latest official figures speak of 521 dead and 56 missing, with the post-earthquake tsunami responsible for many of the fatalities and almost all of the missing people.

TECTONIC AND SEISMOLOGICAL ASPECTS

The west coast of South America, including most of Chile, is located at the union of two tectonic plates: the Nazca Plate under the Pacific Ocean and the South American Plate under the continent. The Nazca Plate is a subducting plate in constant motion from the ocean to inside the earth, under the overriding South American Plate.

Due to friction between the plates, the constant movement of the Nazca Plate generates deformation of the continent's coastal zone, storing energy like a spring during tens or hundreds of years. When the restorative force of the overriding plate exceeds the friction force between plates, the South American Plate backs aggressively to its original position, displacing its deformed surface to the west and causing earthquakes and tsunamis (Figure 1a).

A geographical gap existed between the areas already affected by previous earthquakes, north and south of the location of the recent move, which was completed with the last event (Figure 1b). Therefore, the possibility of another large earthquake in the area had already been identified.

Land displacement due to the recovery of the South American Plate affected even remote areas on the other side of the continent (Figure 1b).

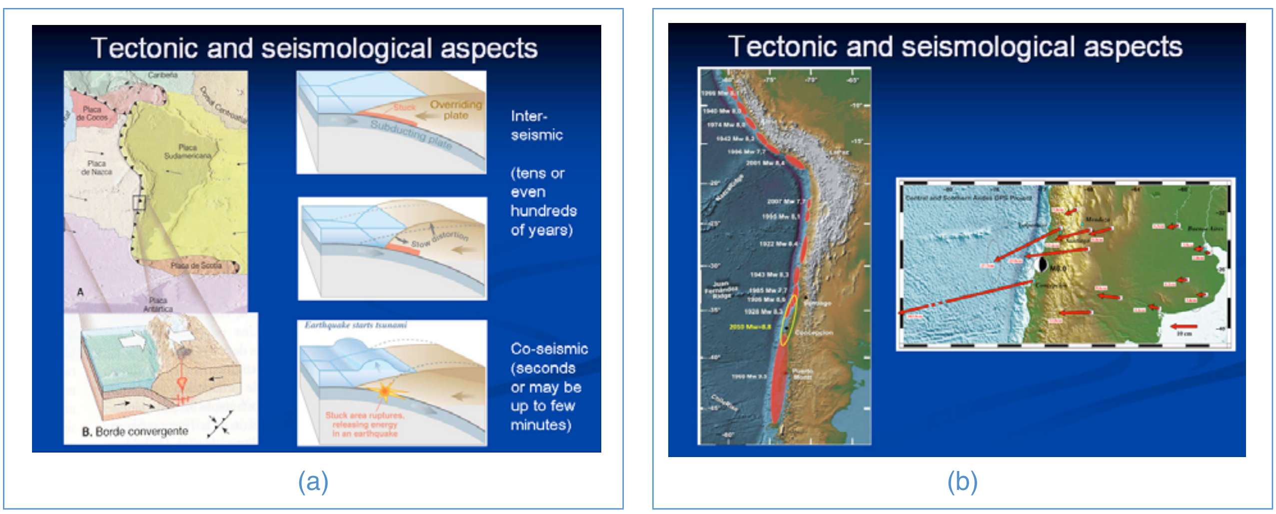


Figure 1 (a) Dynamic of tectonics plates, and (b) geographical gap and land displacement

A week after the earthquake, more than 200 aftershocks had been registered in the affected area, some of which had a magnitude of around 7 Mw (Figure 2a). The post-earthquake tsunami hit the Chilean south-central coast hard, and its effects could be seen over almost the entire Pacific Ocean (Figure 2b).

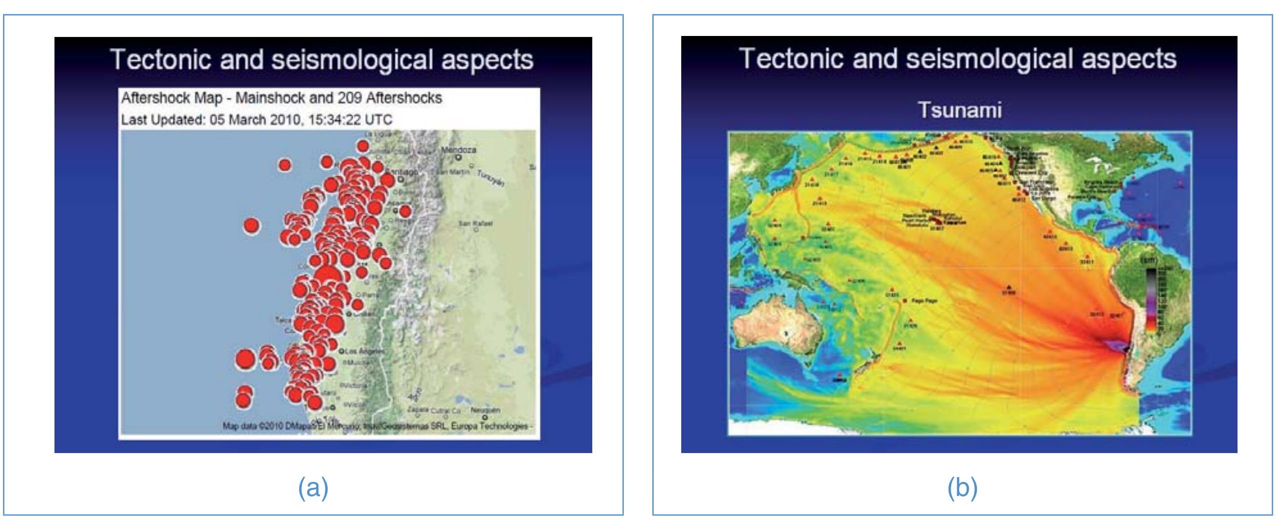


Figure 2 (a) Aftershock map, and (b) tsunami effect in the Pacific Ocean

Damage permitted in the seismic code

The Chilean code of seismic design (NCh433.Of1996: seismic design of buildings), does not set specific requirements that buildings must meet under seismic loads (Figure 3).

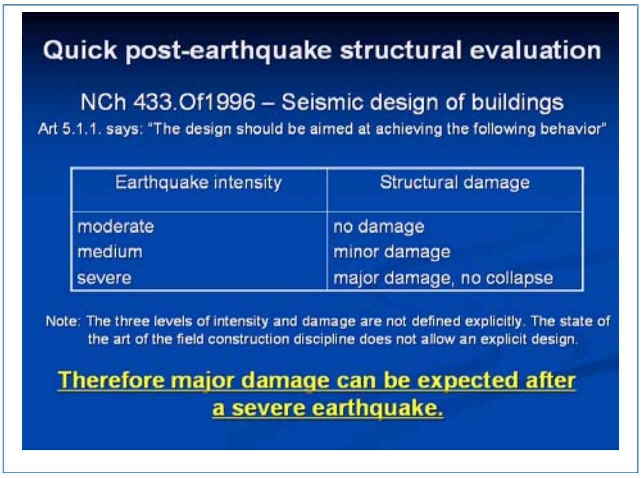


Figure 3 Required structural seismic behaviour

Moreover, in structural design, a gap still exists between theory and practice, which does not allow a greater degree of specificity in performance requirements. In addition, the Chilean code specifies reduction factors that are applicable to the seismic load impacting buildings, requiring greater ductility and therefore greater expected damage.

Structural evaluations and emergency systems

The structural evaluations conducted in this research focused on determining the severity of building damage in order to protect the lives of occupants. Possible building classes according to the severity of damage are shown in Figure 4.

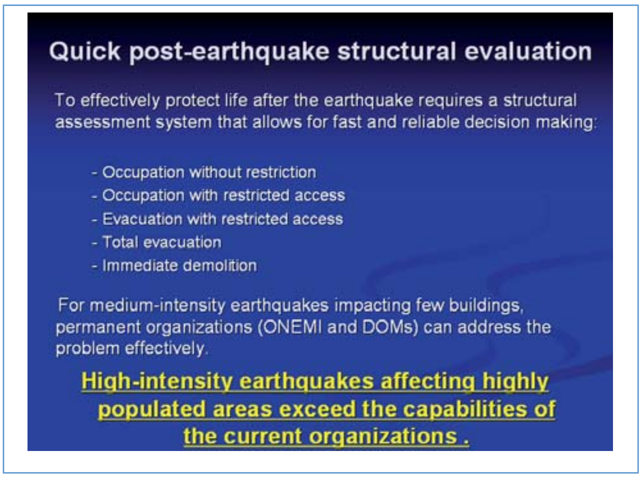


Figure 4 Classification of damaged buildings and responsiveness of organizations

Experience after the 27 February earthquake

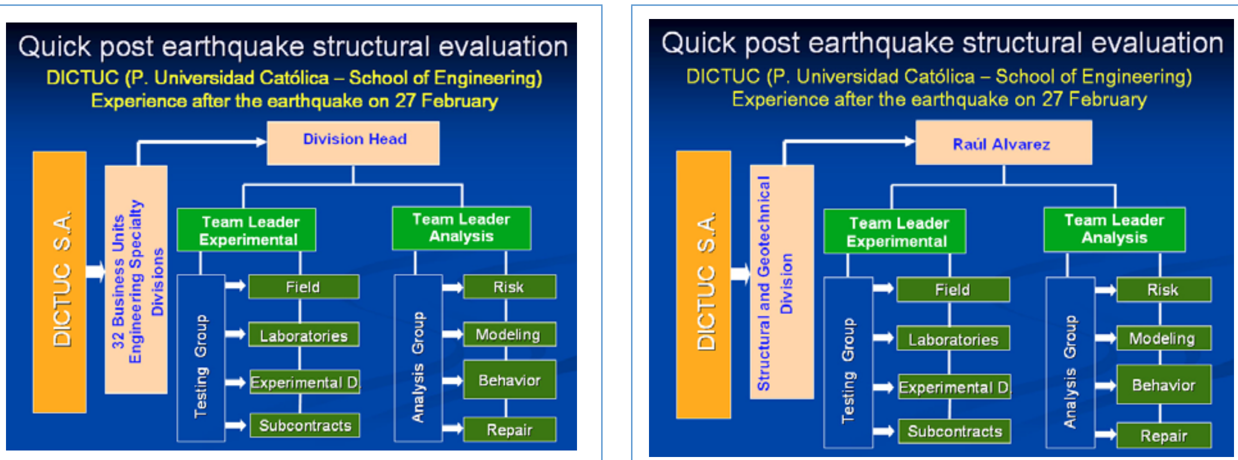
Four months after the earthquake, an overview was produced of the actions performed in the initial evaluation stage and reconstruction period, including the following:

- Many forms of volunteer work were carried out without a centralized organization, causing problems in terms of coordination and logistics.
- Many different forms of structural evaluation were implemented for different purposes, private and public, using different, incomparable formats.
- Information of varying quality disseminated without a common format.
- Poor coordination between evaluation entities led to duplicate information in some places and a possible lack elsewhere.
- Fire-fighters demonstrated a quick response.
- Municipalities and the government did everything they could using their professional and financial available resources.
- Ministry of Housing (MINVU) provided resources for assessment, outsourcing to professional associations.
- Municipalities received help from experts worldwide.
- Universities and quality control engineering labs (DICTUC and IDIEM) provided professional resources for structural assessments.
- The National Emergency Office (ONEMI) had difficulty analysing and consolidating information and statistics, and failed to issue a tsunami warning that could have prevented large numbers of deaths.

DICTUC experience

DICTUC (the Scientific and Technological Research Department of the Catholic University) is a subsidiary of the Pontificia Universidad Católica de Chile, which provides engineering services to public and private entities that require them.

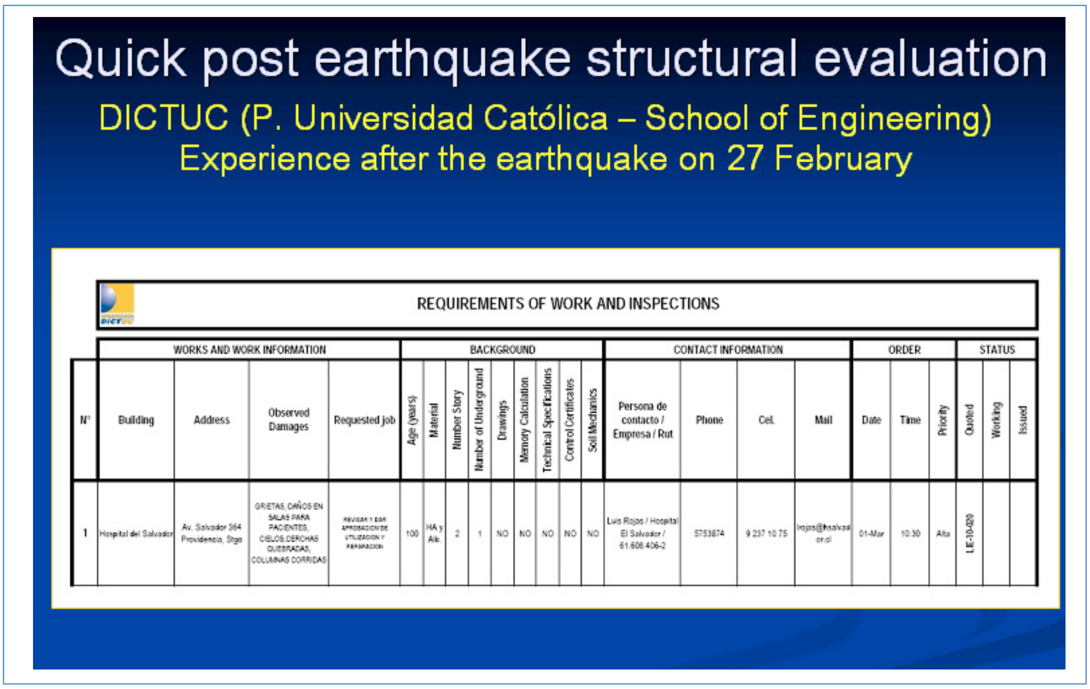
The Structural Engineering Area of DICTUC is headed by Raúl Álvarez M. and has several engineers experienced in structural design and field activities. Figure 5 shows organization charts for the department and its structural engineering team.



(a) (b)

Figure 5 Organization charts for (a) DICTUC and (b) the structural engineering team

To handle the information on the large number of buildings requiring structural evaluations, a database with available information on the structures was created to produce a reference for what would be faced in each case, as shown in Figure 6.

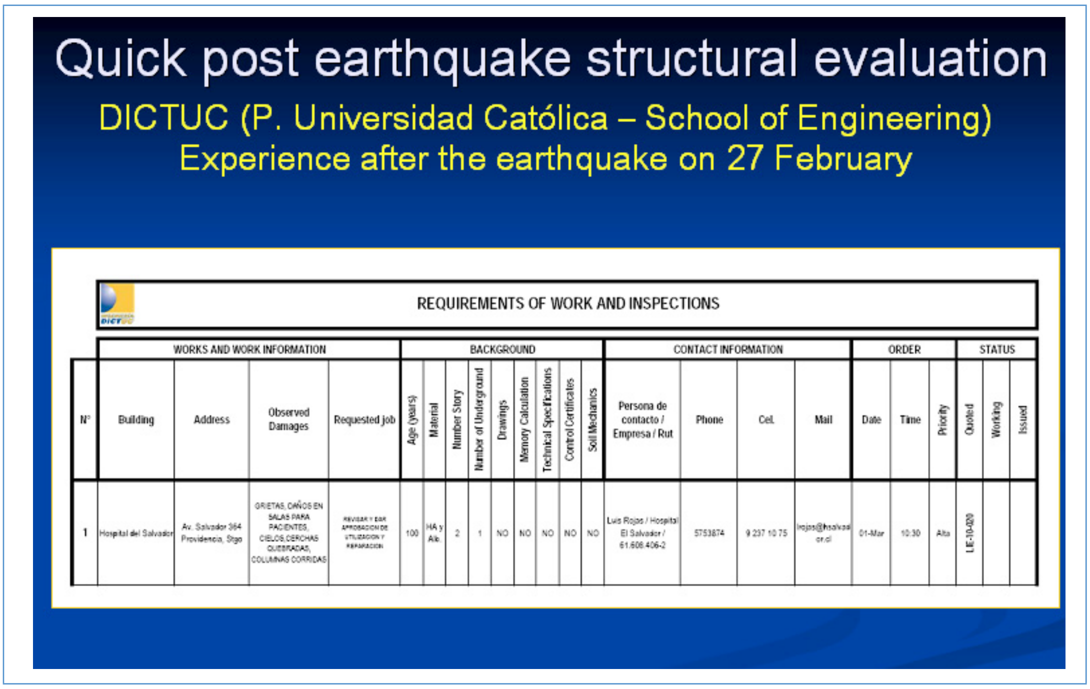


WORKS AND WORK INFORMATION					BACKGROUND									CONTACT INFORMATION				ORDER			STATUS		
N°	Building	Address	Observed Damages	Requested job	Age (years)	Material	Number Story	Number of Underground	Drawings	Memory Calculation	Technical Specifications	Control Certificates	Soil Mechanics	Persona de contacto / Empresa / Rut	Phone	Cel.	Mail	Date	Time	Priority	Quoted	Working	Issued
1	Hospital del Salvador	Av. Salvador 364 Providencia, Stgo	GRIETAS, DAÑOS EN SALAS PARA PACIENTES, CIELOS, CERCHAS QUEBRADAS, COLUMNAS CORRIDAS	REVISAR Y DAR APROBACION DE UTILIZACION Y REPARACION	100	HA y Alb.	2	1	NO	NO	NO	NO	NO	Luis Rojas / Hospital El Salvador / 61.608.406-2	5753874	9 237 10 75	lrojas@hsalvador.cl	01-Mar	10:30	Alta	LIE-10-020		

Figure 6 Database of buildings requiring structural evaluation

The required data includes building name, address, observed damage, age, materials, number of storeys, number of underground storeys, availability of drawings, calculation report, technical specifications, soil mechanics report and contact information.

To determine the order of actions, the process of recovery chart of the BRI (Building Research Institute) was used as reference. In this way, DICTUC participated in the Quick Inspection and Detailed Inspection process.



WORKS AND WORK INFORMATION					BACKGROUND									CONTACT INFORMATION				ORDER			STATUS		
N°	Building	Address	Observed Damages	Requested job	Age (years)	Material	Number Story	Number of Underground	Drawings	Memory Calculation	Technical Specifications	Control Certificates	Soil Mechanics	Persona de contacto / Empresa / Rut	Phone	Cel.	Mail	Date	Time	Priority	Quoted	Working	Issued
1	Hospital del Salvador	Av. Salvador 364 Providencia, Stgo	GRIETAS, DAÑOS EN SALAS PARA PACIENTES, CIELOS, CERCHAS QUEBRADAS, COLUMNAS CORRIDAS	REVISAR Y DAR APROBACION DE UTILIZACION Y REPARACION	100	HA y Alb.	2	1	NO	NO	NO	NO	NO	Luis Rojas / Hospital El Salvador / 61.608.406-2	5753874	9 237 10 75	lrojas@hsalvador.cl	01-Mar	10:30	Alta	LIE-10-020		

Figure 7 Process of recovery from earthquake disaster (Building Research Institute)

Since there were no official evaluation sheets for quick inspection of buildings in Chile before the earthquake, the Structural Engineering Area of DICTUC compiled evaluation sheets used in other countries to use as a reference for creating its own sheet.

Some examples of foreign sheets are shown in Figure 8.

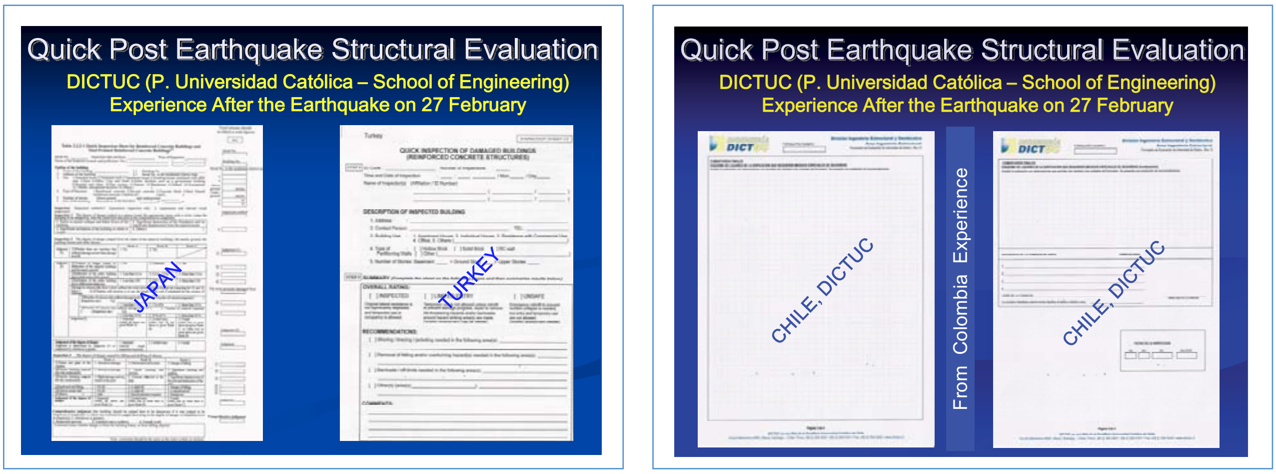


Figure 8 Examples of foreign evaluation sheets used for reference

Finally, Colombia's evaluation sheet was used as a model, considering the similarities in the type of buildings in Colombia and Chile, and the familiarity of the identified damage and used concepts.

The evaluation sheet prepared by DICTUC (Figure 9) consisted of two pages of forms to fill out, explaining general and specific features of the building, the most common types of damage and the building security status. In addition, two pages were included for notes that could be helpful to a future report.

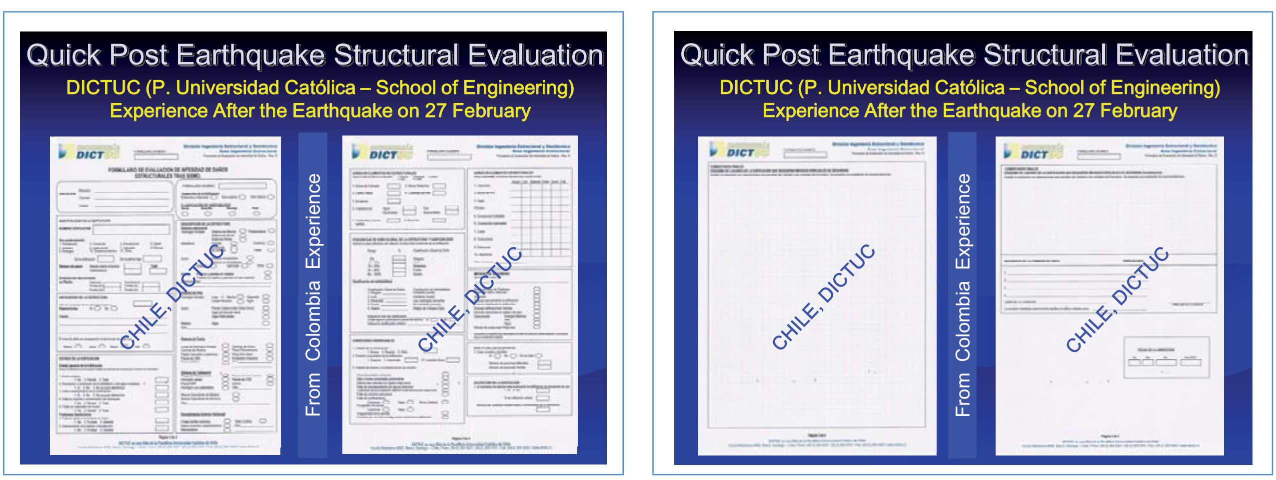


Figure 9 Evaluation sheet created by DICTUC, using the Colombian evaluation sheet as a model

For the buildings visited, a provisional report was made (Figure 10), specifying its safety condition (habitable, restricted access, uninhabitable or dangerous), and immediate actions required to make the building safe (underpinning, demolishing elements, removing coatings, evacuating the building, etc.)

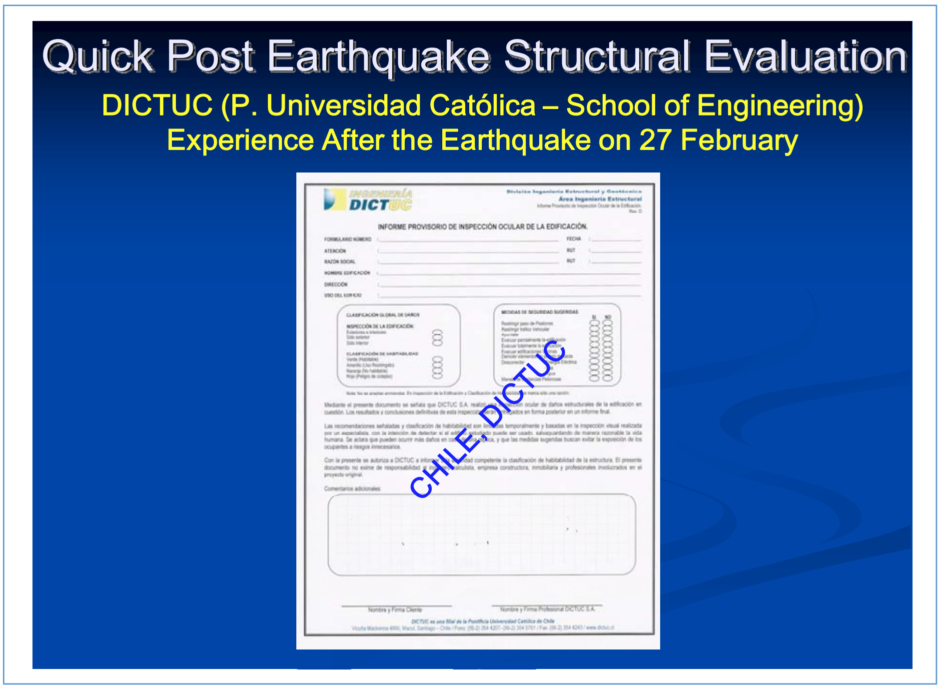


Figure 10 Provisional report for inspected buildings

For quick building inspection, several working groups were created, made up of an engineer and an assistant, both equipped with the implements shown in Figure 11 (e.g. helmet, work vest, tape measure, digital level, flashlight, digital camera, geological hammer, crack measuring equipment and evaluation forms).

Figure 11 Working groups and inspection equipment

OBSERVED DAMAGE

Despite the strong earthquake, there was no widespread damage to the country's major cities, highly built with medium and high-rise buildings (Figure 12a).

Concepción, the large city closest to the earthquake epicentre, was one of the most affected. A panoramic view of the city is shown in Figure 12b.

Tall buildings

Typical damage observed to high-rise buildings was due to the presence of soft storeys, both in the first level, and intermediate levels, including stiffness change in height.

Figure 13a shows the only tall structure experiencing total collapse due to earthquake. This building had a double height soft first storey, which is very common in Chilean construction. Figure 13b shows an intermediate soft storey collapse, without total collapse of the building. Both buildings are in Concepción City.

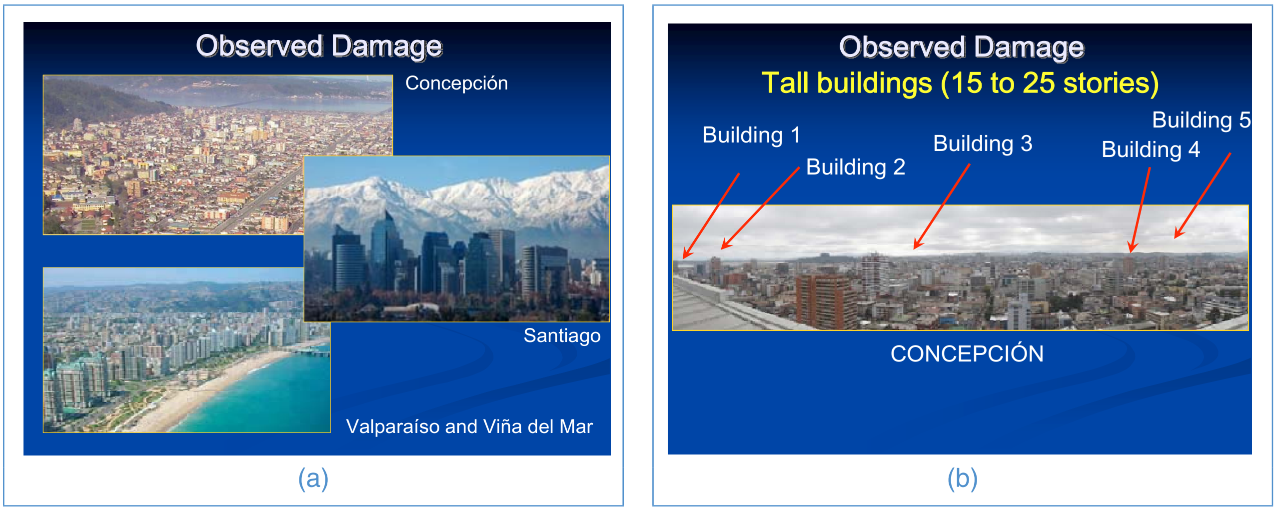


Figure 12 (a) General view of the largest cities in Chile, and (b) panoramic view of Concepción City

Figure 13 (a) Collapsed building with soft first storey, and (b) building with partially collapsed soft intermediate storey

Together with soft first storeys, because of lax requirements in the Chilean building Code until 2008 (before NCh430.2008), there is commonly a low confinement in compressed wall heads, resulting in concrete fractures and loosening, and buckling of compressed bars.

Small buildings

Damage to low-rise buildings was not very different to the damage already mentioned. A lack of confinement in walls and soft storeys is still common, and many buildings have very thin walls, meaning that, during the earthquake, the large-diameter reinforcing bars did not have enough material to develop their strength (Figures 14–15).

Figure 14 Typical failure due to lack of confinement in compressed wall heads

Figure 15 Typical failures due to lack of confinement in compressed wall heads and thin walls

Non-structural elements

The most common damage observed in almost all buildings in the affected areas was to non-structural elements. Many buildings had fragile partition walls, mainly consisting of plasterboard without adequate anchoring and isolation from structural walls and slabs.

In addition, ceilings and air conditioning with poor anchorage suffered severe damage with parts falling off, even injuring people passing the affected areas (Figure 16).

Figure 16 Typical damage to non-structural elements

Bridges

Generally speaking, highway bridges in Chile follow two main designs. The first is a traditional Chilean design with crossbeams connecting longitudinal beams, steel bars anchoring the board to the supports, and side caps, which prevent transverse displacement of the bridge (Figure 17a).

The second type of design was adopted for new bridges as part of highway concessions. This was a new design that did not include crossbeams, with much weaker anchors and virtually nonexistent lateral support (Figure 17b).

A comparison of lateral support systems is shown in Figure 17c.

Poor anchoring systems make up a simply supported slab. If the supports are displaced, the bridge deck may fall almost freely (Figure 18).

Soil mechanics

Near Concepción City, damage was observed to river bridges due to soil foundation failure. At Juan Pablo II bridge, the longest in Chile, soil failure occurred under its piles by liquefaction and settlings, as well as problems with bridge access embankments, where liquefaction also occurred (Figures 17–18).

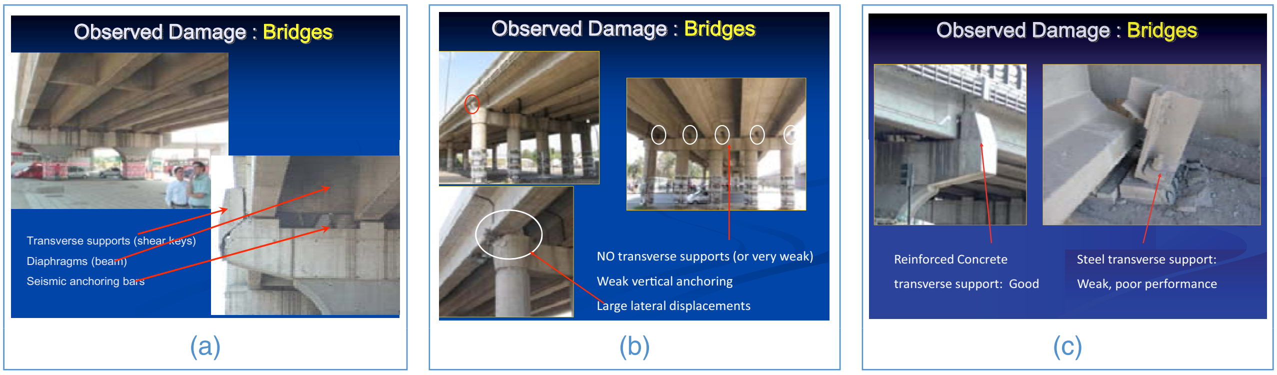


Figure 17 (a) Traditional Chilean bridge design, (b) new bridge design, and, (c) comparison of lateral support systems

Figure 18 Bridge failure due to weak anchoring and lack of lateral support

Figure 19 Bridge failure due to liquefaction and settling

Landslides and poor-quality soil fills caused damage to houses and small social buildings, especially in landfills on the edge of slopes (Figure 20).

Figure 20 Failure of houses and small buildings due to landslides and poor soil conditions

Both fishing and industrial ports experienced coastal soil disturbance, as well as liquefaction and landslides due to poor compaction of embankments and dock walls.

Figure 21 shows soil disturbance and damage to boarding embankments at a small fishing port near the earthquake epicentre, and similar damage to a large port facility near Santiago.

Figure 21 Soil failures in port facilities.

Similar damage occurred as a result of landslides and poor compaction of the embankment along Highway 5, which connects most of the country (Figure 22).

Figure 22 Soil failure and landslides on the embankment of Highway 5

Industrial facilities

Generally speaking, industrial facilities suffered no major damage, and this was limited to specific elements within larger structures (Figure 23).

Figure 24 shows a crane for bulk cargo handling on a warf near Concepción, with failure of the support leg and a large angle of inclination.

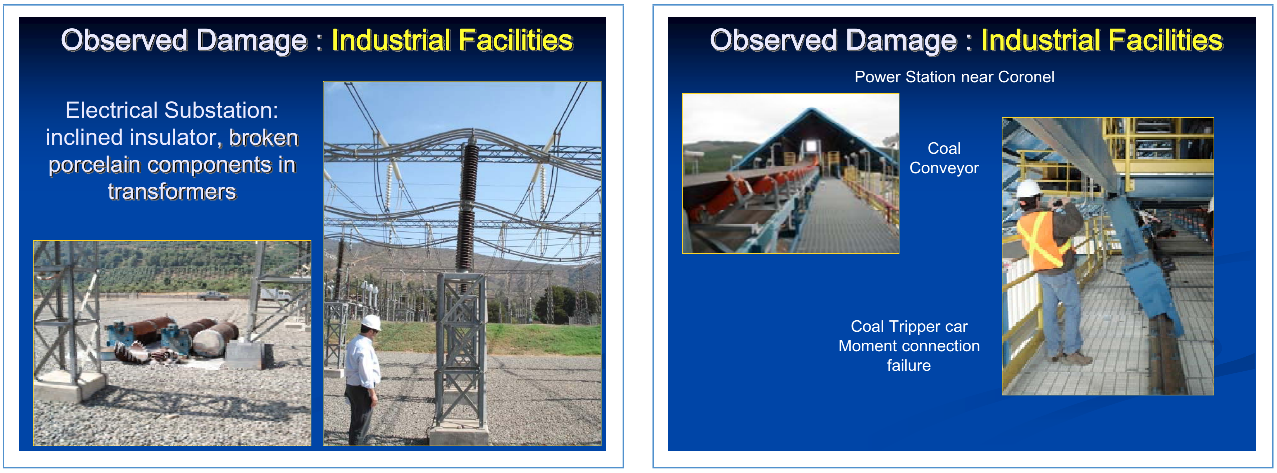


Figure 23 Damage to an electrical substation and industrial facilities

Figure 24 Crane on a warf near Concepción with failure of the support leg

Most of the wine produced in Chile is stored in stainless steel tanks. The earthquake revealed problems with tank anchorage, supports and shell strength (Figure 25), which caused the failure of 25 per cent of wine tanks and the loss of 125 million litres of wine, equivalent to US$250 million or about 12.5 per cent of the 2009 production (El Mercurio, 2010).

Figure 25 Failed stainless steel tanks and loss of wine

Adobe constructions

Adobe is a building material commonly used in old low buildings (houses, churches, etc.). It consists of a mixture of mud and straw moulded into bricks for use in structural walls.

Many of the adobe buildings in the country's central region were severely damaged in the earthquake that struck Chile in 1985. During the 2010 earthquake, most of the remaining buildings collapsed or had to be demolished, given the danger they represented to occupants. Today, adobe is not considered as a regulated construction material.

Figure 26 shows typical damage to adobe buildings observed in the affected area

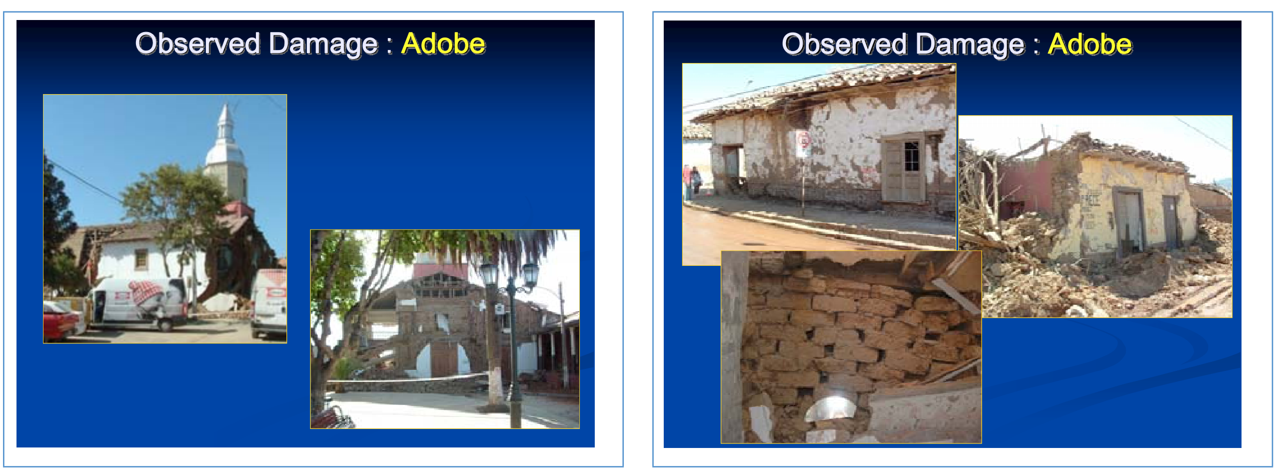


Figure 26 Severely damaged adobe buildings

Tsunami damage

While most of the damage and losses of life on 27 February resulted from the earthquake, the subsequent tsunami caused severe damage and destruction in coastal areas and ports in the centre-south of Chile.

Figure 27 shows tsunami damage to ports, docks, ships and submarines, as well as to coastal towns, supply facilities and roads.

ISOLATED AND DAMPED STRUCTURES

At the time of the earthquake, many buildings with seismic isolation or dissipation systems had an excellent performance, registering no structural damage or problems with their seismic protection systems.

Figure 28 shows some buildings equipped with seismic protection systems, including elastomeric isolators, metallic dampers and tuned mass systems.

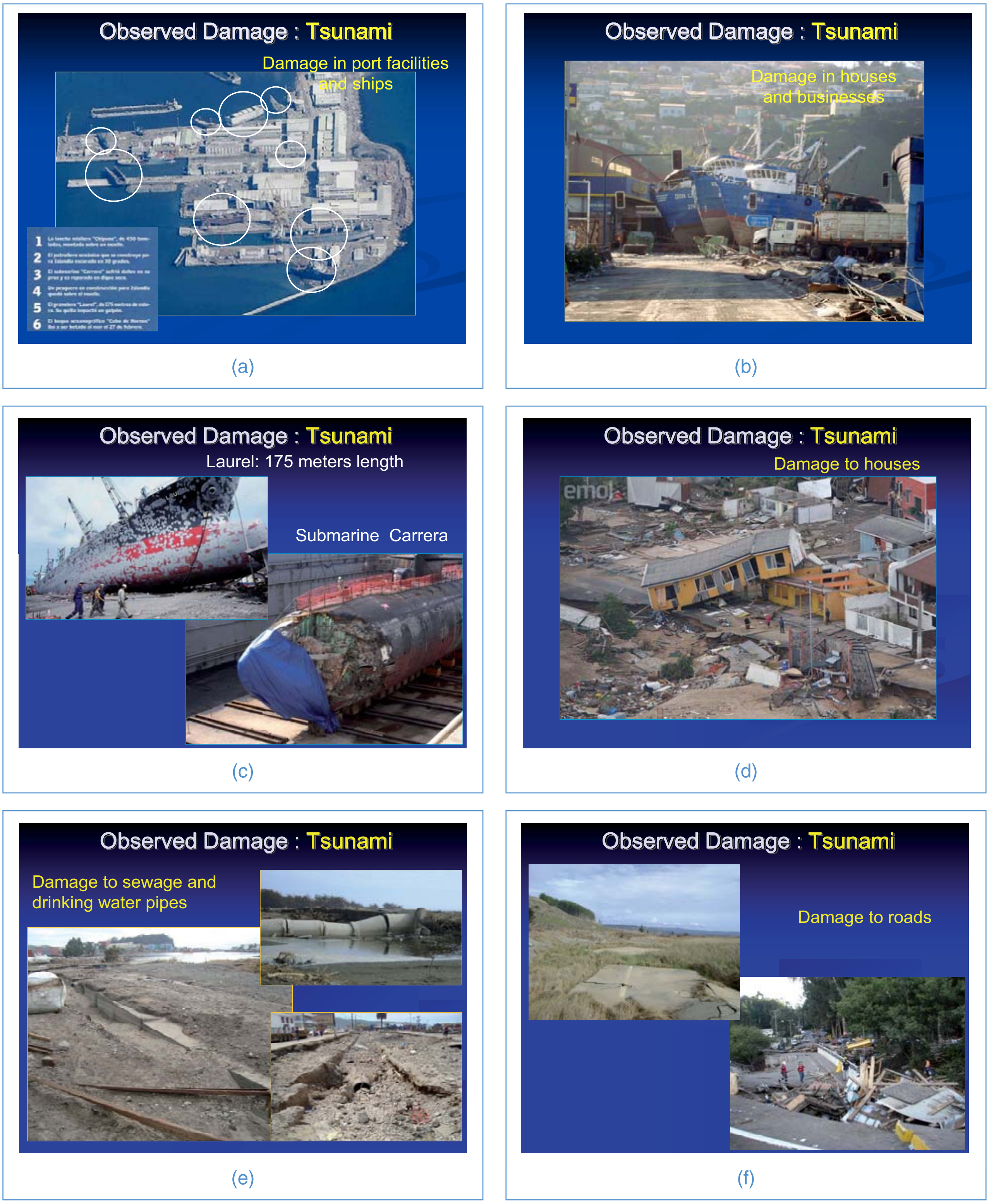


Figure 27 (a) Overview of damaged boats in Talcahuano port, (b) and (c) ships taken from the sea and submarine damaged by tsunami waves, (d) coastal town with houses destroyed by sea water, (e) damaged supply facilities, and (f) roads and bridges destroyed by sea water and debris

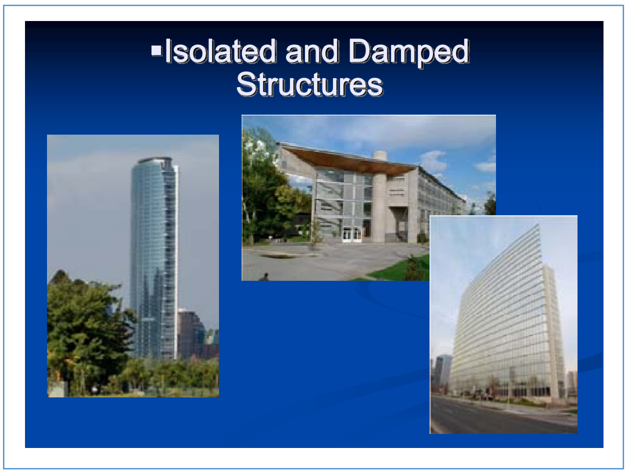


Figure 28 Buildings equipped with seismic protection systems (Sirve, 2011)

CONCLUSIONS

Much can be learned from this event, not only by Chile but the entire international earthquake engineering community.

In general, structures designed with good engineering practices performed well. There were a few exceptions that should be carefully studied for a proper understanding of their poor seismic performance.

In several instances, the requirements of building codes and regulations were clearly inadequate for ensuring appropriate seismic performance. Changes in the codes are therefore required.

Site soil conditions and height irregularities appear to be the major causes of poor performance, rather than earthquake magnitude.

A plan of action for earthquakes is necessary, indicating the steps to be taken by the government in coordination with the various institutions able to provide resources (e.g. logistics and transportation) to perform the urgently required evaluation studies.

It is advisable to avoid centralizing knowledge. Most of the institutions empowered to conduct investigations are located in Santiago, and it is difficult, slow and expensive to conduct studies in areas far from the capital.

ACKNOWLEDGMENTS

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THE NEED FOR INTEGRATION BETWEEN BUILDING ADMINISTRATION AND TECHNICAL STANDARDS IN INDONESIA

K. Shirakawa

JICA expert on building administration enforcement
Japan International Cooperation Agency
Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan
Email: shirakawa.kazushi@gmail.com

ABSTRACT

In general, building design and construction requires standards such as the external load on a certain site, a theory-based design code, and technical specifications. In addition, it is important to manage work adequately to ensure compliance with the relevant standards. In Indonesia, the government checks application documents, including drawings, through administrative procedures such as the building permit system. This system is regulated by Indonesia law, as is the inspection system at the time of completion. In theory, government staff should check application documents against the authorized technical standards. In practice, however, government employees do not know the standards well enough to use them and this checking role is not yet standardized or stable.

Also, in Indonesia, "simple" houses occupied by people of modest means are significantly damaged by every earthquake because of their poor quality and lack of earthquake resistance. These houses should be checked by government staff through the building permit system. However, most of the occupiers of these buildings construct their houses without applying for permission, underlining the inadequacy of the government's building administration service for simple houses. At the same time, owners have difficulty finding the money to hire a building engineer to make drawings and control building work.

For these reasons, the government is currently unable to provide adequate construction services that ensure the safety of poor people in the event of an earthquake.

The Japan International Cooperation Agency (JICA) is carrying out a project to develop building administration and enforcement for seismic resilience. The aim of the project is to enable government building administration employees to provide the necessary support for construction so that the simple houses are safer.

This report presents the research findings, underlining problems in terms of the technical aspects of simple houses.

KEYWORDS

Simple house, non-engineered house, building permit, key requirement, strength of concrete, diameter of reinforcement, awareness building by the government, incentives for building permits

INTRODUCTION

In Indonesia, the building permit system is implemented with a focus on building safety and orderly development in accordance with building law. At the same time, the system involves a processing fee, which represents a major source of revenue for the local government.

Currently, people's awareness of the building permit system depends on their location, and they do not always use it for simple houses. As Indonesia does not have sufficient earthquake resistance, every earthquake has caused simple houses to collapse, always involving losses of lives. It is difficult to solve such problems by merely relying on improving the knowledge of building owners or expecting construction workers to make the effort to enhance the earthquake resistance of simple houses.

Reflecting such conditions, JICA started a project to develop building administration and enforcement after the earthquake in central Java on 27 May 2006. JICA tried to use the building permit system to enhance the quality of earthquake resistance in the reconstruction project carried out in Yogyakarta Province.

Summary of activities in the project for developing building administration and enforcement for seismic resilience conducted by JICA in Indonesia

Review of action after the central Java earthquake: overall goal

This research reviewed the mechanism used in the reconstruction project after the central Java earthquake (Figure 1).

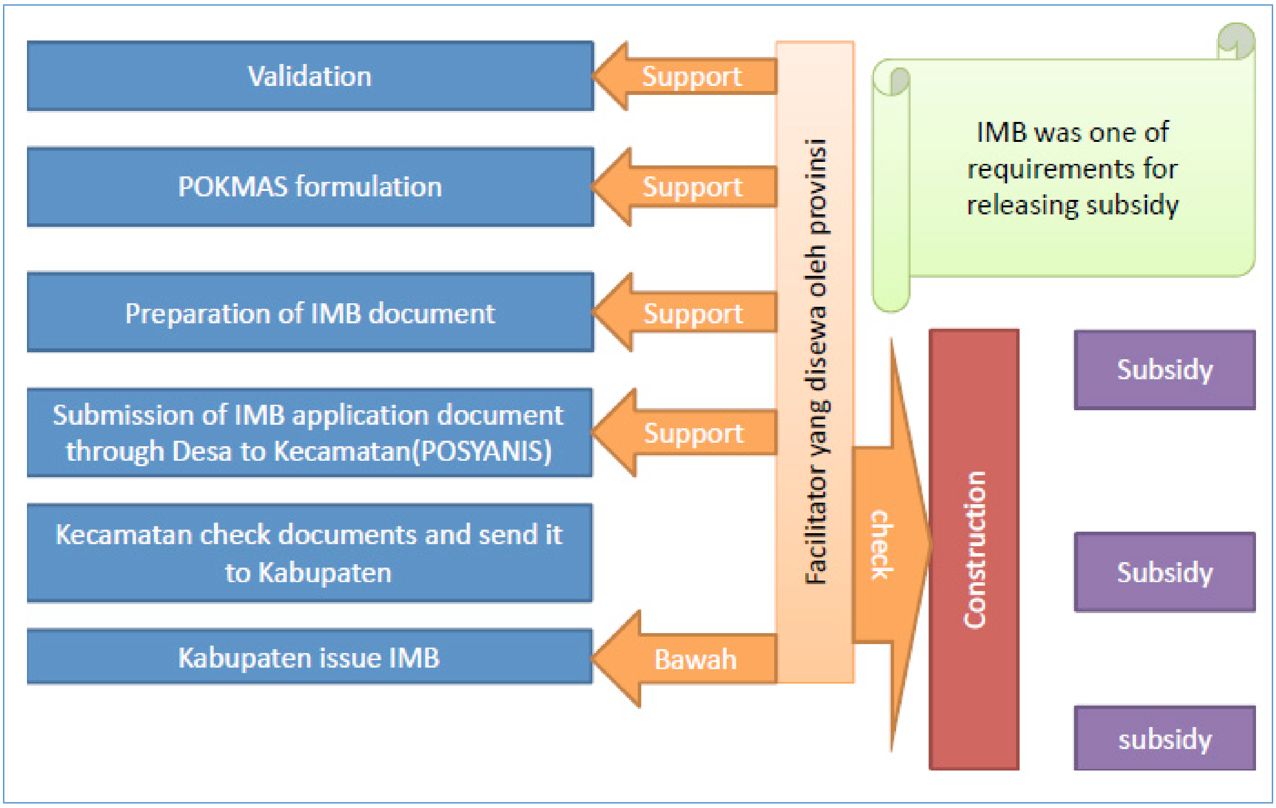


Figure 1 Mechanism of the reconstruction project with the building permit system

The study also aims to show the effectiveness of the building permit system in that it forces people to prepare drawings with adequate information to construct their houses, compared to no drawings at all or drawings with insufficient information. The IMB (building permit) influencing mechanism is shown in Figure 2. As underlined in this chart, an important aim of the building permit system is to force construction clients to provide adequate drawings in line with legal requirements. Given that the future owners of simple houses often do not have enough money to ask engineers to make technically adequate drawings, there is a need to find solutions that the government can implement.

Technical standards are therefore required to enable government employees to check drawings. These standards should be customized to fit local conditions, such as the available materials, especially coarse aggregate. However standards should never be compromised and a method is required to maintain a certain quality level even when local conditions and materials are taken into account. Such research can improve construction at different locations.

This project aims to enable the Indonesian government to manage technical standards autonomously, even though they need to be researched and customized. This requires the government to take strong ownership of the process.

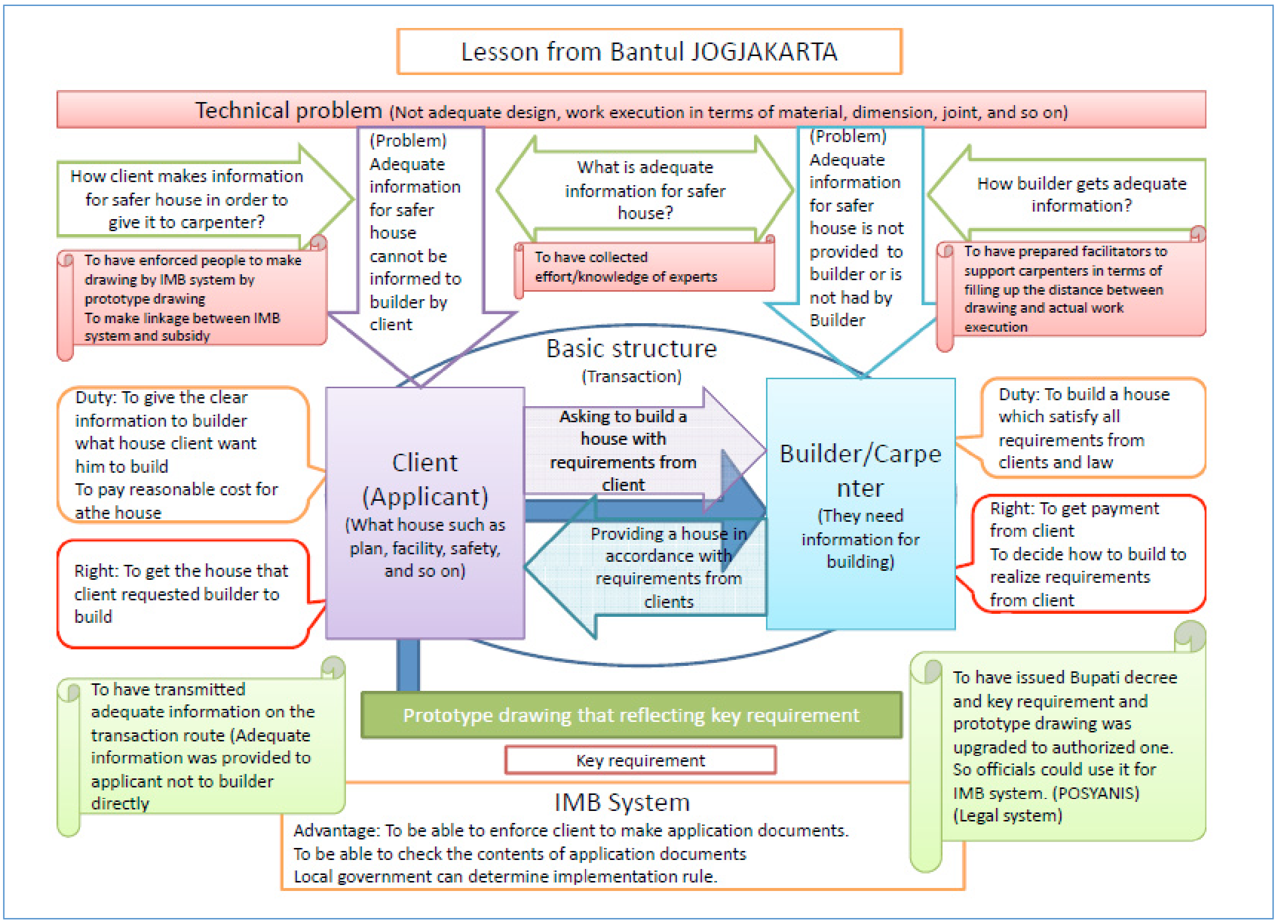


Figure 2 Influence of building permit system on construction work

This project would also create standards on the assumption that Indonesian experts will do it afterwards. Japanese aid is providing logistics for the meetings and research on construction methods for simple houses, as well as research results to use as a reference during a meeting among Indonesian experts and led by them. However, Indonesian experts discussed the matter philosophically (exchanging opinions) while evaluating it quantitatively, and as a result had difficulty reaching consensus. To provide support effectively, foreigners first need to understand this feature of Indonesian culture.

Methodology for integrating building administration and technical standards

The reconstruction project after the central Java earthquake shows the methodology for integrating building administration and technical standards, as follows:

(a) Linking subsidies to the building permit system

The Indonesian government usually subsidizes housing reconstruction and has used subsidies to push people to apply for a building permit. In this way, the government has managed to raise people's awareness of building permits. Such an incentive appears necessary for promoting the building permit system.

(b) Implementing a system of inspections during construction

Yogyakarta Province hired facilitators, who were dispatched to sites. These facilitators checked construction methods and whether workers were implementing construction work in accordance with the drawings submitted in building permit applications. Such inspections are useful for ensuring that the desired quality is reached.

(c) Helping people to apply for a building permit

In Yogyakarta, facilitators hired by the province helped people to write or prepare their applications for building permits. They also produced 36 kinds of prototype drawings that people could use to ensure their applications were adequate. Such prototypes were useful for people who wanted to make an application and provide workers with adequate drawings, since they perfectly reflected technical standards.

(d) Raising awareness of the importance of building permit systems

In the Yogyakarta reconstruction project, facilitators easily raise awareness of the building permit system because of the link with subsidies, and it is useful to do so in advance.

(e) Providing building permits free of charge

In Yogyakarta, the local government decided to provide building permits free of charge. Removing the fee was a good incentive.

Activities to enhance building administration in pilot areas

For this project, the following pilot sites were selected: Tanah Datar District and Pesisir Selatan District in West Sumatra Province; Bengkulu Utara district in Bengkulu Province; and the cities of Manado, Bitung and Tomohon in North Sulawesi Province. JICA acted to enhance building administration. Padang Pariaman was added along the way, attempting to copy the reconstruction systems used in Yogyakarta. Fortunately, consensus was easily obtained from stakeholders such as the governor of Padang Pariaman, the people in charge of the Disaster Management Agency and the Province, enabling the project to support the establishment of the reconstruction system. In the implementation stage, however, difficulties were faced in such areas as training and managing facilitators, underlining the gap between theory and practice.

Technical problems in the pilot areas

This project focuses on simple houses. The structural materials for simple confined masonry houses comprise concrete, reinforcement, bricks and mortar. It is important to research the quality of materials since this is the basis of structural quality. The results for concrete are shown in Figure 3, revealing that surprisingly low strength concrete is used for the construction of simple houses: less than 100 kg/cm2 on average. These results highlight the need for correct mixing to achieve adequate strength concrete.

In addition, reinforcement testing was carried out by the University of Padang, revealing that most reinforcements do not have the correct diameter and the cross section area is therefore weaker. Above all, the required strength of beams and columns, consisting of concrete and reinforcement, is not guaranteed, implying that the whole structure of simple houses lacks strength.

The strength of bricks bought directly from factories was also checked, and the poor results of compression tests are shown in Figure 4. In general, brick strength does not meet the technical standards authorized by Indonesia government for reinforcement concrete structures. In case of simple houses, however, we cannot help counting as burden parts against external load such as earthquakes.

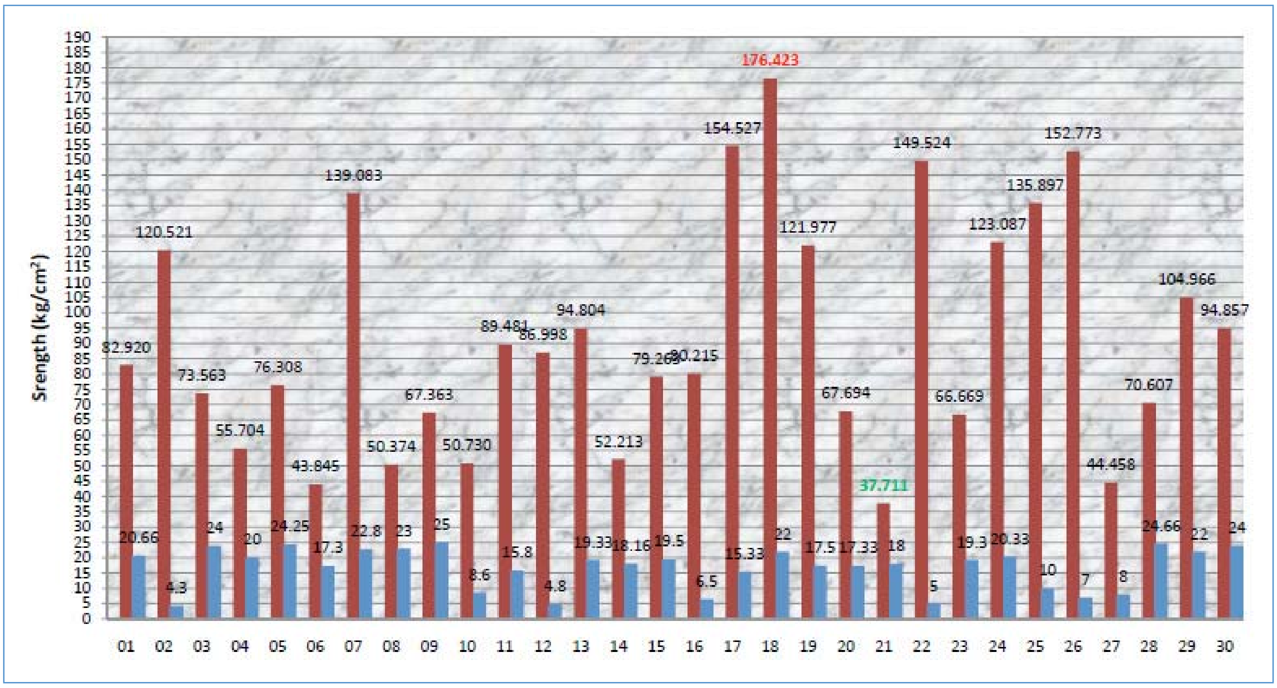


Figure 3 Results of compression testing for concrete from 30 locations in Manado City

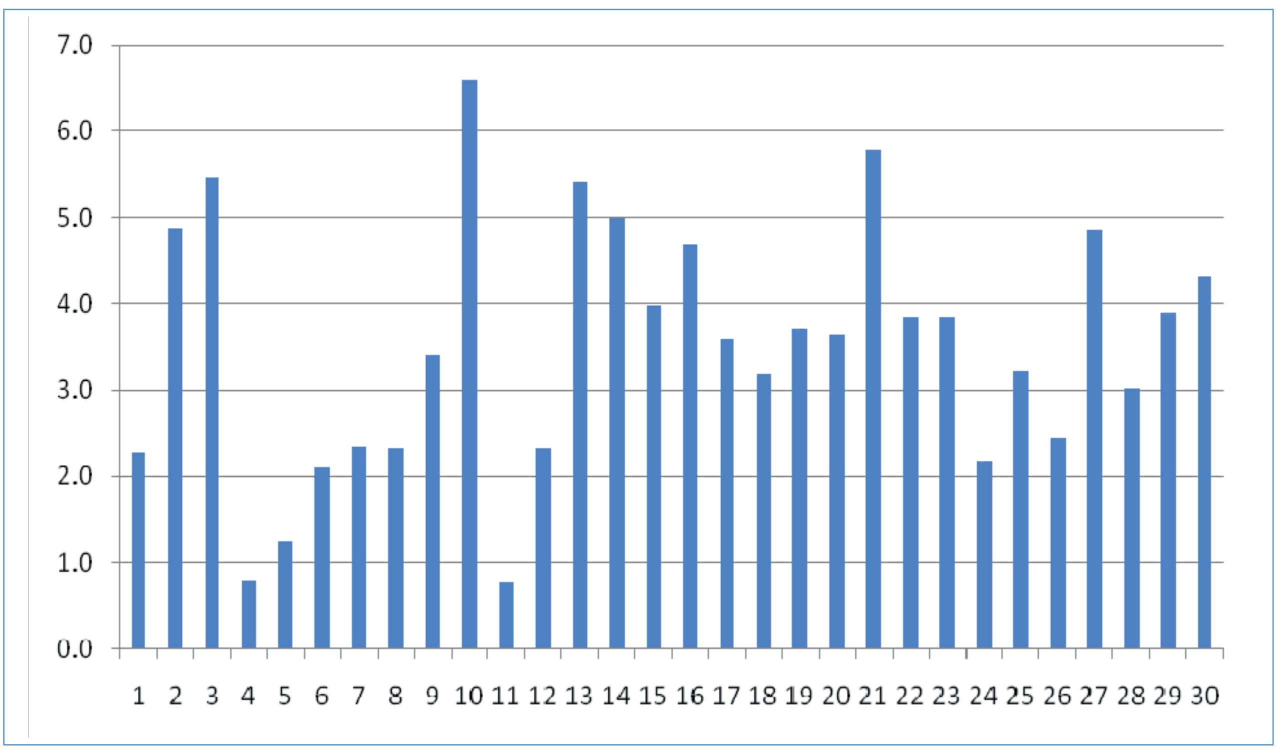


Figure 4 Compression strength of bricks bought from a brick factory near Manado

No.	(A) Said Diameter (mm)	(B) ActualDiameter (mm)	(B)/(A)	((B)/(A))^2	(G) Yield stress corresponding to (B) (N/mm2) E/C	(H) Failure stress corresponding to (B) (N/mm2) F/C	(I) Yield stress corresponding to (A) (N/mm2) E/C	(J) Failure stress corresponding to (A) (N/mm2) F/C
1	6	4.4	0.73	0.54	210.6	292.8	113.23	159.24
2	8	6.6	0.83	0.68	216.4	386.0	147.29	262.74
3	8	6.7	0.84	0.70	232.7	391.6	163.22	274.68
4	8	7.7	0.96	0.93	249.2	423.3	230.89	392.12
5	8	7.9	0.99	0.98	253.1	400.1	246.82	390.13
6	10	8.3	0.83	0.69	244.1	355.0	168.15	244.59
7	10	8.6	0.86	0.74	246.3	378.9	182.17	280.25
8	10	10.2	1.02	1.04	440.8	619.6	458.60	644.59
9	10	9.7	0.97	0.94	352.0	454.9	331.21	428.03
10	12	10.4	0.87	0.75	329.8	413.4	247.70	310.51
11	12	11.7	0.98	0.95	284.8	479.3	270.70	455.59
12	12	11.8	0.98	0.97	331.2	466.6	320.24	451.17
13	12	11.9	0.99	0.98	341.8	469.6	336.16	461.78

Table 1 Diameters of bought reinforcement

Mortar should be mixed in a 1:4 ratio, which is perhaps enough strength for brick accumulation. The results of compression testing of mortar carried out in Manado Politeknik University are shown in Figure 5.

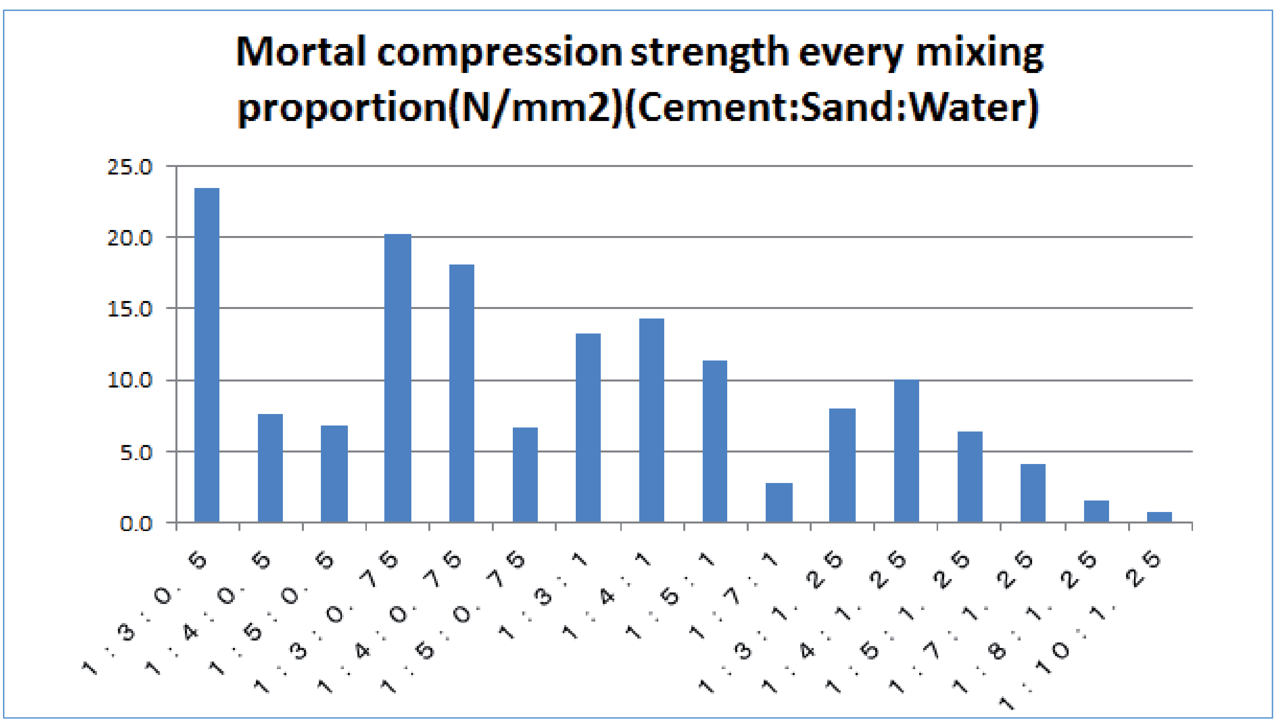


Figure 5 Mortar compression strength

In addition, workers were interviewed regarding mortar mixing proportions. According to workers, these may be, for instance, 1:5, 1:8 and 1:10. With such proportions, the desired strength cannot be obtained, which is a major problem.

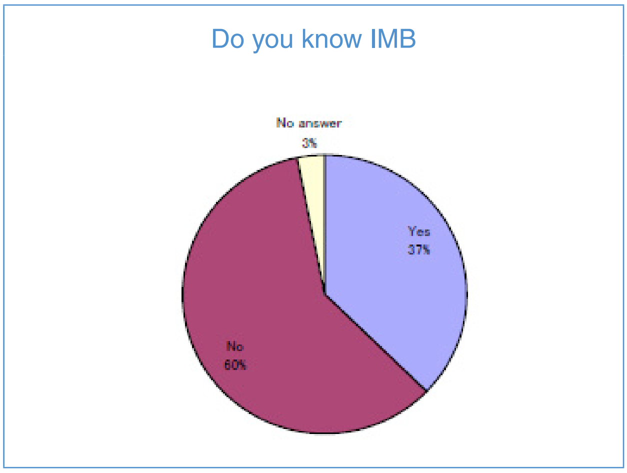
Above all, the research shows that all materials used for structural elements lack strength. To resolve such problems, other government sections should manage the relevant factories.

Activities in pilot areas

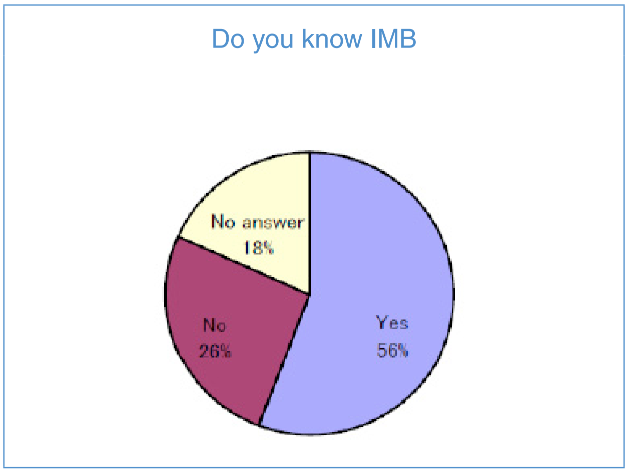
The main activities carried out in pilot areas are as follows:

(a) Survey of people's awareness

One objective of this project was to transfer technical know-how, which requires an understanding of people's level of awareness. Ideally, administrations provide service and adjust their work to fit people's needs, but in practice this is not necessarily the case. The project therefore asked government employees to interview people as a trial, and find out whether they know about building permits. Interestingly, people from areas where the government implements building administration have a much higher awareness of the building permit (IMB) system than those from other areas (Figure 6). These results show that there is scope to raise awareness of and interest in building administration in society.



Benkulu Utara
(Rural area in mountain area)



Pesisir Selatan in SUBAR
(Rural area in coastal area)

Figure 6 Awareness of the building permits system in two areas

(b) Basic survey for the installation of a computerized building information system

One of the aims of this project was for the local government to introduce a computerized building information system. This requires knowledge of the available human resources for operating computers and software such as Microsoft Office, and the ability to introduce software for a building information system.

(c) Survey of construction methods of simple houses

This research surveyed the current construction methods for simple houses, confirming that quality was lower for simple buildings than for buildings constructed in compliance with technical standards.

(d) Proposed improvements to building administration regulations

Building administration must be based on regulations. In other words, employees need regulations. A draft was therefore proposed, altering the existing regulations to take into account the lessons learnt from the reconstruction project after the central Java earthquake.

These changes were discussed many times with local government employees, who were asked for clarification. The process revealed that every local government has its own structure and its own needs for additional content to implement building law.

Therefore, even though the content of local building regulation was discussed with central government, there was no clear picture of the scope that the central government can allow local government to decide by themselves. This scope should be clarified to avoid a widening gap between the central and local governments.

(e) A proposed checklist for building permit application documents, combined with training in how to use the checklist

Training (e.g. simulation training) was necessary for employees to understand the improved building permit system and checklist.

(f) A proposed computerized building information system and training

A computerized system would provide transparency, enabling people to better follow the processing of building permits. Another advantage would be data that can be analyzed easily for urban design and other purposes.

CONCLUSIONS

Integration of building administration and technical standards for safer houses

Technical standards should be integrated into building administration. To this end, the government should undertake a number of needs:

a) Raising awareness of the building administration system and technical standards
b) A need for the government to consider the link between the building permit system and other government action to promote synergies
c) A need for the government to earn people's trust through a transparent building administration
d) A need for the government to remove obstacles to applying for building permits, through its building administration, for example by using sub-district offices to receive applications.

As the government improves the building administration system and technical standards are integrated, the system could be expanded and more readily integrated into people's everyday lives.

ACKNOWLEDGMENTS

The author expresses gratitude to UNESCO for this opportunity, and all the people who supported the project.

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TENSILE TESTING OF KSTI-SNI PLAIN CONCRETE-REINFORCING STEEL IN THE LABORATORY

Raimon Kopa

Lecturer, Faculty Technology Civil Engineering Department
State University of Padang (UNP), Indonesia
Email: raimon_unp@yahoo.co.id

ABSTRACT

Up until now, no information has been made available on the quality of concrete-reinforcing steel sold on the market. In addition, this steel is always bent 180° by manufacturers and then straightened out in construction. The earthquake on 30 September 2009 caused many buildings to collapse after their reinforced-concrete or steel structures were broken, or twisted but not broken; what made then not further functional for buildings. This research aimed to determine the physical properties and tensile strength of plain KSTI concrete-reinforcing steel samples of different diameters (8 mm, 10 mm, 12 mm, 16 mm and 19 mm) and different forms (bent, once bent, twice bent and market bent). The results were compared to the quality requirements stipulated in the Indonesian National Standard, SNI 07-2052-2002. All the tested samples were fully compliant (in terms of visual aspect, shape, diameter tolerance, roundness tolerance and weight tolerance), except for the 8 mm and 16 mm diameters, which failed to meet the required weight tolerance. Tensile test results showed different quality classes for different diameters: BjTP-14 grade for a diameter of 8 mm, BjTP-21 for 10 mm, BjTP-25 for 12 mm, BjTP-33 for 16 mm, and BjTP-32 for 19 mm. Rupture strength increased for bent steel bars (by 2.2 per cent for usual bent bars and by 8.3 per cent for market bent bars). The ductility factor decreased by 30 per cent, although still exceeding the minimum requirements stipulated by SNI 07-2052-2002.

KEYWORDS

Steel reinforced plain concrete, tensile strength, SNI 07-2052-2002.

BACKGROUND

Steel bars are used to reinforce concrete structures to compensate for their very weak tensile strength. They are generally placed in the tensile region.

Steel bars are sold in the market in various forms and with various quality levels from different factories. Consumers do not have information about the quality of reinforcing steel and generally users only consider its price, not quality.

The Indonesian National Standard (SNI) has defined quality standards (SNI 07-2052-2002) for products including concrete-reinforcing steel. These terms cover: visual aspect, shape, size, tolerance, mechanical properties and tagging or labels. Reinforcing steel should not contain any visible fragments, folds, cracks or waves, and should have only minor rust on the surface. In addition, treinforcing steel should be flat and not finned. Other requirements cover diameter tolerance, roundness, and weight per metre. Mechanical properties such as yield limit, strain and bend tests are used as a basis for grading reinforcing steel.

Reinforcing steel on the market is generally 12 m long, folded 180o to a length of 6 m, and straightened again during installation. In West Sumatra, the earthquake on 30 September 2009 led to many reinforced concrete structures collapsing, or being twisted but not broken. Traces of iron-reinforced concrete structures that had collapsed were widely used by the general public to create new reinforced concrete structures. A key question is whether reinforcing steel that has been bent is safe to use. To answer this question, it is necessary to test concrete-reinforcing steel that is widely used by the general public.

This research aims to determine the physical and mechanical properties of a variety of samples: unbent, once bent, twice bent and market bent reinforcing steel. The test results are compared with the quality requirements stipulated in SNI 07-2052-2002.

RESEARCH METHODOLOGY

The samples used for testing were plain steel bars (KSTI-SNI) with different diameters: 8 mm, 10 mm, 12 mm, 16 mm and 19 mm, based on the widely-used products in the community. Four types were involved: unbent with a sign (0), once bent with signs (1), twice bent with a sign (2), and crooked with a sign (1p), and three samples were taken in each group (approval from JICA) for a total of 60 samples.

Size of steel reinforcement	Sample treatment testing				Amount	Sample material
	Unbent (0)	Once bent (1)	Twice bent (2)	Market bent (1p)	Sample	Bar 12 m
8 mm	3	3	3	3	12	1
10 mm	3	3	3	3	12	1
12 mm	3	3	3	3	12	1
16 mm	3	3	3	3	12	1
19 mm	3	3	3	3	12	1
20 mm	-	-	-	-	-	-
Amount	15	15	15	15	60	6

Table 1 Testing of KSTI concrete-reinforcing steel samples

Unbent (0) samples were taken from the straight sections. Once bent (1) samples were taken from straight sections, then bent in the centre with a bending tool at a 900 angle and straightened again. Twice bent (2) samples were the same as once bent samples but bent again in the opposite direction to the first bend. Market bent samples (1p) were taken from the curved section of each sample material, one sample from the middle and two with the tip of edges bent which clamped during testing. These were considered unbent.

The samples consisted of five concrete-reinforcing steel rods with different diameters: 8 mm, 10 mm, 12 mm, 16 mm and 19 mm, as mentioned. Each was cut with a hacksaw to produce the required number and length of samples. The length of the samples was: 20 mm + 8 mm x diameter (SNI 07-0371-1998). Bending and straightening was carried out with a bending iron.

Cut and bent samples were marked with three digits (e.g. 10-1-2). The first number indicates the diameter, the second indicates the treatment (unbent, once bent, etc.) and the third indicates the number of samples in the group (1, 2 or 3). As an illustration, sample group 10-1-2 had a diameter of 10 mm, was bent once and involved two individual samples.

All samples were measured using a Skatemach (Verner) measuring instrument to obtain a maximum and minimum diameter. Tensile testing of plain concrete-reinforcing steel samples was carried out using a Hydraulic Universal Testing Machine (Type 2000.2/1057) with a maximum loading of 1000 kN. Tests were conducted at the Laboratory of Construction, Department of Civil Engineering, Engineering Faculty, State University of Padang.

Test results from each sample produced the following data:

1. Yield tensile force (Fy): the large tensile force when specimens have yield / yield that is characterized by increased load despite the cessation of deformation / extension is underway
2. Yield extension (ΔLy): the extension of the sample when the yield tensile force (Fy)
3. Failure tensile force (Fy): the maximum tensile force when the sample had dropped out
4. Failure elongation (ΔLf), which extended the sample size when the tensile force failure
5. Graph of tensile force (F) and elongation (ΔL)
6. Sample failure condition

The data from the test results were processed to produce the following values:

1.	Yield strain:	$\varepsilon y = \Delta Ly / Lo$	(1)
2.	Failure strain:	$\varepsilon f = \Delta Lf / Lo$	(2)
3.	Yield stress:	$\sigma y = Fy / A$	(3)
4.	Failure stress:	$\sigma f = Ff / A$	(4)
5.	Modulus of elasticity:	$E = \sigma y / \varepsilon y$	(5)
6.	Ductility factor:	$\mu = \Delta Lf / \Delta Lf$	(6)

The average value was then found for the above parameters in the group and the average value of parameters in the treatment.

TEST RESULTS AND DISCUSSION

Physical properties testing

The results are shown in Table 2.

Visual aspect

According to SNI 07-2052-2002 Article 5.1, reinforcing steel should not contain fragments, folds, cracks or waves. Based on a visual inspection, all samples were in compliance.

Surface

According to SNI 07-2052-2002 Article 5.2, the surface of concrete-reinforcing steel should be flat and not finned. Based on a visual inspection, all samples were in compliance.

Diameter and weight

All the samples fully met the tolerance requirements specified by SNI 07-02052-2002, except for the 8 mm and 16 mm diameter samples, which did not meet the specified weight tolerance.

Data from tensile testing of concrete-reinforcing steel samples is shown in Table 3. The average results for each type of sample according to diameter and treatment are shown in Table 4 and according to treatment are shown in Table 5.

The averages shown in Tables 4–5 lead to the following observations:

1. Yield strain on bent reinforced steel tends to increase for 12 mm, 16 mm, and 19 mm diameters and decrease for 8 mm and 10 mm diameters. For all diameters, yield strain tends to increase by 1.7 per cent for normal bent and 13.7 per cent for market bent bars. Failure strain on bent reinforced steel tends to decrease for all diameters by 29.6 per cent for normal bent bars and 20.4 per cent for market bent bars.
2. Yield stress on bent reinforced steel tends to decrease by 1 per cent for normal bent bars and increase by 20.3 per cent for market bent bars.
3. The failure strength of bent reinforced steel tends to rise by 2.2 per cent for normal bent bars and 8.3 per cent for market bent bars.
4. The elastic modulus of bent reinforcing steel tends to decrease by 3.1 per cent for normal bent bars and rise by 9.1 per cent for market bent bars.
5. The ductility factor of bent reinforced steel tends to decrease by 30.8 per cent for normal bent bars and by 30 per cent for market bent bars.

APARATUS	: Hidraulic Universal Testing Machine	TANGGAL PENGUJIAN	: 22 - 23 Februari 2010
Type	: 2000.2/1057	Type	: 2000.2/1058
Max load	: 1000 kN	BAHAN UJI	: Besi Beton KSTI-SNI

No.	Sampel	Diam. Max.	Diam. Min.	Diam. Rata-rata	Sec.Area A	Panjang sampel	Panjang uji	weight W	Weight/m W/ m	Bentuk	Toleransi Diameter	Toleransi Kebudaran	Toleransi Berat
		(mm)	(mm)	(mm)	(mm2)	(mm)	(mm)	gr.	kg/m				
1	**8-0-1**	7,8	7,6	7,70	46,54	264	75,00	95,7	0,363	ok	(7.6)ok	(0.28)ok	(0.367)No
2	**8-0-2**	7,8	7,6	7,70	46,54	264	72,00	96	0,364	ok	ok	ok	No
3	**8-0-3**	7,8	7,6	7,70	46,54	264	73,00	96	0,364	ok	ok	ok	No
4	**8-1-1**	7,8	7,6	7,70	46,54	268	78,00	96,5	0,360	ok	ok	ok	No
5	**8-1-2**	7,8	7,6	7,70	46,54	267	78,00	96,9	0,363	ok	ok	ok	No
6	**8-1-3**	7,8	7,6	7,70	46,54	263	69,00	95,7	0,364	ok	ok	ok	No
7	**8-2-1**	7,8	7,6	7,70	46,54	263	84,00	95,4	0,363	ok	ok	ok	No
8	**8-2-2**	7,8	7,6	7,70	46,54	263	84,00	95,4	0,363	ok	ok	ok	No
9	**8-2-3**	7,8	7,6	7,70	46,54	263	84,00	95,2	0,362	ok	ok	ok	No
10	**10-0-1**	10	9,8	9,90	76,94	282	99,00	166,2	0,589	ok	(9.6)ok	ok	(0.579)Ok
11	**10-0-2**	10	9,8	9,90	76,94	280	99,00	165,5	0,591	ok	ok	ok	ok
12	**10-0-3**	10	9,8	9,90	76,94	283	10,00	167,5	0,592	ok	ok	ok	Ok
13	**10-1-1**	9,9	9,7	9,80	75,39	281	101,00	165,4	0,589	ok	ok	ok	Ok
14	**10-1-2**	9,9	9,7	9,80	75,39	284	100,00	167,3	0,589	ok	ok	ok	Ok
15	**10-1-3**	9,9	9,7	9,80	75,39	281	100,00	166	0,591	ok	ok	ok	Ok
16	**10-2-1**	9,9	9,7	9,80	75,39	281	100,00	163,8	0,583	ok	ok	ok	ok
17	**10-2-2**	9,9	9,7	9,80	75,39	283	100,00	165,6	0,585	ok	ok	ok	ok
18	**10-2-3**	9,9	9,7	9,80	75,39	281	100,00	165,5	0,589	ok	ok	ok	Ok
19	**12-0-1**	11,9	11,7	11,80	109,30	296	116,00	252,3	0,852	ok	(11.6)ok	ok	(0,834)ok
20	**12-0-2**	11,9	11,7	11,80	109,30	296	116,00	252,8	0,854	ok	ok	ok	ok
21	**12-0-3**	11,9	11,7	11,80	109,30	295	116,00	252,5	0,856	ok	ok	ok	Ok
22	**12-1-1**	11,9	11,6	11,75	108,38	296	116,00	251,2	0,849	ok	ok	ok	Ok
23	**12-1-2**	11,9	11,6	11,75	108,38	296	116,00	251,8	0,851	ok	ok	ok	Ok
24	**12-1-3**	11,9	11,6	11,75	108,38	296	116,00	251,7	0,850	ok	ok	ok	Ok
25	**12-2-1**	11,9	11,6	11,75	108,38	295	116,00	250,05	0,848	ok	ok	ok	Ok
26	**12-2-2**	11,9	11,6	11,75	108,38	296	116,00	252,1	0,852	ok	ok	ok	Ok
27	**12-2-3**	11,9	11,6	11,75	108,38	298	116,00	254,7	0,855	ok	ok	ok	Ok
28	**16-0-1**	15,8	15,5	15,65	192,26	329	148,00	492,2	1,496	ok	(15.5)ok	(0.35)ok	(1.501)No
29	**16-0-2**	15,8	15,5	15,65	192,26	332	148,00	497,1	1,497	ok	ok	ok	No
30	**16-0-3**	15,8	15,5	15,65	192,26	330	148,00	494,4	1,498	ok	ok	ok	No
31	**16-1-1**	15,8	15,5	15,65	192,26	332	148,00	493,5	1,486	ok	ok	ok	No
32	**16-1-2**	15,8	15,5	15,65	192,26	329	148,00	488,5	1,485	ok	ok	ok	No
33	**16-1-3**	15,8	15,5	15,65	192,26	330	148,00	492,2	1,492	ok	ok	ok	No
34	**16-2-1**	15,8	15,4	15,60	191,04	332	148,00	492,9	1,485	ok	ok	ok	No
35	**16-2-2**	15,8	15,4	15,60	191,04	332	148,00	492,2	1,483	ok	ok	ok	No
36	**16-2-3**	15,8	15,4	15,60	191,04	332	148,00	494,6	1,490	ok	ok	ok	No
37	**19-0-1**	19,1	18,3	18,70	274,51	372	178,00	800	2,151	ok	18.5)ok	ok	(2.118)ok
38	**19-0-2**	19,1	18,3	18,70	274,51	373	179,00	801,8	2,150	ok	ok	ok	Ok
39	**19-0-3**	18,8	18,6	18,70	274,51	372	180,00	795,7	2,139	ok	ok	ok	ok
40	**19-1-1**	18,8	18,6	18,70	274,51	373	180,00	796,9	2,136	ok	ok	ok	ok
41	**19-1-2**	18,8	18,6	18,70	274,51	373	182,00	798,2	2,140	ok	ok	ok	Ok
42	**19-1-3**	18,7	18,3	18,50	268,67	373	181,00	795,6	2,133	ok	ok	ok	ok
43	**19-2-1**	18,6	18,3	18,45	267,22	375	181,00	791,8	2,111	ok	ok	ok	ok
44	**19-2-2**	18,8	18,3	18,55	270,12	375	181,00	796,8	2,125	ok	ok	ok	ok
45	**19-2-3**	18,7	18,4	18,55	270,12	375	183,00	799,9	2,133	ok	ok	Ok	ok
46	**8-1p-1**	7,8	7,6	7,70	46,54	252	82,00	91,5	0,363	ok	ok	ok	no
47	**8-1p-2**	7,8	7,6	7,70	46,54	265	84,00	95,7	0,361	ok	ok	ok	No
48	**8-1p-3**	7,8	7,6	7,70	46,54	266	84,00	95,7	0,360	ok	ok	ok	No
49	**10-1p-1**	9,8	9,6	9,70	73,86	269	100,00	157,1	0,584	ok	ok	ok	ok
50	**10-1p-2**	9,8	9,6	9,70	73,86	278	100,00	164,3	0,591	ok	ok	ok	Ok
51	**10-1p-3**	9,9	9,7	9,80	75,39	278	100,00	164,8	0,593	ok	ok	ok	Ok
52	**12-1p-1**	11,8	11,7	11,75	108,38	282	116,00	241,1	0,855	ok	ok	ok	ok
53	**12-1p-2**	11,8	11,7	11,75	108,38	293	116,00	251	0,857	ok	ok	ok	ok
54	**12-1p-3**	11,8	11,7	11,75	108,38	294	116,00	252,5	0,859	ok	ok	ok	Ok
55	**16-1p-1**	15,8	15,4	15,60	191,04	324	148,00	482,2	1,488	ok	ok	ok	No
56	**16-1p-2**	15,8	15,4	15,60	191,04	308	148,00	458,9	1,490	ok	ok	ok	No
57	**16-1p-3**	15,8	15,4	15,60	191,04	327	148,00	487,7	1,491	ok	ok	ok	No
58	**19-1p-1**	18,6	18,3	18,45	267,22	372	178,00	792,5	2,130	ok	ok	ok	ok
59	**19-1p-2**	18,7	18,3	18,50	268,67	350	160,00	745,3	2,129	ok	ok	ok	ok
60	**19-1p-3**	18,6	18,3	18,45	267,22	374	182,00	796,5	2,130	ok	ok	ok	ok

Table 2 Data from physical property testing

APARATUS : Hidraulic Universal Testing Machine
TANGGAL PENGUJIAN : ....

Type : 2000.2/1057
TEMPAT PENGUJIAN : Labor Konstruksi T. Sipil

Max load : 1000 kN
BAHAN UJI : Besi Beton KSTI-SNI

No.	Sampel	D	A	L.	ΔL	ΔL	Strain	Strain.	Force	Force	Tegangan Yield		Tegangan Failure		Modulus
		Uji	Uji	Uji	Yield	Failure	ε_y	ε_f	F_y	F_f	σ_y		σ_f		E
	(mm)	(mm)	(mm2)	(mm)	(mm)	(mm)	-	-	kN	kN	N/mm^2	**Kgf/cm^2**	N/mm^2	**Kgf/cm^2**	kg/cm^2
1	**8-0-1**	7,70	46,54	75,00	1,20	30,00	0,0160	0,4000	6,50	12,50	139,66	**1424,50**	268,57	**2739,42**	**89031,24**
2	**8-0-2**	7,70	46,54	72,00	1,00	29,50	0,0139	0,4097	6,50	13,60	139,66	**1424,50**	292,21	**2980,49**	**102563,99**
3	**8-0-3**	7,70	46,54	73,00	1,00	30,00	0,0137	0,4110	6,80	13,00	146,10	**1490,25**	279,31	**2849,00**	**108787,96**
4	**8-1-1**	7,70	46,54	78,00	1,00	28,50	0,0128	0,3654	6,50	13,00	139,66	**1424,50**	279,31	**2849,00**	**111110,99**
5	**8-1-2**	7,70	46,54	78,00	1,00	25,00	0,0128	0,3205	6,00	13,40	128,91	**1314,92**	287,91	**2936,66**	**102563,99**
6	**8-1-3**	7,70	46,54	69,00	1,00	23,00	0,0145	0,3333	6,00	13,00	128,91	**1314,92**	279,31	**2849,00**	**90729,69**
7	**8-2-1**	7,70	46,54	84,00	1,00	19,50	0,0119	0,2321	6,00	13,00	128,91	**1314,92**	279,31	**2849,00**	**110453,53**
8	**8-2-2**	7,70	46,54	84,00	1,00	22,00	0,0119	0,2619	6,00	13,00	128,91	**1314,92**	279,31	**2849,00**	**110453,53**
9	**8-2-3**	7,70	46,54	84,00	1,00	20,50	0,0119	0,2440	6,00	13,00	128,91	**1314,92**	279,31	**2849,00**	**110453,53**
10	**10-0-1**	9,90	76,94	99,00	2,00	35,50	0,0202	0,3586	16,00	28,00	207,96	**2121,19**	363,93	**3712,09**	**104999,03**
11	**10-0-2**	9,90	76,94	99,00	2,00	33,00	0,0202	0,3333	16,50	28,30	214,46	**2187,48**	367,83	**3751,86**	**108280,25**
12	**10-0-3**	9,90	76,94	100,00	2,00	36,50	0,0200	0,3650	17,00	28,40	220,96	**2253,77**	369,13	**3765,12**	**112688,36**
13	**10-1-1**	9,80	75,39	101,00	2,20	26,00	0,0218	0,2574	17,00	29,10	225,49	**2300,00**	385,99	**3937,05**	**105590,78**
14	**10-1-2**	9,80	75,39	100,00	1,80	30,00	0,0180	0,3000	16,50	29,00	218,86	**2232,35**	384,66	**3923,52**	**124019,45**
15	**10-1-3**	9,80	75,39	100,00	2,00	24,00	0,0200	0,2400	17,00	29,00	225,49	**2300,00**	384,66	**3923,52**	**114999,85**
16	**10-2-1**	9,80	75,39	100,00	2,00	25,00	0,0200	0,2500	16,00	29,00	212,23	**2164,70**	384,66	**3923,52**	**108235,16**
17	**10-2-2**	9,80	75,39	100,00	2,00	24,00	0,0200	0,2400	16,00	29,00	212,23	**2164,70**	384,66	**3923,52**	**108235,16**
18	**10-2-3**	9,80	75,39	100,00	2,00	27,00	0,0200	0,2700	16,00	29,00	212,23	**2164,70**	384,66	**3923,52**	**108235,16**
19	**12-0-1**	11,80	109,30	116,00	2,50	40,50	0,0216	0,3491	27,00	42,50	247,02	**2519,59**	388,83	**3966,02**	**116909,08**
20	**12-0-2**	11,80	109,30	116,00	2,50	40,00	0,0216	0,3448	27,00	43,00	247,02	**2519,59**	393,40	**4012,68**	**116909,08**
21	**12-0-3**	11,80	109,30	116,00	2,60	37,00	0,0224	0,3190	28,00	42,50	256,17	**2612,91**	388,83	**3966,02**	**116576,01**
22	**12-1-1**	11,75	108,38	116,00	2,50	20,00	0,0216	0,1724	28,00	44,00	258,35	**2635,20**	405,98	**4141,02**	**122273,06**
23	**12-1-2**	11,75	108,38	116,00	2,50	20,00	0,0216	0,1724	28,00	43,50	258,35	**2635,20**	401,37	**4093,96**	**122273,06**
24	**12-1-3**	11,75	108,38	116,00	2,50	18,50	0,0216	0,1595	26,00	43,50	239,90	**2446,97**	401,37	**4093,96**	**113539,27**
25	**12-2-1**	11,75	108,38	116,00	2,80	19,00	0,0241	0,1638	27,50	43,00	253,74	**2588,14**	396,76	**4046,91**	**107222,87**
26	**12-2-2**	11,75	108,38	116,00	2,80	21,00	0,0241	0,1810	28,00	43,50	258,35	**2635,20**	401,37	**4093,96**	**109172,38**
27	**12-2-3**	11,75	108,38	116,00	2,40	21,50	0,0207	0,1853	27,00	44,00	249,13	**2541,08**	405,98	**4141,02**	**122818,93**
28	**16-0-1**	15,65	192,26	148,00	2,50	28,00	0,0169	0,1892	63,50	98,00	330,27	**3368,80**	509,72	**5199,10**	**199433,11**
29	**16-0-2**	15,65	192,26	148,00	2,50	60,00	0,0169	0,4054	64,00	98,00	332,88	**3395,33**	509,72	**5199,10**	**201003,45**
30	**16-0-3**	15,65	192,26	148,00	2,50	55,00	0,0169	0,3716	62,00	98,50	322,47	**3289,22**	512,32	**5225,62**	**194722,09**
31	**16-1-1**	15,65	192,26	148,00	2,50	32,50	0,0169	0,2196	63,00	99,50	327,67	**3342,28**	517,52	**5278,67**	**197862,77**
32	**16-1-2**	15,65	192,26	148,00	2,50	38,00	0,0169	0,2568	63,00	99,00	327,67	**3342,28**	514,92	**5252,15**	**197862,77**
33	**16-1-3**	15,65	192,26	148,00	2,50	37,50	0,0169	0,2534	61,50	99,00	319,87	**3262,70**	514,92	**5252,15**	**193151,75**
34	**16-2-1**	15,60	191,04	148,00	3,60	47,00	0,0243	0,3176	61,50	99,00	321,93	**3283,65**	518,22	**5285,87**	**134994,37**
35	**16-2-2**	15,60	191,04	148,00	2,60	45,00	0,0176	0,3041	60,00	99,00	314,07	**3203,56**	518,22	**5285,87**	**182356,37**
36	**16-2-3**	15,60	191,04	148,00	3,50	42,00	0,0236	0,2838	60,00	99,00	314,07	**3203,56**	518,22	**5285,87**	**135464,73**
37	**19-0-1**	18,70	274,51	178,00	3,00	67,00	0,0169	0,3764	87,00	132,00	316,93	**3232,71**	480,86	**4904,80**	**191807,38**
38	**19-0-2**	18,70	274,51	179,00	3,00	63,00	0,0168	0,3520	87,00	132,00	316,93	**3232,71**	480,86	**4904,80**	**192884,94**
39	**19-0-3**	18,70	274,51	180,00	3,20	75,00	0,0178	0,4167	88,00	131,20	320,58	**3269,87**	477,95	**4875,07**	**183929,97**
40	**19-1-1**	18,70	274,51	180,00	3,00	50,00	0,0167	0,2778	85,00	132,00	309,65	**3158,39**	480,86	**4904,80**	**189503,61**
41	**19-1-2**	18,70	274,51	182,00	3,00	49,50	0,0165	0,2720	88,00	133,00	320,58	**3269,87**	484,51	**4941,96**	**198371,88**
42	**19-1-3**	18,50	268,67	181,00	3,00	48,50	0,0166	0,2680	85,00	132,00	316,38	**3227,05**	491,32	**5011,42**	**194698,81**
43	**19-2-1**	18,45	267,22	181,00	4,00	48,50	0,0221	0,2680	86,00	131,50	321,84	**3282,74**	492,11	**5019,54**	**148543,90**
44	**19-2-2**	18,55	270,12	181,00	3,20	46,00	0,0177	0,2541	86,50	132,00	320,23	**3266,32**	488,67	**4984,44**	**184751,25**
45	**19-2-3**	18,55	270,12	183,00	3,20	52,00	0,0175	0,2842	87,00	133,00	322,08	**3285,20**	492,37	**5022,20**	**187872,43**
46	**8-1p-1***	7,70	46,54	82,00	1,00	26,00	0,0122	0,3171	7,00	13,80	150,40	**1534,08**	296,50	**3024,32**	**125794,30**
47	**8-1p-2**	7,70	46,54	84,00	1,00	30,00	0,0119	0,3571	6,00	12,60	128,91	**1314,92**	270,72	**2761,34**	**110453,53**
48	**8-1p-3**	7,70	46,54	84,00	1,00	26,00	0,0119	0,3095	6,00	13,00	128,91	**1314,92**	279,31	**2849,00**	**110453,53**
49	**10-1p-1***	9,70	73,86	100,00	2,40	28,00	0,0240	0,2800	18,00	30,00	243,70	**2485,76**	406,17	**4142,94**	**103573,42**
50	**10-1p-2**	9,70	73,86	100,00	2,00	33,00	0,0200	0,3300	16,50	28,50	223,39	**2278,62**	385,86	**3935,79**	**113930,76**
51	**10-1p-3**	9,80	75,39	100,00	2,20	32,00	0,0220	0,3200	16,50	28,30	218,86	**2232,35**	375,37	**3828,82**	**101470,46**
52	**12-1p-1***	11,75	108,38	116,00	3,00	24,50	0,0259	0,2112	35,00	48,00	322,94	**3293,99**	442,89	**4517,48**	**127367,77**
53	**12-1p-2**	11,75	108,38	116,00	2,50	30,50	0,0216	0,2629	27,80	43,00	256,51	**2616,37**	396,76	**4046,91**	**121399,68**
54	**12-1p-3**	11,75	108,38	116,00	2,50	33,00	0,0216	0,2845	28,00	43,30	258,35	**2635,20**	399,52	**4075,14**	**122273,06**
55	**16-1p-2***	15,60	191,04	148,00	2,70	32,00	0,0182	0,2162	77,00	106,00	403,06	**4111,23**	554,86	**5659,62**	**225356,45**
56	**16-1p-1**	15,60	191,04	148,00	3,30	45,00	0,0223	0,3041	61,50	98,50	321,93	**3283,65**	515,61	**5259,17**	**147266,58**
57	**16-1p-3**	15,60	191,04	148,00	3,20	47,00	0,0216	0,3176	63,50	98,50	332,40	**3390,43**	515,61	**5259,17**	**156807,48**
58	**19-1p-2***	18,50	268,67	160,00	4,70	36,00	0,0294	0,2250	105,00	143,00	390,82	**3986,36**	532,26	**5429,04**	**135705,82**
59	**19-1p-1**	18,45	267,22	178,00	4,00	55,00	0,0225	0,3090	87,00	132,00	325,58	**3320,91**	493,98	**5038,62**	**147780,47**
60	**19-1p-3**	18,45	267,22	182,00	3,20	63,00	0,0176	0,3462	84,50	130,80	316,22	**3225,48**	489,49	**4992,82**	**183449,23**

Table 3 Data from tensile testing of concrete-reinforcing samples

		ε_y	ε_f	F_y	F_f	σ_y		σ_f		E	daktilitas
	(mm)	-	-	kN	kN	N/mm^2	Kgf/cm^2	N/mm^2	Kgf/cm^2	kg/cm^2	
0	8-0	0.0145	0.4069	6.60	13.03	141.81	1446.42	280.03	2856.30	100127.73	28.01
1	8-1	0.0134	0.3397	6.17	13.13	132.49	1351.45	282.18	2878.22	101468.22	25.40
2	8-2	0.0119	0.2460	6.00	13.00	128.91	1314.92	279.31	2849.00	110453.53	20.67
3	10-0	0.0201	0.3523	16.50	28.23	214.46	2187.48	366.96	3743.02	108655.88	17.50
4	10-1	0.0199	0.2658	16.83	29.03	223.28	2277.45	385.10	3928.03	114870.03	13.34
5	10-2	0.0200	0.2533	16.00	29.00	212.23	2164.70	384.66	3923.52	108235.16	12.67
6	12-0	0.0218	0.3376	27.33	42.67	250.07	2550.70	390.35	3981.58	116798.06	15.46
7	12-1	0.0216	0.1681	27.33	43.67	252.20	2572.45	402.91	4109.65	119361.80	7.80
8	12-2	0.0230	0.1767	27.50	43.50	253.74	2588.14	401.37	4093.96	113071.39	7.69
9	16-0	0.0169	0.3221	63.17	98.17	328.54	3351.12	510.58	5207.94	198386.22	19.07
10	16-1	0.0169	0.2432	62.50	99.17	325.07	3315.75	515.78	5260.99	196292.43	14.40
11	16-2	0.0218	0.3018	60.50	99.00	316.69	3230.25	518.22	5285.87	150938.49	13.81
12	19-0	0.0171	0.3817	87.33	131.73	318.15	3245.09	479.89	4894.89	189540.76	22.28
13	19-1	0.0166	0.2726	86.00	132.33	315.53	3218.44	485.56	4952.73	194191.43	16.44
14	19-2	0.0191	0.2688	86.50	132.17	321.38	3278.09	491.05	5008.73	173722.53	14.08
15	8-1p*	0.0122	0.3171	7.00	13.80	150.40	1534.08	296.50	3024.32	125794.30	26.00
16	8-1p	0.0119	0.3333	6.00	12.80	128.91	1314.92	275.02	2805.17	110453.53	28.00
17	10-1p*	0.0240	0.2800	18.00	30.00	243.70	2485.76	406.17	4142.94	103573.42	11.67
18	10-1p	0.0210	0.3250	16.50	28.40	221.13	2255.48	380.62	3882.30	107700.61	15.48
19	12-1p*	0.0259	0.2112	35.00	48.00	322.94	3293.99	442.89	4517.48	127367.77	8.17
20	12-1p	0.0216	0.2737	27.90	43.15	257.43	2625.78	398.14	4061.02	121836.37	12.70
21	16-1p*	0.0182	0.2162	77.00	106.00	403.06	4111.23	554.86	5659.62	225356.45	11.85
22	16-1p	0.0220	0.3108	62.50	98.50	327.16	3337.04	515.61	5259.17	152037.03	14.15
23	19-p*	0.0294	0.2250	105.00	143.00	390.82	3986.36	532.26	5429.04	135705.82	7.66
24	19-p	0.0200	0.3276	85.75	131.40	320.90	3273.20	491.74	5015.72	165614.85	16.36

* market bent

Table 4 The average results for each type of sample (according to diameter and treatment)

	Strain	Strain.	Force	Force	Tegangan Yield		Tegangan Failure		Modulus	Faktor	Kondisi
Perlakuan	ε_y	ε_f	F_y	F_f	σ_y		σ_f		E	Duktilitas	Putus
	-	-	kN	kN	N/mm^2	Kgf/cm^2	N/mm^2	Kgf/cm^2	kg/cm^2		
0	0.0147	0.2951	27.60	43.16	185.55	1892.57	303.75	3098.25	103390.17	20.04598	di tengah
1x	0.0177	0.2579	39.77	63.47	249.72	2547.11	414.31	4225.92	145236.78	14.59933	di jepit
2x	0.0192	0.2493	39.30	63.33	246.59	2515.22	414.92	4232.22	131284.22	13.00908	di jepit
1x&2x	0.0184	0.2536	39.53	63.40	248.15	2531.16	414.61	4229.07	138260.50	13.77181	di jepit
(%)	25.1	-14.1	43.2	46.9	33.7	33.7	36.5	36.5	33.7	-31.3	
0p	0.0193	0.3141	39.73	62.85	251.11	2561.28	412.22	4204.68	131528.48	16.28341	di tengah
1xp*	0.0219	0.2499	48.40	68.16	302.18	3082.28	446.54	4554.68	143559.55	11.39267	bengkok
(%)	13.7	-20.4	21.8	8.4	20.3	20.3	8.3	8.3	9.1	-30.0	

* market bent

Table 5 Average results for each type of sample according to treatment

The failure point tends to occur in regions grappling of bent reinforcing steel and towards the middle (not the clips) in unbent reinforcing steel, as shown in Figure 1. This failure occurs because the cross-section steel is bent and straightened his strength increased, whereas the cross sections near the clamps are unbent and lower in strength.

For the samples of unbent steel bars, the yield point in the mark with style manometer needle stopped moving momentarily, even though the deformation continued. The yield point of bent steel bars could not be determined, however, because the needle manometer moved continually until the sample broke.

Based on SNI 07-2052-2002, Clause 5.4, shows the test results: the 8 mm diameter sample, including BjTP-14 class, had a 1,446.4 kg/cm2 yield limit and 2,856.3 kg/cm2 tensile strength; the 10 mm diameter sample, including BjTP-21 class, had a 2,187.5kg/cm2 yield limit and 3,743.2 kg/cm2 tensile strength; the 12 mm diameter sample, including BjTP-25 class, had a 2,550.7 kg/cm2 yield limit and 3,981.6 kg/cm2 tensile strength; the 16 mm diameter sample, including BjTP-33 class, had a 3,351.1kg/cm2 yield limit and 5,207.9 kg/cm2 tensile strength; and the 19 mm diameter samples including BjTP-33 class, had a 3,245.1kg/cm2 yield limit and 4,894.9 kg/cm2 tensile strength.

Based on SNI 07-2052-2002, Clause 5.4, the required minimum strain was 20 per cent, which was exceeded by the bent test sample (25 per cent strain).

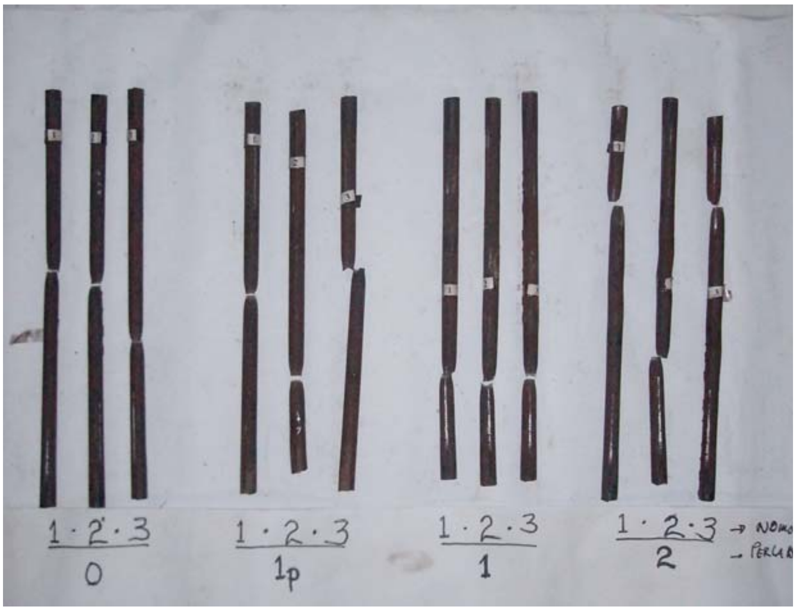

Figure 1 16 mm diameter samples after testing

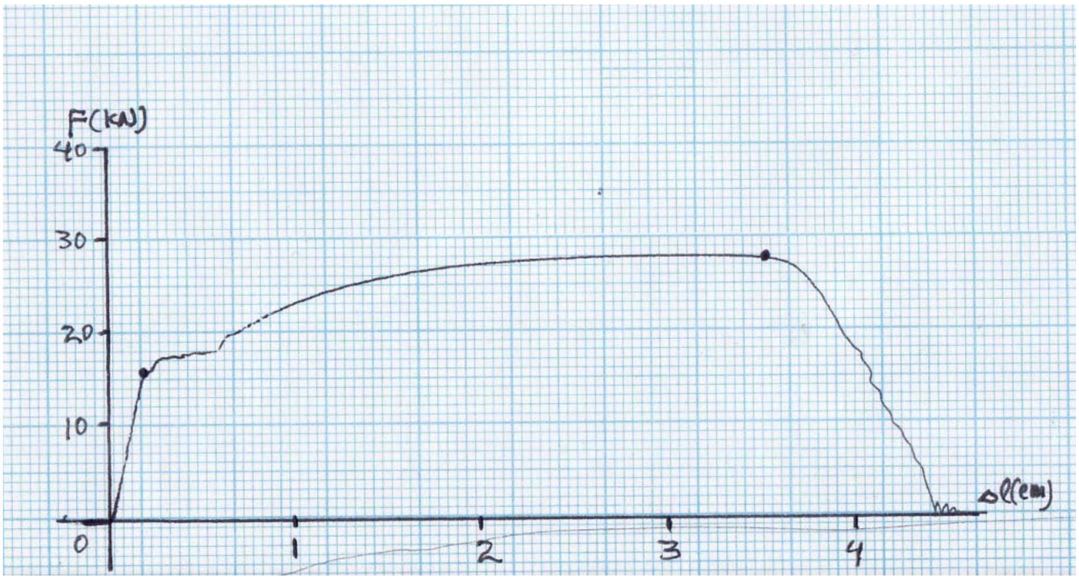

Figure 2 Force (F) and added length (ΔL) unbent samples (10-0-1)

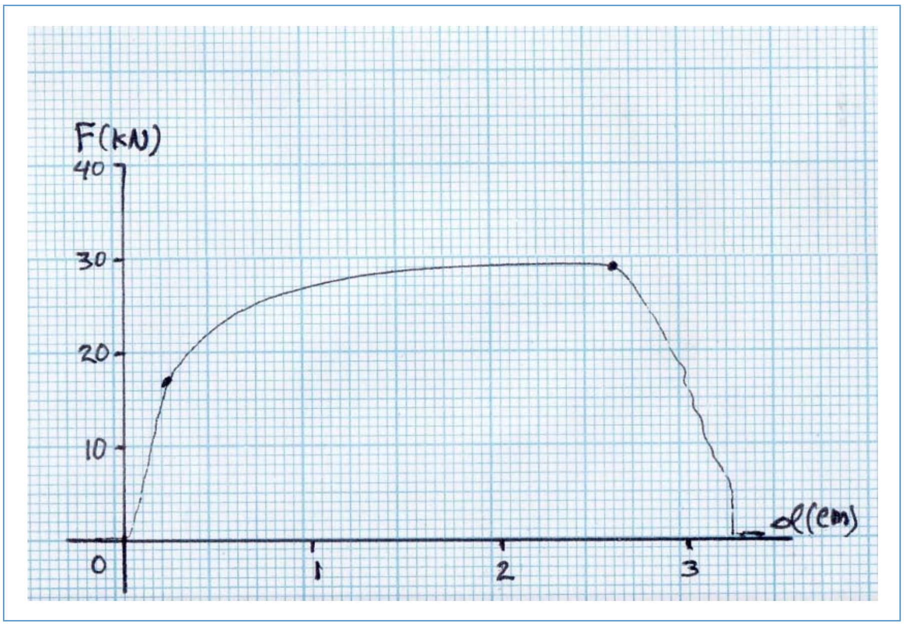

Figure 3 Force (F) and added length (ΔL) once bent samples (10-0-1)

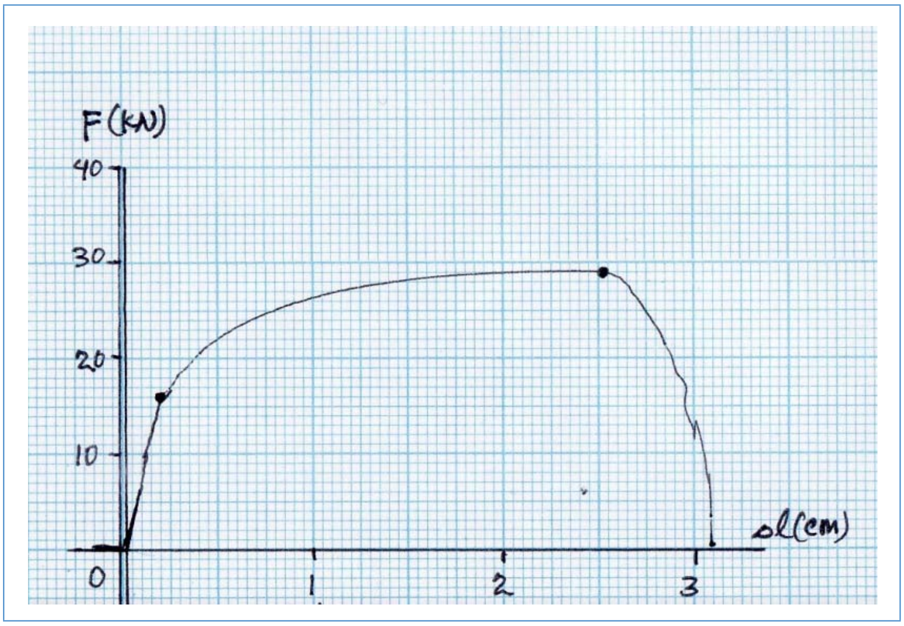

Figure 4 Force (F) and added length (ΔL) of twice bent samples (10-0-1)

CONCLUSIONS

All the tested samples of KSTI concrete-reinforcing steel met SNI 07-2052-2002 requirements in terms of visual aspect, shape, diameter tolerance, roundness tolerance and weight tolerance, except for the 8 mm and 16 mm diameter bars, which failed to meet the requirements for weight tolerance.

KSTI-SNI concrete-reinforcing steel bars were tested to produce different quality classes: the 8 mm diameter including BjTP-14 class, the 10 mm diameter including BjTP-21 class, the 12 mm diameter including BjTP-25 class, the 16 mm diameter including BjTP-33 class, and the 19 mm diameter including BjTP-32 class .

The breaking strength of reinforcing steel that is bent and straightened again increased by 2.2 per cent for normal bent bars and 8.3 per cent for market bent bars.

The ductility factor of reinforcing steel that is bent and straightened again declined by up to 30 per cent for market bent and normal bent bars. In addition, the strain dropped by 25 per cent for bent, although this still exceeded the minimum 20 per cent strain stipulated by SNI 07-2052-2002.

Parameters resulting from normal bent and market bent bars testing are different. This could be explain due that only the centre of the rod bending was taken as a sample in the normal bent, while in the market bent the curved rod bending was tested.

RECOMMENDATIONS

KSTI-SNI concrete-reinforcing steel from the ruins of collapsed buildings is safe to use in the future, because its strength tends to increase and only the ductility factor tends to decrease, although still exceeding requirements.

In the reinforcing steel market, the bent area should not be placed in the middle stretch of reinforced concrete beams, due to ductility factors that decrease and do not have a clear yield point. This if the failure was preceded by the sign tended without extreme deflection.

All concrete reinforcing steel products in the market need to be tested with a sufficient number of samples.

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BRICK CHARACTERISTICS IN WEST SUMATRA

Eka Juliafad,[1] Bambang Heriyadi[2] and Totoh Handoyo[3]

[1]Lecturer of Padang State University, Civil Engineering Department, Padang, Indonesia
Email: x_julcatcha@yahoo.com

[2]Lecturer of Padang State University, Civil Engineering Department, Padang, Indonesia
Email: bambang_heriyadi@yahoo.co.id

[3]Lecturer of Padang State University, Civil Engineering Department, Padang, Indonesia
Email: gustotok@yahoo.co.id

ABSTRACT

Many houses and other buildings collapsed after the West Sumatra earthquake on 30 September 2009. The fact that most of these buildings were made of brick calls for an investigation into the quality of bricks used by the community for homes and other buildings. This study examines the characteristics and quality of bricks required to meet the standards stipulated in Indonesian building codes (NI-10-78 and SII-0021-78). Tests were conducted in the Material Testing Laboratory Department of the Civil Engineering Faculty of Engineering at the State University of Padang and involved testing the physical characteristics and compressive strength of brick samples compared with existing standards. Samples were taken from burning stoves at brick factories and collapsed houses in the Padang Pariaman area. Bricks from burning stoves were taken from three places: near the source of fire, in the middle and far from the source. The bricks from collapsed house were taken from 10 buildings in Padang Pariaman and the surrounding area. The results showed that bricks from burning stoves did not met the standard shape, curve, measurement and compressive strength, while bricks from collapsed buildings meet the SII-0021-78 standard in terms of shape and compressive strength. This may due to the burning stove system failing to meet existing government requirements. The results indicate that brick factories should use a standard burning system with a sufficient, evenly spread temperature. Comprehensive further research using a larger sample is required to better understand the quality of bricks used by the community.

KEYWORDS

Brick strength quality, earthquake, building codes, burning stove, collapsed building.

INTRODUCTION

Many buildings including hotels, offices and homes collapsed after the West Sumatra earthquake on 30 September 2011 (Figure 1). Most the collapsed buildings were made of brick. Therefore the Department of Civil Engineering, Faculty of Engineering at the State University of Padang (UNP) and Japan International Corporation Agency (JICA) decided to conduct research into the quality and characteristics of bricks used by the West Sumatra community. Brick samples were taken from brick factories (in burning stoves) and collapsed buildings in the Padang–Pariaman area. Tests were conducted in the Material Testing Laboratory Department of the Civil Engineering Faculty of Engineering at the State University of Padang.

Figure 1 One of the collapsed houses in the research

This study examines the characteristics and quality of bricks used by the community, compared with the standards stipulated in Indonesia's building codes (NI-10-78 and SII-0021-78). Characteristics including shape, dimensions and compressive strength of brick samples from brick factories (burning stoves) and collapsed houses, were compared with the standards stipulated by the Indonesian government. The Indonesian standard codes uses in this research are NI-10-78 and SII-0021-78.

RESEARCH METHODOLOGY

Brick sampling procedure

Brick samples were taken from collapsed houses in the Padang–Pariaman district and surrounding area. Thirty samples were taken from 10 houses (three for each house), as shown in Table 1 and Figure 2.

Sample no.	Name of owner	Location	Number
I	Zaidar	Pasir Lawas	3
II	Budi	Padang Kalupang	3
III	Nurlis	Sitoga	3
IV	Riltayani	Nan Sabaris Paga Duku	3
V	Ides	Simpang IV Toboh Kp.Dalam	3
VI	Syawal	Desa Lohong Kec.Sei Limau	3
VII	Siska	Sei.Sarik Malai Batang Gasan	3
VII	Madiyos	Tobo Mandailing Kec.VII Koto	3
IX	Wati	Kiambang 2x11 Enam Lingkung	3
X	Mainas	Desa Buayan Kec. Batang Anai	3

Table 1 Location of brick samples from collapsed houses

Figure 2 Brick samples from collapsed houses

Eighteen further samples were taken from two stoves from a brick factory at Rimbo Kalam, Lubuk Alung Sub district (Figure 3). Three samples were taken from each of three places for each burning stove: near the stove, in the middle of the stove and far from the stove.

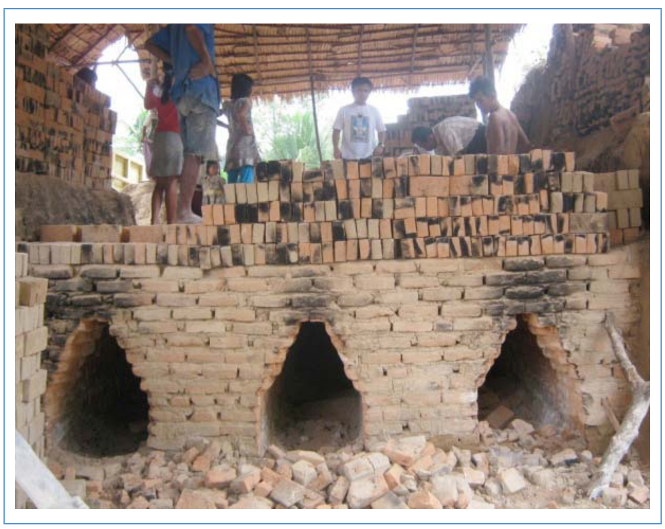

Figure 3 Bricks from a burning stove

Brick testing

Tests covered bricks' shape, colour, weight, measurement and compressive strength. According to the NI-10-78 code, the procedure for testing bricks is as follows:

Shape

A sample must be measured by ruler to ensure squared sides (Figure 4).

Figure 4 Measuring a brick sample

Colour

Bricks should be dark red, pink, yellow-red or brown.

Weight

A sample must be weighed digitally in the Material Testing Laboratory Department of Civil Engineering, Faculty of Engineering at the State University of Padang (Figure 5).

Figure 5 UNP Research Team Weighing Brick Sample

Measurement

A sample must be measured using callipers for length, width and thickness (three measurements for each sample).

Compressive Strength

Compressive Strength should be tested using the Universal Testing Machine (UTM) and the 2kg/cm2/s speed test (Figure 6).

Figure 6 Compressive strength test

The brick sample should be cut into two pieces, with one piece cut again into two to produce three pieces. The total sample should comprise 144 pieces. The compressive strength is force divided by the sample area (Figure 7).

Figure 7 Factory brick sample

Brick quality

The quality of brick samples should meet the NI-10-78 and SII-0021-78 codes, in terms of having the right angle and a uniform colour, being sharp, flat and free from fractures, and meeting the standard measurements:

	Length (mm)	Width (mm)	Thickness (mm)
1	240	115	52
2	230	110	50

Table 2 NI-10-1978 standard brick measurements

Module	Thickness (mm)	Width (mm)	Length (mm)
M-5a	65	90	190
M-5b	65	140	190
M-6	55	110	220

Table 3 SII-0021-78 standard brick measurements

Class	Maximum deviation (mm)					
	M-5a and M-5b			M-6		
	Thickness (mm)	Width (mm)	Length (mm)	Thickness (mm)	Width (mm)	Length (mm)
25	2	3	5	2	3	5
50	2	3	5	2	3	5
100	2	3	4	2	3	4
150	2	2	4	2	2	4
200	2	2	4	2	2	4
250	2	2	4	2	2	4

Table 4 SII-0021-78 authorized deviation of brick measurements

The compressive strength of brick samples must meet the Indonesian industry standard (SII-002101978) as follows:

Class	Minimum mean compressive strength of 30 pieces tested		Variation coefficient allowed for mean compressive strength (%)
	Kg/cm²	N/mm²	
25	25	2.5	25
50	50	5.0	22
100	100	10.0	22
150	150	15.0	15
200	200	20.0	15
250	250	25.0	15

Table 5 SII-0021-1978 compressive strength and authorized variation coefficient

According to NI-10-1978, brick quality is divided into three classes, as follows:

1. Class 1, with a mean compressive strength exceeding 100 kg/cm2 and no deviation
2. Class 2, with a mean compressive strength of 80–100 kg/cm2
3. Class 3, with a mean compressive strength of 60–80 kg/cm2

TEST RESULTS AND ANALYSIS

Brick characteristics

Brick samples were tested for characteristics including colour, curviness, sharpness and flatness, as shown in Table 6.

Sample	Colour	Curve	Sharp	Flat/brittle
	Dark red, pink, red-brown or brown	Curved/uncurved	Sharp/smooth	Flat/not flat, brittle/not brittle
House 1				
Sample I.A	Pink	Curved	Sharp	Flat-not flat-not flat
Sample I.B	Pink	Uncurved	Sharp	Flat-not flat-not flat
Sample I.C	Pink	Curved	Sharp	Flat-not flat-not flat
House 2				
Sample II.A	Pink	Curved	Sharp	Flat-not flat-not flat
Sample II.B	Pink	Curved	Sharp	Flat-not flat-not flat
Sample II.C	Pink	Curved	Sharp	Flat-not flat-not flat
House 3				
Sample III.A	Pink	Uncurved	Sharp	Not flat-not flat-not flat
Sample III.B	Pink	Uncurved	Sharp	Not flat-not flat-not flat
Sample III.C	Red-brown	Uncurved	Sharp	Not flat-not flat-not flat

Table 6 Characteristics of brick samples from collapsed houses

Sample	Colour	Curve	Sharp	Flat/brittle
	Dark red, pink, red-brown or brown	Curved/uncurved	Sharp/smooth	Flat/not flat, brittle/not brittle
Factory No. 1				
Near burning stove				
Sample 2-D-A	Dark red	Uncurved	Sharp	Flat-not flat-not flat
Sample 2-D-B	Dark red	Uncurved	Smooth	Flat-not flat-not flat
Sample 2-D-C	Dark red	Curved	Smooth	Flat-not flat-not flat
In middle of burning stove				
Sample 2-T-A	Dark red	Uncurved	Sharp	Flat-not flat-not flat
Sample 2-T-B	Dark red	Curved	Smooth	Flat-not flat-not flat
Sample 2-T-C	Dark red	Curved	Smooth	Flat-not flat-flat
Far from Burning stove				
Sample 2-JH-A	Dark red	Curved	Sharp	Flat-not flat-not flat
Sample 2-JH-B	Dark red	Curved	Smooth	Flat-not flat-not flat
Sample 2-JH-C	Dark red	Curved	Sharp	Flat-not flat-not flat
Factory no.2				
Near burning stove				
Sample 3-D-A	Dark red	Curved	Sharp	Not flat-not flat-not flat
Sample 3-D-B	Dark red	Curved	Smooth	Not flat-not flat-flat
Sample 3-D-C	Dark red	Curved	Sharp	Flat-not flat-not flat
In middle of burning stove				
Sample 3-T-A	Dark red	Uncurved	Sharp	Not flat-not flat-not flat
Sample 3-T-B	Pink	Curved	Smooth	Not flat-not flat-not flat

Sample	Colour	Curve	Sharp	Flat/brittle
	Dark red, pink, red-brown or brown	Curved/uncurved	Sharp/smooth	Flat/not flat, brittle/not brittle
Sample 3-T-C	Dark red	Curved	Smooth	Flat-not flat-not flat
Far from burning stove				
Sample 3-JH-A	Pink	Uncurved	Smooth	Flat-not flat-not flat
Sample 3-JH-B	Pink	Uncurved	Sharp	Flat-not flat-not flat
Sample 3-JH-C	Pink	Curved	Sharp	Flat-not flat-not flat

Table 7 Characteristics of brick samples from factories

The results show that bricks from Factory I have a Dark red colour at the three layers of stove: near, in the middle and far from the fire source. Bricks from Factory II have a dark red colour when taken from near the fire source, but are pink or dark red when taken from the middle of the stove and pink when taken far from fire source. Bricks from collapsed houses are pink (70 per cent), dark red (17 per cent) and red-brown (13 per cent).

Bricks from the factories are both uncurved (33 per cent) and curved (67 per cent), like bricks from collapsed houses (47 per cent curved and 53 per cent uncurved). Fifty per cent of factory bricks were sharp, compared to 23 per cent of bricks from collapsed houses.

Only 27 per cent of the sample of factory bricks have a rough surface, while 73 per cent are flat and not brittle. Thirty-seven per cent of the sample from collapsed houses have a smooth surface and 63 per cent with a bad surface condition.

Measurement results show that the entire sample of factory bricks fails to meet standards (NI-10-1978 and SII-0021-1978), compared to 43 percent of the sample from collapsed houses.

Compressive strength of bricks

The results of compressive strength tests are shown in Tables 8–9.

Sample	Maximum force (kg)	Compressive strength (kg/m²)	Mean compressive strength (kg/m²)	Compliance with standards
Near fire source				
Sample 2DA.1	786.19	14.81	17.28	Compliant with NI-10 and SII-0021 standards
Sample 2DA.2	304.33	11.87		
Sample 2DA.3	278.97	11.52		
Sample 2DB.1	1090.50	21.15		
Sample 2DB.2	557.94	22.56		
Sample 2DB.3	507.22	19.23		
Sample 2DC.1	1090.50	20.35		
Sample 2DC.2	431.14	16.59		
Sample 2DC.3	431.14	17.45		
In middle of burning stove				

Sample	Maximum force (kg)	Compressive strength (kg/m²)	Mean compressive strength (kg/m²)	Compliance with standards
Sample 2TA.1	1090.50	20.96	16.72	Non-compliant with NI-10 and SII-0021 standards
Sample 2TA.2	532.58	22.30		
Sample 2TA.3	557.94	20.55		
Sample 2TB.1	684.75	13.23		
Sample 2TB.2	304.33	11.90		
Sample 2TB.3	355.05	13.12		
Sample 2TC.1	684.75	13.47		
Sample 2TC.2	481.86	18.55		
Sample 2TC.3	456.50	16.40		
Far from fire source				
Sample 2JA.1	595.98	10.49	10.80	Non-compliant with NI-10 and SII-0021 standards
Sample 2JA.2	253.61	8.30		
Sample 2JA.3	215.57	9.92		
Sample 2JB.1	481.86	8.77		
Sample 2JB.2	355.05	12.85		
Sample 2JB.3	304.33	11.96		
Sample 2JC.1	735.47	13.01		
Sample 2JC.2	304.33	11.39		
Sample 2JC.3	304.33	10.47		

Table 8 Results of compressive strength testing of bricks from factories

Sample	Maximum force (kg)	Compressive strength (kg/m²)	Mean compressive strength (kg/m²)	Compliance with standards
Houses I				
Sample I/A.1	1902.08	31.69	31.95	Non-compliant with NI-10 standard but compliant with SII-0021 standard for Class 25
Sample I/A.2	634.03	20.79		
Sample I/A.3	684.75	23.93		
Sample I/B.1	1470.94	29.21		
Sample I/B.2	1192.00	50.95		
Sample I/B.3	659.39	27.76		
Sample I/C.1	2485.38	40.79		
Sample I/C.2	811.55	28.75		
Sample I/C.3	1065.20	33.70		
House II				
Sample II/A.1	1572.38	26.70	24.24	Non-compliant with NI-10 standard but compliant with SII-0021 standard
Sample II/A.2	380.42	12.76		
Sample II/A.3	304.33	11.17		
Sample II/B.1	2181.05	35.53		
Sample II/B.2	760.83	25.78		
Sample II/B.3	684.75	21.59		
Sample II/C.1	1724.55	29.27		
Sample II/C.2	811.55	28.94		
Sample II/C.3	786.19	26.40		

Sample	Maximum force (kg)	Compressive strength (kg/m²)	Mean compressive strength (kg/m²)	Compliance with standards
House III				
Sample III/A.1	1724.55	43.75	43.08	Compliant with NI-10 standard but non-compliant with SII-0021 for Class 25
Sample III/A.2	81.55	41.41		
Sample III/A.3	887.64	47.23		
Sample III/B.1	2104.96	47.39		
Sample III/B.2	887.64	48.07		
Sample III/B.3	786.19	38.25		
Sample III/C.1	1876.72	45.44		
Sample III/C.2	583.30	31.19		
Sample III/C.3	1014.40	45.02		

Table 9 Results of compressive strength testing of bricks from collapsed houses

Table 8 shows that most of the samples fail to meet the NI-10-1978 standard, where the minimum compressive strength of brick class III should be 60 kg/cm^2, and the SII-0021-1978 standard, where the minimum compressive strength is 25 kg/cm^2. Table 8 also shows that the mean compressive strength is 17.28 kg/cm^2 for bricks from Factory I, and 19.19 kg/cm^2 for bricks from Factory II. Bricks from near the fire source have a higher compressive strength than bricks from the middle of the stove or far from fire source.

Table 9 shows that bricks from collapsed houses fail to meet the minimum compressive strength stipulated in the NI-10-1978 standard, but do meet the SII-0021-1978 Class 25 standard, where the minimum compressive strength is 25 kg/cm^2.

CONCLUSIONS

1. Factory bricks do not meet the standards in terms of physical characteristic and compressive strength.
2. The compressive strength is greater for bricks near the fire source than bricks in the middle of burning stove or far from the fire source.
3. The physical characteristics and compressive strength of bricks from collapsed houses are better since they meet the Class 25 standard.

RECOMMENDATIONS

1. Comprehensive further research using more samples is required for a better understanding of the quality of bricks used by society.
2. Industry awareness of brick standards needs to be raised.
3. A brick burning system with sufficient, evenly spread temperature is recommended.

ACKNOWLEDGMENTS

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THE PADANG EARTHQUAKE: BUILDING BACK BETTER AND RETROFITTING

Paul Grundy

Emeritus Professor, Department of Civil Engineering, Monash University, Australia
Email: paul.grundy@monash.edu

ABSTRACT

Although the Padang earthquake was severe, an even bigger earthquake is likely in the foreseeable future, this time with a tsunami. The observed failures – building collapses, landslides and soil liquefaction – indicate the issues to be faced in "building back better". The three principal aspects of response to and recovery from the earthquake are: building back better, improving emergency response planning and preparedness, and retrofitting structures and infrastructure that are still functioning but at risk from a larger earthquake. Reinforced-concrete framed structures exhibited many weaknesses of poor design, detailing and workmanship, with foundations unable to cope with soil liquefaction. However there are some shining examples of building back better and overcoming all these problems. One particular challenge is retrofitting domestic masonry buildings. After previous earthquakes in Indonesia, viable schemes have been developed for rebuilding with the masonry integral enclosing light reinforced concrete frame. These schemes involve rebuilding from the foundations up. A proposal is made for adapting this concept to existing buildings. The basic concept consists of "strapping on" a reinforced concrete or timber framework.

KEYWORDS

Disaster risk reduction, earthquake, building back better, retrofitting, reinforced concrete, masonry.

INTRODUCTION

The West Sumatra earthquake of 30 September 2009 was severe, with a magnitude of 7.6 and a death toll in excess of 1,100, but it did not generate a tsunami. The Padang earthquake came between very severe earthquakes in recent times along the Sunda Trench, where a more severe earthquake, generating a tsunami, can be expected in the foreseeable future. The performance of buildings in the Padang earthquake can be used as a guide to the required standards for building back better and retrofitting buildings that survived the earthquake. This applies to both engineered buildings that should comply with building codes, and the many domestic and low-rise non-engineered buildings that present a greater risk to lives in a more severe earthquake. In addition, the impact of a tsunami must be taken into account in planning retrofitting and emergency response. One particular challenge is retrofitting non-engineered masonry buildings.

Earthquake response and recovery involves three main aspects:

1. Building back better when buildings and infrastructure have been destroyed
2. Improving earthquake preparedness and emergency response
3. Retrofitting buildings and infrastructure that were not damaged but remain at risk from future earthquakes.

There appears to have been a varying response to the first two aspects and a very limited response to the third.

A more balanced response, including more retrofitting, is urgently needed. About a fifth of all humanitarian aid between 2001 and 2008 was devoted to disaster relief and response (World Bank, 2010). The proportion devoted to disaster prevention was extremely small, rising to 0.7 per cent in 2008 from from 0.1 per cent in 2001.

Indonesia has already had some good experiences of building back better after earthquakes. After the 2006 Yogyakarta earthquake, Gadjah Mada University and Kobe University developed through community consultation a methodology for building seismically resistant housing. Traditional masonry construction was rendered seismically resistant by enclosing masonry walls in light reinforced concrete frames that were formed integrally within the brickwork as it was laid. Training sessions were organized to upgrade traditional bricklaying skills. Examples of this form of construction were already in place in a few locations before the Yogyakarta earthquake, and they performed well.

PERFORMANCE OF STRUCTURES IN PADANG

Buildings

Many public buildings collapsed through the soft-storey syndrome, exacerbated by poor reinforcement detailing, especially at the joints, and poor quality concrete (Figure 1).

(a) Soft-storey failure exacerbated by liquefaction (Provincial Public Works Office)

(b) Strong beam/weak column failure exacerbated by poor detail and quality (Food Security Agency Building)

Figure 1 Typical public sector building failures

In the commercial district, buiding failures were most common on east-west streets and relatively few on north-south streets. The strong motions were in the east-west direction. The relatively robust performance of east- or west-facing buildings is attributed to the long party walls of load bearing masonry or reinforced concrete frames with brick infill, without openings.

One structure that survived with very superficial damage was a mosque under construction (Figure 2). This was being funded from international sources. The basic design was a seismic-resistant form, with strong columns compared with beams, large buttresses and piling to prevent failure through soil liquefaction. The concrete strengths used were higher than usual for the district, resulting in very good quality concrete.

Soil liquefaction

Large areas of Padang are flat and barely above sea level. The proximity to volcanoes means that ash and mudslides have filled the valleys in geological time. It is not surprising that the potential for soil liquefaction is high.

Sand "boiling" occurred in some locations and there were many cases of subsidence. Soft soil amplifies ground motion and ideally reconstruction would avoid sites where liquefaction might occur. In practice this does not happen, so special attention must be given to piles that penetrate to bedrock – at a cost.

Figure 2 Mosque under construction, surviving intact

Landslides

Many landslides occurred in the mountainous hinterland. In many cases, poor slope stability was exacerbated by cut and fill for roads. In most instances, villagers have rebuilt in adjacent areas where a landslide had not occurred. Although building back better should include relocation of dwellings on stable slopes, the social upheaval that this causes often prevents this happening.

RESPONSE AND RECOVERY

Spatial planning issues

The principal factors adversely affecting risk reduction in relation to building sites are the potential for soil liquefaction, exposure to tsunamis and exposure to landslides. The simple technical solution is to relocate buildings from exposed sites to safer sites. The reality is that the potential social upheaval is considered too great for the community to accept relocation. Thus, engineered solutions and emergency response planning must be made to work despite sites' unsuitability from a disaster-risk perspective.

Structures with post-disaster function

There are a few shining examples of buildings that address the need for safe refuge and emergency accommodation after a major earthquake and tsunami, such as a combined evacuation centre and school in a steel-framed construction that was nearing completion in July 2010 (Figure 3). Features of this building include:

- A location approximately 1 km from the coast in an area at risk of a tsunami
- Three storeys and a helipad
- Steel-framed, concrete encased columns
- Foundations based on 18–24 m reinforced concrete piles to resist liquefaction
- Built by a construction company and labour from Jakarta
- Funded by the Buddhist Compassion Tzu Chi Foundation

This building is estimated to cost three times more than a traditional school. This extra cost is justified by the building's crucial post-disaster function.

It is unlikely that the standard of disaster resilience built into this building could have been achieved using familiar local construction methods for reinforced concrete. It takes at least a decade of reform and a change in cultural perceptions to eliminate detrimental practices. This is illustrated by the quality of the reinforced concrete stairways in this building that reflects standard local practices in concrete construction: the reinforcement is not properly supported on bar chairs and the concrete is not correctly compacted.

(a) Castellated beams in a bolted steel frame and concrete encased columns

(b) A cast in situ stairway

Figure 3 Regional school with post-disaster function

Tsunami preparedness

A number of DART (Direct Analysis in Real Time) sensors deployed around Indonesia are not functioning, thus compromising the effectiveness of the tsunami warning system. As always, a strong motion exceeding 20 seconds is the most reliable and earliest warning of a potential tsunami. The people of Padang have rehearsed evacuation following a tsunami warning. This has sometimes consisted of running a kilometre or more to higher ground. Some people did evacuate after the motion was felt in 2009, returning to their homes 1½ hours or more after the event.

There remains a need for clearer thinking about the response to potential tsunamis. For example, the earthquake response instructions at the beach hotel where the author stayed were to evacuate via the staircases as soon as motion stops. However, if the hotel did not collapse, it would be safer to stay in the hotel, in case a tsunami follows.

BUILDING BACK BETTER

Reinforced-concrete frame construction

The available standards for reinforced-concrete framed commercial and institutional buildings are adequate for the task of building back better. The shortcomings noted in the field surveys relate to reinforcement detailing, especially at connections, and the quality of construction. For these to improve to an adequate uniform standard, a long-term programme of training and re-education in best practice is required.

Foundation design must improve significantly if buildings are to remain at sites of potential soil liquefaction. Piles need to penetrate to bedrock.

Grundy (2005, 2008) has advocated the adoption of the disaster limit state for institutional buildings and accommodation where many lives are at risk from a single hazardous event. Essentially, the emphasis is on structural robustness resisting total collapse and non-structural strategies of evacuation, refuge, etc., to mitigate the loss of life when a structure is inadequate for withstanding the hazard.

Masonry housing

Non-engineered masonry housing presents the greatest challenge for building back better. However, methods of adapting traditional masonry construction to a seismically resistant form have been developed in response to previous earthquakes in Indonesia. With suitable education and training, local communities can develop the skills to build seismically resistant dwellings themselves. It is well known that community resilience is developed most effectively when the community is engaged in its own re-education and adaptation of traditional construction methods. The challenge is disseminating these forms of construction and implement training programmes.

The most common form of building back better with masonry dwellings consists of incorporating masonry into a light reinforced concrete frame comprising columns, a cap beam on top of the wall and a plinth beam at the bottom. An example of this is the Manual for Reconstruction after an Earthquake (Suryabrata et al, 2007) developed through collaboration between the local communities and the University of Gadjah Mada, in particular after the 2006 Yogyakarta earthquake. Figure 4 shows pages from this publication indicating how concrete-column construction is integrated into brick laying. Of equal importance to the dissemination of this methodology is training builders in construction methods.

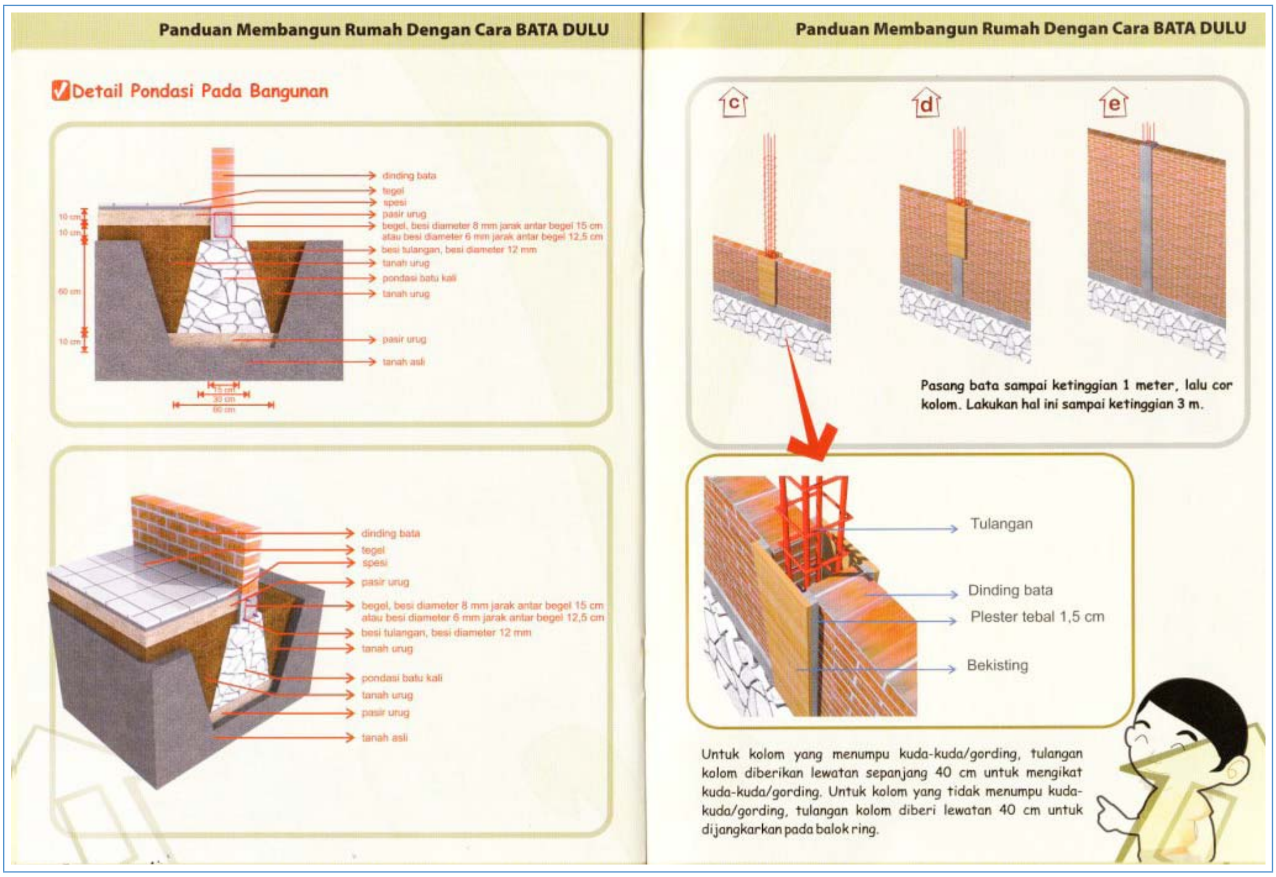

Figure 4 Extract of the Manual for Reconstruction after an Earthquake (Suryabrata et al, 2007)

This form of construction was already in place to a limited extent before the Yogyakarta earthquake. A number of variants of this method are being advocated by non-governmental organizations in Padang.

RETROFITTING

Reinforced-concrete frame construction

A practical problem for Padang is to establish whether buildings still standing after the earthquake will be able to survive a more severe earthquake in the future. Assessment of their structural condition is difficult, requiring experience and training.

Common deficiencies of reinforced-concrete frame construction for seismic resistance are well known. Appropriate retrofitting technologies to overcome these deficiencies are not. Specialist workshops are required to develop effective retrofitting methods.

One of the most critical factors in establishing the robustness of this form of construction is the integration of masonry as infill within reinforced concrete. frames. Solid infill masonry tied to beams and columns can significantly enhance a building's capacity to resist seismic loading. The building might be severely damaged, but actual collapse may be averted, saving many lives. However, the infill panels need to be distributed spatially to balance the inertial forces of seismic loading. Openings for windows and doors can have an adverse affect on robustness. A wall to partial height of the column in the absence of other full infill walls can lead to the partially stiffened column attracting all the lateral forces and collapsing.

The effect of openings in masonry walls is illustrated in Figure 5. If there is no fully infilled panel in line with the panel with openings, the resistance to lateral earthquake forces is severely compromised. This is illustrated by the failure of a condominium in Hanwang, China, during the Wenchuan earthquake, where every cross wall at ground floor level was pierced by a doorway.

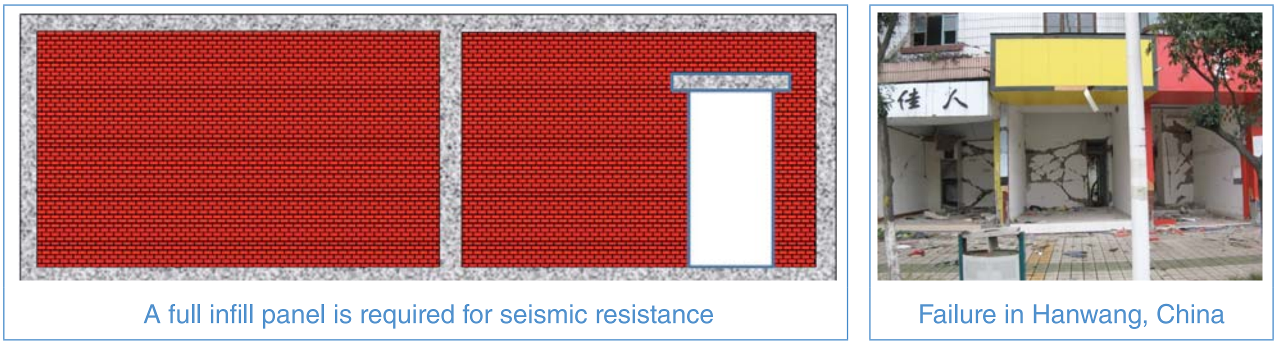

Figure 5 Seismic resistance weakened by openings

Masonry housing

After a disaster, the preoccupation with building back better – replacing collapsed structures – leaves little time or resources to retrofit existing weak constructions. In addition, it is difficult to devise cost-effective retrofits for existing structures. These retrofits are different to the forms suitable for new construction.

The challenge is to adapt the concept of light ductile moment resisting framing to existing masonry housing. It is not possible to insert reinforced concrete beams and columns into existing masonry. Grundy (2010) has proposed a methodology for "strapping on" columns to walls in need of constraint. This can be achieved with timber (Figure 6) or reinforced concrete (Figure 7). If timber is used, the interface between the timber and brick must be grouted or bonded. In addition to these added columns, cap beams and plinth (base) beams (not illustrated here) are required to complete the structural framing, with proper connections between the vertical and horizontal components.

It should be immediately apparent that the house framing systems illustrated in Figures 6–7 will require training or retraining of bricklayers and other workers if they are to be executed properly. Even more challenging is the educational component – raising community awareness of the need for retrofitting. This requires the engagement of non-governmental organizations, the provincial government and village leaders in the programme.

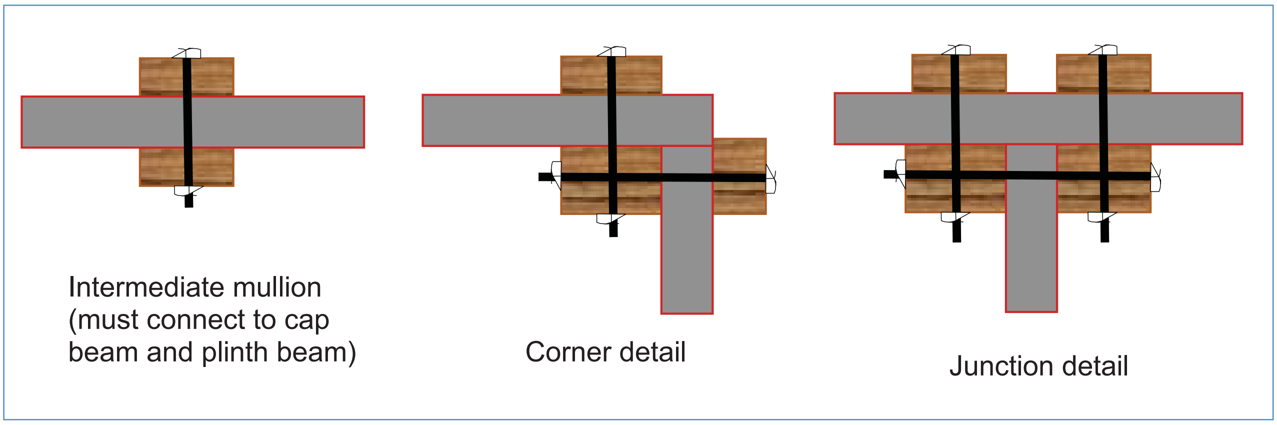

Figure 6 Strengthening of existing masonry constructions with timber posts and beams

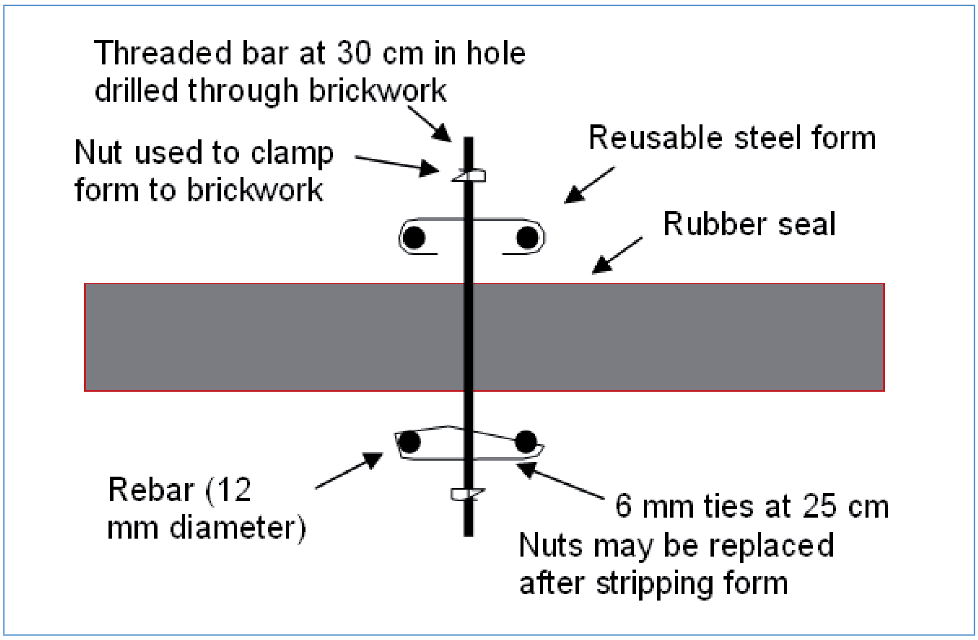

Figure 7 Strengthening of existing masonry construction with reinforced concrete posts and beams

More research and development is required on these proposed retrofits.

CONCLUSIONS

The Padang earthquake revealed vulnerable sites with regard to soil liquefaction; landslides; the poor foundations, design, detail and construction of reinforced-concrete framed buildings; and the inherent weakness of non-engineered masonry construction. It is possible to build back better with improvements in design, detailing and construction quality, as well as measures to withstand soil liquefaction. There are already examples of buildings demonstrating such improvements. These higher standards are required to withstand a more severe earthquake and tsunami in the foreseeable future.

The challenge to build community disaster resilience by retrofitting structures to withstand natural hazards is a global challenge, reflected in the response to the earthquake in Padang. This is particularly true for non-engineered domestic masonry construction. There are no established and affordable methods.

A method of adding timber or reinforced concrete framing to standing masonry housing is proposed, although more development is required.

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REVISION OF IAEE GUIDELINES FOR EARTHQUAKE RESISTANT NON-ENGINEERED CONSTRUCTION

Y. Ishiyama

Professor Emeritus, Hokkaido University, Japan
Executive Director, NewsT Research Lab
Email: to-yuji@nifty.com

ABSTRACT

The vast majority of houses and buildings in the world can be classified as non-engineered constructions. These include (1) un-reinforced masonry (stone, brick or concrete block masonry), (2) wooden constructions, (3) earthen constructions (adobe or tapial) and (4) confined masonry, etc. Most of the losses of lives in earthquakes have been caused by the collapse of these buildings. The continued use of such construction methods around the world makes it is essential to introduce earthquake resistant features. The International Association for Earthquake Engineering (IAEE) published Guidelines for Earthquake Resistant Non-Engineered Construction in 1986. As more than 20 years have since passed and these guidelines are still used in many parts in the world, the possible revision of the guidelines was discussed by three of the members of the 1986 edition committee. Revision is underway with the support of UNESCO and the International Institute of Seismology and Earthquake Engineering (IISEE), Japan, and will be completed soon.

KEYWORDS

Non-engineered construction, un-reinforced masonry, confined masonry, wooden construction, earthen construction, earthquake.

INTRODUCTION

The vast majority of houses and other buildings around the world can be classified as non-engineered constructions. Most of the losses of lives in earthquakes have been caused by the collapse of these buildings. Because of the continued use of such construction in the world, the International Association for Earthquake Engineering (IAEE) published Guidelines for Earthquake Resistant Non-Engineered Construction in 1986. As more than 20 years have since passed and these guidelines are still used in many parts in the world, the revision of the guidelines will be helpful to minimize the damage and loss of lives caused by earthquakes.

NON-ENGINEERED CONSTRUCTION

Many buildings are spontaneously and informally constructed in various countries in a traditional manner with little or no intervention by qualified architects and/or engineers. Some types of non-engineered construction are (1) un-reinforced masonry (stone, brick or concrete block masonry, as shown in Figure 1a), (2) confined masonry (Figure 1b), (3) wooden construction (Figure 2), and (4) earthen construction (adobe or tapial, i.e. rammed earth, as shown in Figure 3).

IAEE GUIDELINES IN 1986

Guidelines for Earthquake Resistant Non-Engineered Construction was published by the International Association for Earthquake Engineering (IAEE) in 1986 (Figure 4). This document is a revised and expanded version of Basic Concepts of Seismic Codes, Vol.1, Part II, Non-Engineered Construction published by IAEE in 1980. The revision resulted from the work of an ad-hoc committee composed of Anand S. Arya, Chairman

(India), Teddy Boen (Indonesia), Yuji Ishiyama (Japan), A. I. Martemianov (USSR), Roberto Meli (Mexico), Charles Scawthorn (USA), Julio N. Vargas (Peru) and Ye Yaoxian (China). Their efforts were guided by the objectives of IAEE, related to the promotion of international cooperation among scientists, engineers and other professionals in the field of earthquake engineering through the exchange of knowledge, ideas and the results of research and practical experience.

The guidelines start with a presentation of the basic concepts that determine the performance of constructions when subjected to high intensity earthquakes, and the sensitivity of performance to the basic geometrical and mechanical properties of the affected systems. This information is later applied to the formulation of simplified design rules and to the presentation of practical construction procedures, both intended to prevent system collapse and to control the level of damage produced by seismic excitations. The document focuses on basic principles and simple solutions that can be applied to different types of structural systems, representative of those ordinarily used in low-cost housing constructions in different regions and countries around the world.

The guidelines consist of nine chapters: 1) The Problem, Objective and Scope, 2) Structural Performance during Earthquakes, 3) General Concept of Earthquake Resistant Design, 4) Buildings in Fired-Brick and Other Masonry Units, 5) Stone Buildings, 6) Wooden Buildings, 7) Earthen Buildings, 8) Non-Engineered Reinforced Concrete Buildings, 9) Repair, Restoration and Strengthening of Buildings, and Appendices.

REVISION OF THE GUIDELINES

Three members of the committee for the 1986 edition, Dr. Anand S. Arya, Ir. Teddy Boen and Dr. Yuji Ishiyama, met in Tokyo, Japan during The International Symposium 2008 on Earthquake Safe Housing, which took place on 28–29 November 2008. Since more than 20 years had passed since the guidelines had been published and the guidelines were still used in many parts in the world, these experts discussed the possible revision of the guidelines and agreed to form an IAEE working group made up of original and new members who wished to participate. Since no special funds have been allocated to this IAEE working group, the revision has mainly been coordinated by email. Now the revision is underway with the support of UNESCO and the International Institute of Seismology and Earthquake Engineering (IISEE), Japan. The three members met in Delhi, India in April 2010 and in Singapore in March 2011. The draft for the IAEE Guidelines can be downloaded from the IISEE website (http://iisee.kenken.go.jp). The revision will be soon completed and reported at the next World Conference on Earthquake Engineering (WCEE) in Portugal in 2012.

This revised edition essentially retains the Guidelines in the original form except for some minor editorial changes and modifications in the data tables. Some building damage photographs from recent earthquakes have been included for illustration. A major addition is Confined Masonry in Chapter 4, and Appendices in Chapter 10 giving the MSK Intensity Scale as related to buildings, a table for assessing the seismic safety of a masonry building, and examples of posters on brick and wooden buildings.

CONCLUDING REMARKS

The revision of the IAEE Guidelines for Earthquake Resistant Non-Engineered Construction will soon be completed. Any comments on the revision should kindly be sent on the draft to: Anand S. Arya (India) at asarun3155@gmail.com, Teddy Boen (Indonesia) at tedboen@cbn.net.id, or Yuji Ishiyama (Japan) at to-yuji@nifty.com.

ACKNOWLEDGMENTS

The meetings and activities for the revision of the guidelines have been supported in part by UNESCO, and the International Institute of Seismology and Earthquake Engineering (IISEE) in Japan. Their assistance is gratefully acknowledged.

REFERENCES

Arya, A.S., Boen, T., Ishiyama, Y. et al. 1986. *Guidelines for Earthquake Resistant Non-Engineered Construction*. The International Association for Earthquake Engineering, pp. 1–158.

(a) Unreinforced brick masonry (Indonesia)

(b) Confined masonry under construction (Indonesia)

Figure 1 Typical non-engineered construction (1)

(a) Damaged tapial house (Peru)

(b) Tapial under construction (Peru)

Figure 2 Typical non-engineered construction (2)

(a) Damaged wooden house (Japan)

(b) Detail of damaged wooden house (Japan)

Figure 3 Typical non-engineered construction (3)

GUIDELINES FOR EARTHQUAKE RESISTANT NON-ENGINEERED CONSTRUCTION

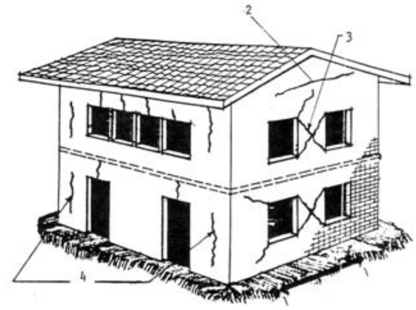
Revised Edition of "Basic Concepts of Seismic Codes" Vol. I, Part 2, 1980

IAEE COMMITTEE

ANAND S. ARYA *(India, Chairman)*
TEDDY BOEN *(Indonesia)*
YUJI ISHIYAMA *(Japan)*
A.I. MARTEMIANOV *(USSR)*
ROBERTO MELI *(Mexico)*
CHARLES SCAWTHORN *(USA)*
VARGAS JULIO N. *(Peru)*
YE YAOXIAN *(China)*

THE INTERNATIONAL ASSOCIATION FOR EARTHQUAKE ENGINEERING
Central Office
KENCHIKU KAIKAN 3rd Floor, 5-26-20, Shiba, Minato-ku, Tokyo, 108, Japan
Cable Address: INTERQUAKE TOKYO
October 1986

(a) Title page of IAEE Guidelines (1986)



1-1 Earthquake motion, 2-Horizontal crack in gables, 3-Diagonal cracks due to shear, 4-Cracks due to bending of wall.

FIG.4.1. CRACKING IN BEARING WALL BUILDING DUE TO BENDING AND SHEAR.

ii) A wall can fail as a bending member loaded by seismic inertia forces on the mass of the wall itself in a direction, transverse to the plane of the wall. Tension cracks occur vertically at the centre, ends or corners of walls. Longer the wall and longer the openings more prominent is the damage (Fig.4.1.). Since earthquake effects occur along both axes of a building simultaneously, bending and shearing effects occur often together and the two modes of failure are often combined. Failure in the piers occurs due to combined action of flexure and shear.

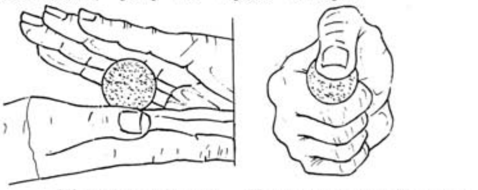
iii) Unreinforced gable end masonry walls are very unstable and the strutting action of purlins imposes additional force to cause their failure. Horizontal bending tension cracks are caused in the gables.

iv) The deep beam between two openings one above the other is a weak point of the wall under lateral in-plane forces. Cracking in this zone occurs before diagonal cracking of piers (Fig.4.2.). In order to prevent it and to enable the full distribution of shear among all piers, either a rigid slab or r.c. band must exist between them.

(b) Easy-to-read guide with illustrations

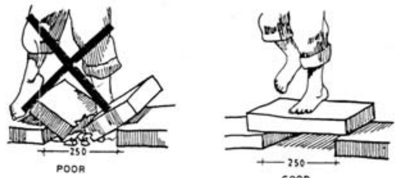
b. Fissuring Control Test

At least eight sandwich units are manufactured with mortars made with mixtures in different proportions of soil and coarse sand. It is recommended that the proportion of soil to coarse sand vary between 1:0 and 1:3 in volume. The sandwich having the least content of coarse sand which, when opened after 48 hours, does not show visible fissures in the mortar, will indicate the most adequate proportion of soil/sand for adobe constructions, giving the highest strength.



(i) Making the ball (ii) Crushing the dried ball

(a). DRY-BALL STRENGTH TEST FOR SOIL.



(b). TESTING OF ADOBE STRENGTH.

FIG.7.3 FIELD TESTING OF STRENGTH OF SOIL AND ADOBE.

Strength Test of Adobe

The strength of adobe can be qualitatively ascertained as follows: After 4 weeks of sundrying the adobe it should be strong enough to support in bending the weight of a man (Fig.7.3.b). If it breaks, more clay and fibrous material is to be added. Quantitatively, the compressure strength may be determined by testing 10cm cubes of clay after completely drying them. A minimum value of 1.2N/mm^2 will be desirable.

(c) Applicable at construction site

7.8. SUMMARY OF DESIRABLE FEATURES

The desirable features for earthquake resistance of earthen houses are briefly illustrated in Fig.7.14.

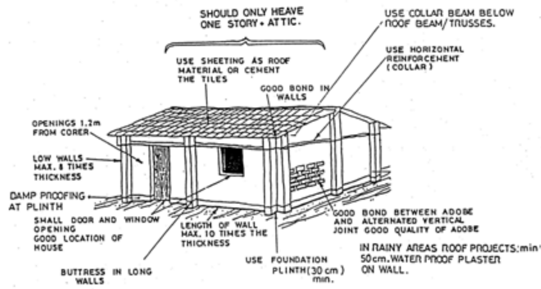


FIG.7.14. GOOD FEATURES OF EARTHQUAKE RESISTANT CONSTRUCTION.

7.9. WORKING STRESSES

7.9.1. Unit Compressive Strength

The compressive strength of the unit is an index of its quality and not of the masonry.

It will be determined by testing cubes of approximately 100mm. The compressive strength (fo) is the value exceeded by 80% of the number of specimens tested.

The minimum number of specimens is six (6) and th:y should be completely dry at the time of testing. The minimum value of (fo) is 1.2 N/mm^2.

(d) Desirable features of earthen construction

Figure 4 IAEE Guidelines for Earthquake Resistant Non-Engineered construction (1986)

RESEARCH FINDINGS OF THE SURVEY ON NON-ENGINEERED HOUSES IN DEVELOPING COUNTRIES

K.S. Pribadi,[1] K. Okazaki,[2] D. Kusumastuti,[3] T. Saito,[4] E. Lim,[5] A. Utami[5]

[1]Associate Professor, Institute of Technology Bandung, Indonesia
Email: ksuryanto@si.itb.ac.id

[2]Professor, National Graduate Institute for Policy Studies (GRIPS), Japan
Email: okazakik@grips.ac.jp

[3]Researcher, Institute of Technology Bandung, Indonesia
Email: dkusumastuti@si.itb.ac.id

[4]Senior Researcher, Building Research Institute, Japan
Email: tsaito@kenken.go.jp

[5]Research Assistants, Center for Disaster Mitigation, Institute of Technology Bandung, Indonesia
Email: fx_edwin@yahoo.com; anin@pmb.itb.ac.id

ABSTRACT

The practice of non-engineered construction, especially in developing countries, is a major global concern. Facts from past earthquake disasters have shown that damage to non-engineered constructions causes most of the total casualties. To address the need to reduce losses and casualties, this research aims to study the current situation and practices of non-engineered construction in developing countries. Based on the study, suitable technologies and policies can be developed to reduce vulnerability against future earthquakes. This research has been conducted in seven developing countries: Egypt, India, Indonesia, Nepal, Pakistan, Peru and Turkey. Information related to the planning, design and construction of non-engineered buildings, as well as compliance with local building codes, has been obtained by conducting interviews with owners and builders, carrying out non-destructive and laboratory tests and studying the relevant literature. Although this research reveals each country has its own typical problems in non-engineered construction, some technical and non-technical issues can be generalized to non-engineered practices in developing countries. Based on these findings, global recommendations are proposed to deal with the problems and produce safer non-engineered constructions.

KEYWORDS

Developing countries, earthquake, non-engineered construction.

INTRODUCTION

Non-engineered buildings are commonly found in many cities in developing countries, which unfortunately often lie in earthquake-prone areas. This type of structure is built in a traditional way with or without minimum intervention by an architect or structural engineer in the design and construction process, and encompasses houses and buildings for commercial or even public use, such as schools, health facilities and small government functions. Most of these structures have no technical specifications or engineered drawings. However, conceptual and descriptive drawings are sometimes available for this type of structure to help workers build a proper structure. Masonry and wooden structures are commonly found in this category of structure (IAEE, 1986; Kusumastuti et al, 2008).

The proper construction of non-engineered houses has been challenged by many earthquake disasters occurring in many cities in developing countries, causing huge losses and casualties due to building damage.

Past earthquakes revealed that damage to non-engineered houses in seismic zones has been responsible for most of the deaths in an earthquake (Narafu et al, 2010; Macabuag, 2008; and Grundy, 2007).

The National Graduate Institute for Policy Studies (GRIPS), the Building Research Institute (BRI) of Japan and the Center for Disaster Mitigation of the Bandung Institute of Technology, Indonesia, jointly initiated research to evaluate non-engineered construction practices in earthquake-prone developing countries, collaborating with various institutions and universities in the targeted countries. Previous studies have been conducted in cities that have experienced earthquake disasters, such as Aceh. This study has revealed that there are still many deficiencies in non-engineered construction practices during reconstruction, such as in planning and design or the quality of materials and building techniques (Okazaki and Pribadi, 2010). However, this study is limited to only a few cities in developing countries and may not reflect the practices in widespread use across those countries.

The research was conducted in seven developing countries (Egypt, India, Indonesia, Nepal, Pakistan, Peru and Turkey) involving local universities and institutions sharing the results of the survey of construction sites and various efforts to study the design and construction of safer houses. This research also aimed to discuss the applicable ways and appropriate techniques for improving the design and construction of non-engineered buildings.

PROJECT GOALS, RESEARCH OBJECTIVES AND SELECTED SAMPLES

Project goals and research objectives

In general, the main purpose of this study was to better understand the current situation and practices used in non-engineered construction in developing countries, in order to develop appropriate technologies and policies to reduce the vulnerability of buildings to earthquakes. This study also has the following aims:

1. Develop a survey form for collecting data on non-engineered construction in developing countries
2. Share information on non-engineered construction work in selected developing countries
3. Compare non-engineered construction in selected developing countries
4. Identify general problems and produce recommendations for improving non-engineered construction in developing countries

Selected samples

Seven developing countries were involved in this study: Egypt, India, Indonesia, Pakistan, Peru, Nepal and Turkey, as mentioned. Each country was responsible for selecting several non-engineered houses that were representative of local non-engineered construction practices.

The following table shows the location of the samples:

No	Country	City/region
1	Egypt	15th May City, Helwan City, Giza Square, 6th October City/ Haram City and El-Marg City
2	India	Balasore, Dehradun, Barmer, Portblair and Shimla
3	Indonesia	Bandung City
4	Pakistan	Potohar Plateau and Plains of Punjab
5	Peru	Puente Piedra, Carabayllo, Independencia, Huachipa and San Juan de Miraflores
6	Nepal	Balkot, Bhaktapur, Nankhel, Kirtipur, Kathmandu, Imadole, Lalitpur, Hattiban and Lalitpur of Kathmandu Valley
7	Turkey	Yenikapi, Sirkeci and Uskudar

Table 1 Location of the selected samples

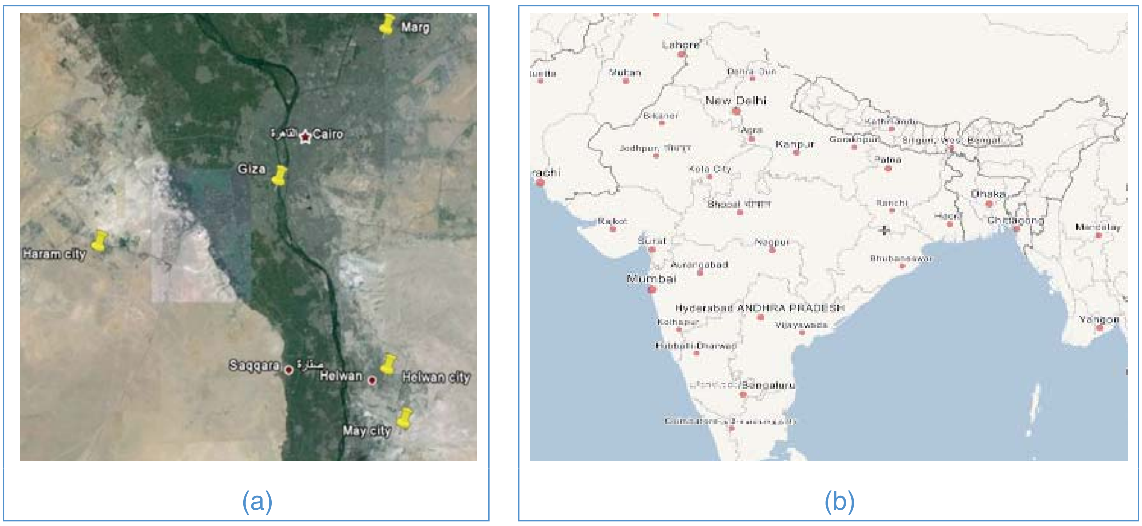


Figure 1 Location of selected samples in (a) Egypt and (b) India

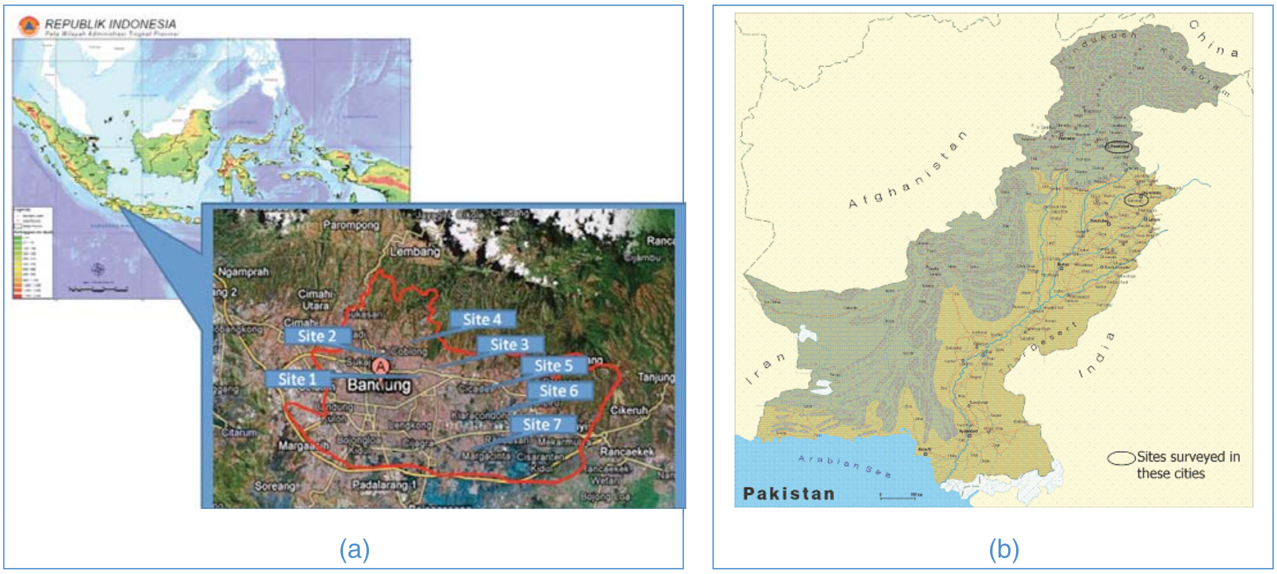


Figure 2 Location of selected samples in (a) Indonesia and (b) Pakistan

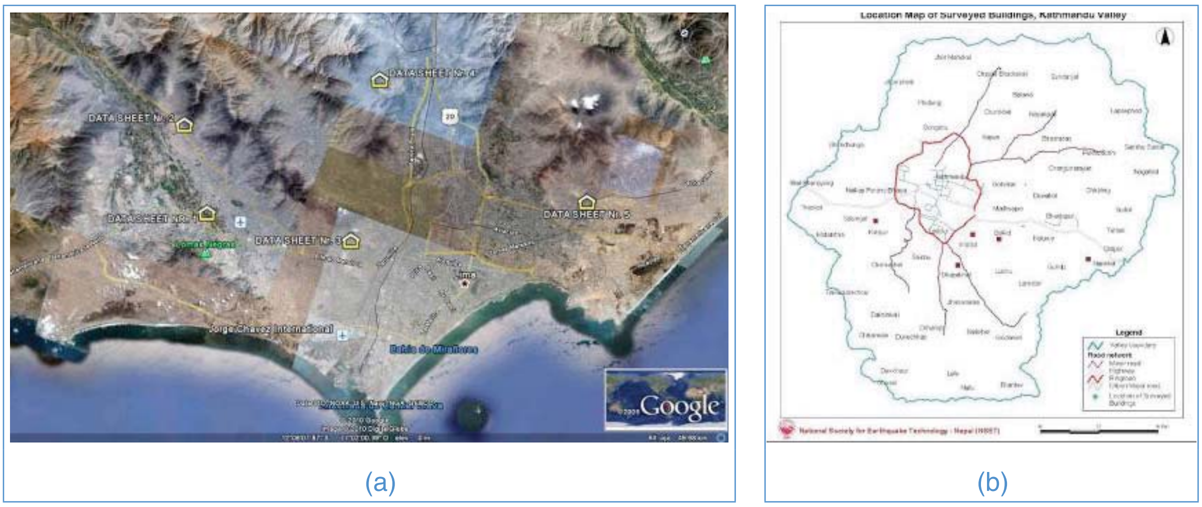


Figure 3 Location of selected samples in (a) Peru and (b) Nepal

Figure 4 Location of selected samples in Turkey

METHODOLOGY

In general, the research was divided into three stages. First, the Center for Disaster Mitigation of the Bandung Institute of Technology initiated the development of a survey form to be used in all the selected countries, in collaboration with GRIPS, Japan and various experts from each country's selected institutions and universities. The following institutions were involved in the entire process of developing and reviewing the survey form, and implementating the building surveys: the National Research Institute of Astronomy and Geophysics (NRIAG), Egypt; SEEDS Technical Services (STS), India; the Center for Disaster Mitigation, Institute of Technology Bandung (CDM ITB), Indonesia; Designmen Consulting Engineers (Pvt) Ltd/ETSSR Center, Pakistan; the Japan–Peru Center for Earthquake Engineering Research and Disaster Mitigation of the National University of Engineering (CISMID–UNI), Peru; the National Society for Earthquake Technology (NSET), Nepal; and the Istanbul Culture University and Istanbul Technical University, Turkey.

The survey form includes the following information:

1. General information (country facts)
2. General information on technical requirements stipulated in local regulations or codes for brick masonry construction
3. General project information and project site facts
4. Building information data – general
5. Building information data – current condition and compliance with regulation
6. Building information data – technical data on masonry materials
7. Building information data – technical data on concrete materials
8. Building information data – technical data on other materials
9. Building information data – technical data on non-structural materials
10. Building information data – contractor data

Second, the survey was conducted by interviewing workers and/or building owners. In addition, non-destructive hammer tests and laboratory tests were conducted to obtain information on the quality of construction materials, such as the compressive strength of concrete and bricks. Some countries conducted the survey on existing buildings due to the rarity of non-engineered construction projects. In these cases, a review of relevant literature was also conducted to complete the data sheet.

Third, the data for each site in each country was compared, using the parameters available on the data sheet. This comparison was based on average value, smallest value, largest value, most used/available or item availability. These results were compared with general construction conditions in each country to obtain representative information. The information for each country was then compared to find possible similarities and differences. Specific problems for each country were summarized, based on the survey results and surveyors' common experiences. In this way, general problems were extracted from the specific problems. Finally, conclusions and recommendations were produced regarding better techniques for improving non-engineered construction in developing countries.

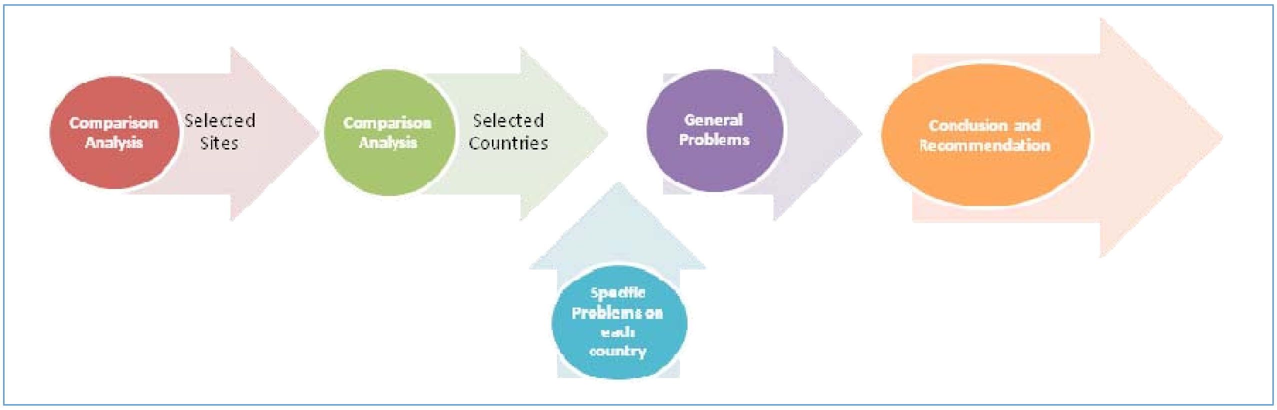


Figure 5 Data analysis flowchart

THE CURRENT STATE OF NON-ENGINEERED CONSTRUCTION IN DEVELOPING COUNTRIES

Regulations for non-engineered construction in selected developing countries

Most of the selected countries in the research (e.g. India, Indonesia, Pakistan, Peru and Nepal) have national regulation, codes and/or guidelines for non-engineered construction. Unfortunately, these mostly fail to be implemented by countries, except in a few big cities. Some countries also have trouble communicating these regulations to workers.

In Turkey and Egypt, no national non-engineered building code is available. However, both countries have local offices in charge of building administration in the surveyed cities. In Turkey, the national building code is for engineered structures only.

Non-engineered building construction in developing countries

India

The most common non-engineered building in India is masonry building (using various types of bricks) one storey high. Most of the brick masonry buildings use mud bricks (adobe), CSEB and quarry stone.

Indonesia

In general, three non-engineered constructions are most commonly found in Indonesia: confined masonry, reinforced concrete with infill masonry and unconfined brick or concrete block masonry.

Figure 6 Typical non-engineered buildings in India (Photos by SEEDS Technical Services, India)

Confined masonry buildings rely on masonry walls as the main load bearing structural elements. The confinement will also help to maintain the integrity of the wall when loads are applied. In this type of structure, the confinement can be developed from various systems such as practical column/beams and steel wire mesh. Most of the confined masonry structures in Bandung are confined by reinforced concrete practical column/beams.

Buildings made from reinforced concrete with infill masonry walls rely on reinforced concrete columns and beams as the main load-bearing structural elements (for both lateral loads and gravity).

Unconfined masonry buildings rely on walls as the only load-bearing structural elements (vertical and lateral). There is no confinement in this type of building, which is rarely found in the Bandung area.

Figure 7 Typical non-engineered buildings in Indonesia (Photos by CDM ITB, Indonesia)

Pakistan

Three types of non-engineered buildings are mostly adopted in non-engineered buildings in Pakistan: confined masonry, unconfined masonry and reinforced concrete with infill masonry.

Figure 8 Typical non-engineered buildings in Pakistan
(Photos by Designmen Consulting Engineers (Pvt) Ltd/ETSSR Center, Pakistan)

Peru

In Peru, there are three types of non-engineered buildings: confined masonry building with horizontal and vertical confinements that support the bricks walls, unconfined masonry wall buildings without a reinforced collar beam and reinforced confined elements, and a concrete moment resistant frame with concrete shear walls or infill masonry.

Figure 9 ypical non-engineered buildings in Peru (Photos by CISMID-UNI Peru)

Egypt

The most common types of non-engineered building in Egypt are reinforced concrete skeleton buildings, wall-bearing limestone buildings, and combined reinforced-concrete and limestone-wall buildings.

Nepal

In Nepal, there are two types of non-engineered brick masonry buildings: unconfined brick masonry buildings and reinforced concrete buildings with brick masonry infill.



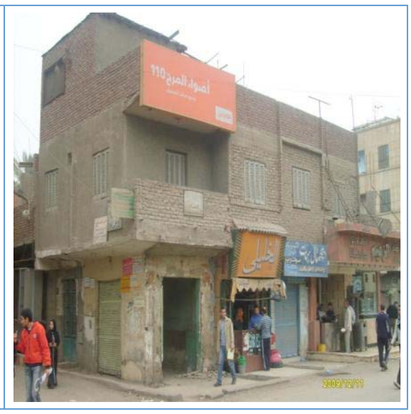


Figure 10 Typical non-engineered buildings in Egypt (Photos by NRIAG, Egypt)


Figure 11 Typical non-engineered buildings in Nepal (Photos by NSET, Nepal)

Turkey

There are three types of non-engineered buildings in Turkey: reinforced concrete frame with clay hollow brick infill walls, unreinforced brick masonry, and wooden structures.



Figure 12 Typical non-engineered buildings in Turkey
(Photos by Istanbul Culture Universiy-Istanbul Technical University, Turkey)

COMPARISON OF NON-ENGINEERED CONSTRUCTION IN SELECTED COUNTRIES

The survey information obtained on each site is extracted into representative information for each country based on the average value, the smallest value, the most common information or available information. In addition, the representative information of each country was compared to identify any similarities or differences.

Project facts and project site facts

- Most sites are located on flat ground or gentle slopes.
- Most of the non-engineered buildings in developing countries (India, Nepal, Peru and Turkey, India) use labourers assigned by owners instead of general contractors (in Egypt and Pakistan).

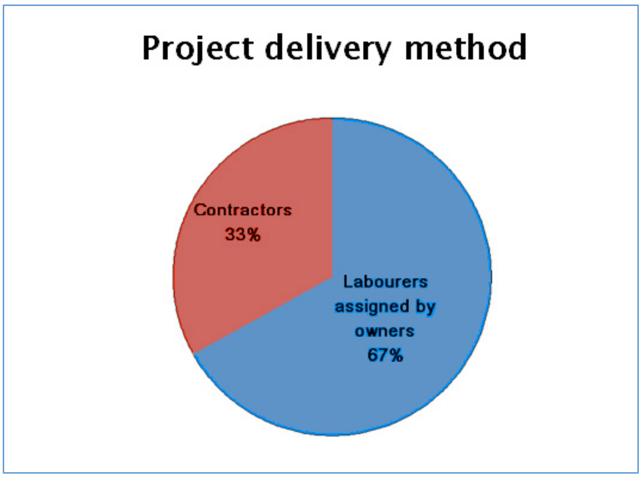


Figure 13 Project delivery method

- In general, the availability of construction materials is not an issue in developing countries.
- Most of the non-engineered buildings are owned by the private sector with the owner intervening in the design phase.

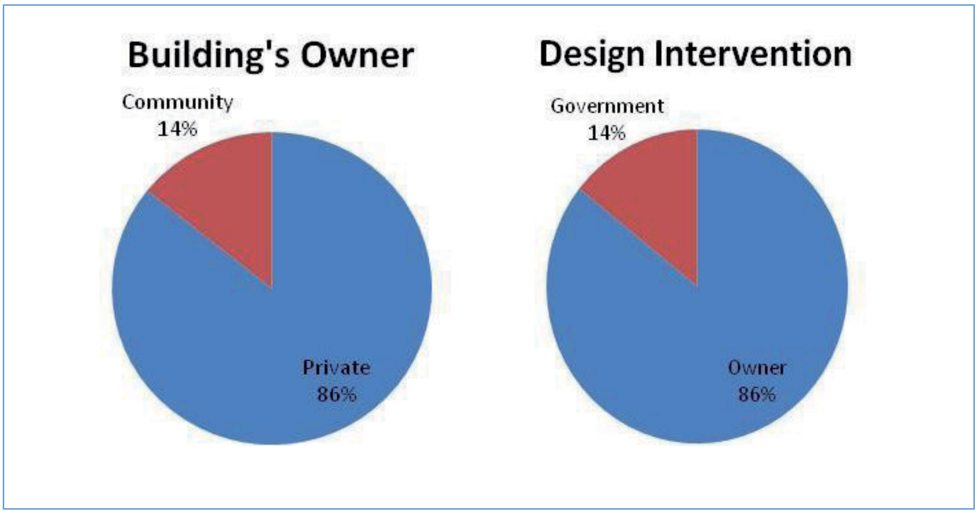


Figure 14 Building owners (left) and design intervention (right)

- Earthquakes have become the most common natural disasters in India, Indonesia, Nepal, Pakistan, Peru and Turkey. Meanwhile, wind has becomes the most common source of natural disaster in Egypt and Indonesia. Some countries, such as India and Peru, also suffer from floods.
- In general, all types of workers are available in developing countries, and simple construction tools are used.
- Owners supervise the construction of most non-engineered buildings.

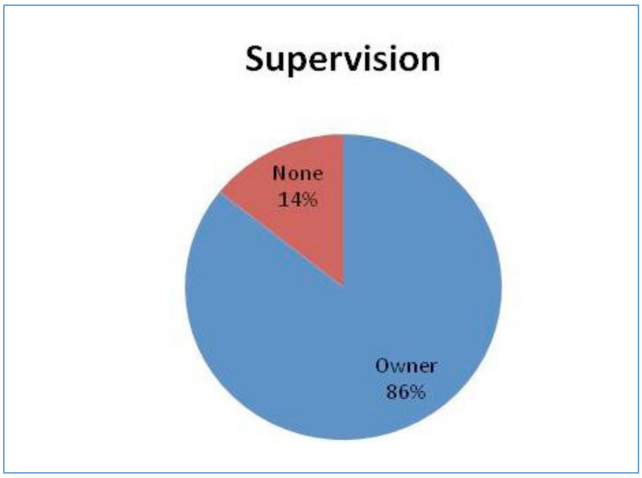


Figure 15 Supervision

- Average project duration varies from 6 to 17 weeks.

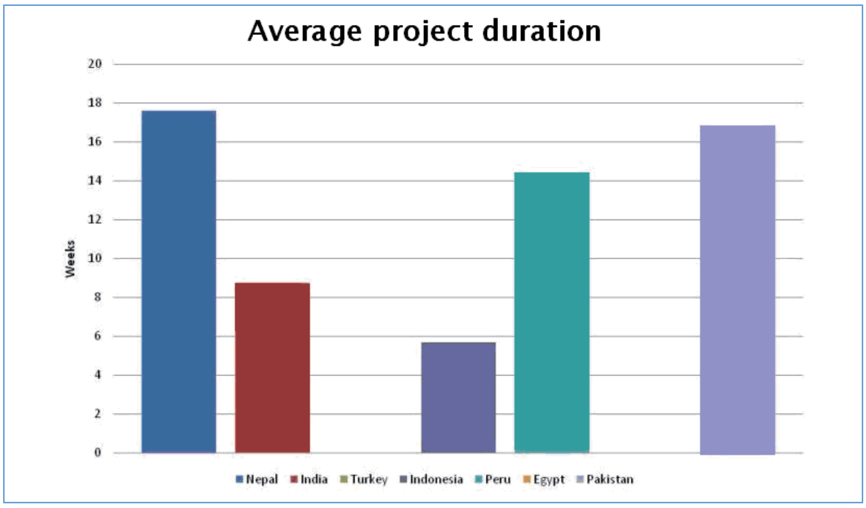


Figure 16 Project duration

Building information data – general

- Most of the non-engineered constructions are used as homes and small commercial buildings, while some are also used as school buildings.
- Strip and isolated pad (the simplest foundation system) is used in non-engineered constructions. Various materials, such as stone and reinforced concrete, are used to build foundations.

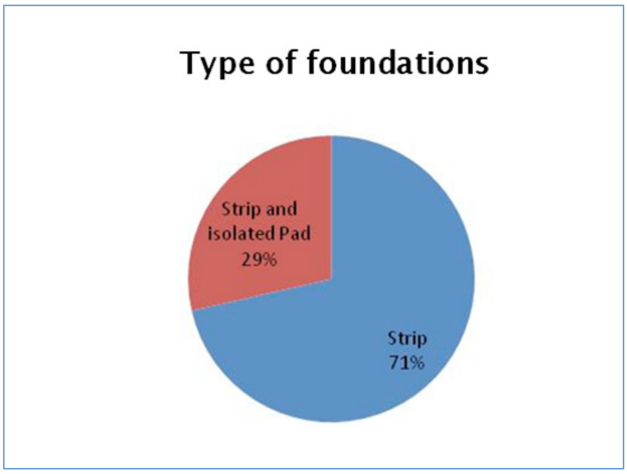


Figure 17 Type of foundations

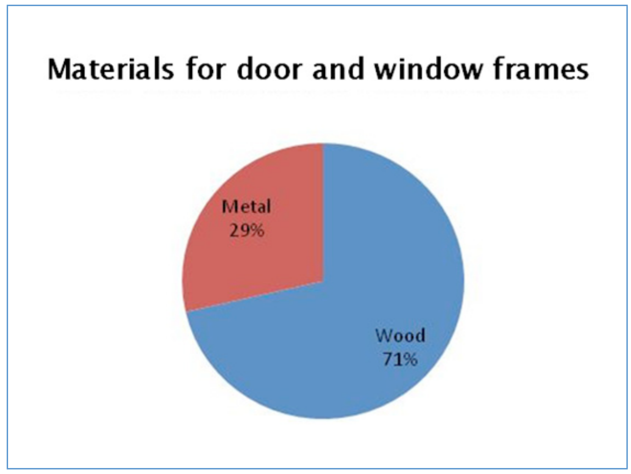


Figure 18 Materials for doors and window frames

- For confined masonry, most buildings use reinforced concrete confinement.
- The most commonly used material for doors and windows frames is wood. Only a few buildings use metal frames.
- Most of the non-engineered constructions in developing countries are unconfined masonry, except in Indonesia and Peru, where confined masonry is more popular.

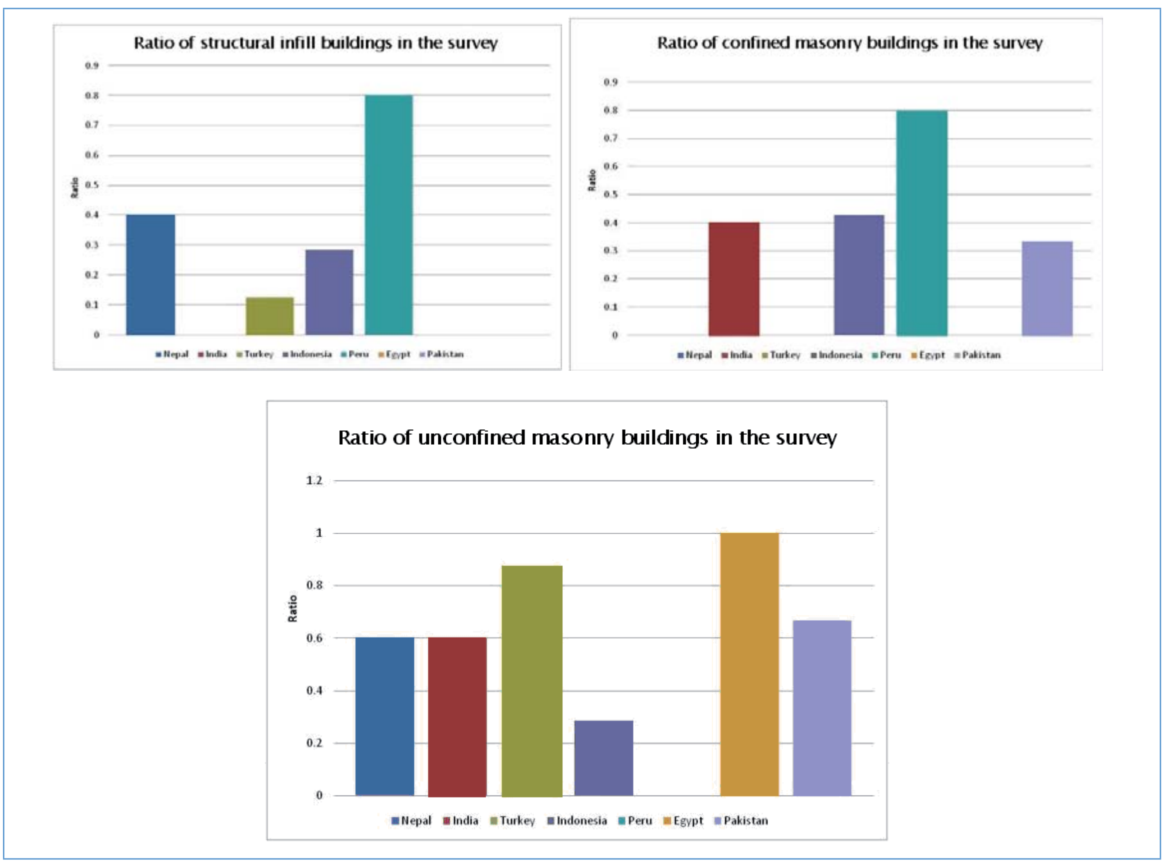


Figure 19 Proportion of different types of structure in the survey

- The building size depends on its main function, varying between 80 m2 and 187 m2 on average.
- The typical number of rooms varies between countries.

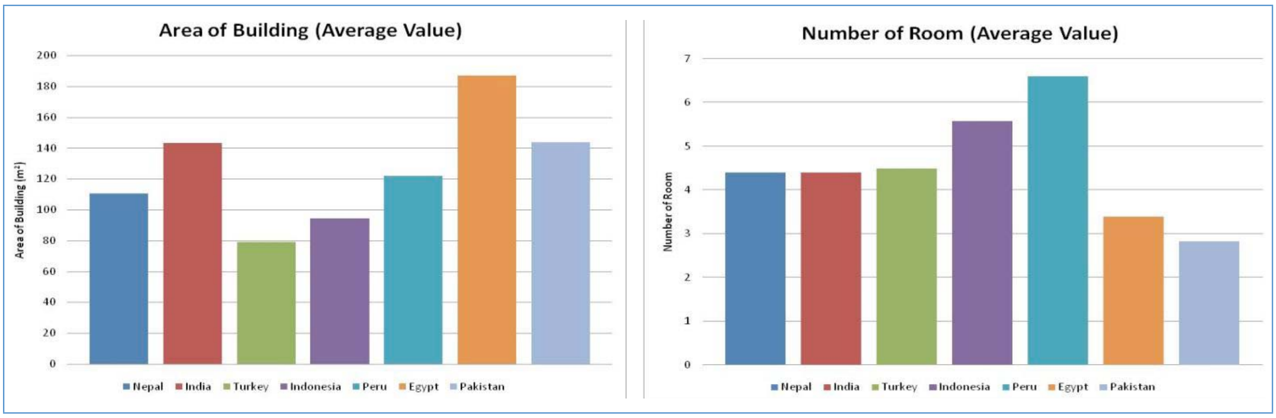


Figure 20 Average building size (left) and number of rooms (right)

Building information data – current state and compliance with regulation

- Strip and isolated pad (the simplest foundation system) is found in non-engineered constructions. Various materials, such as stone and reinforced concrete, are used. Turkey has the highest strip foundation width (0.8 m), while India and Peru have the smallest (0.4 m). Turkey has the deepest foundation depth (1–2 m) ,while Egypt has the shallowest (0.7 m).
- Indonesia has the highest wall height to thickness ratio (19.83), while Egypt has the smallest wall height to thickness ratio (9.00). The higher the value, the weaker the wall.

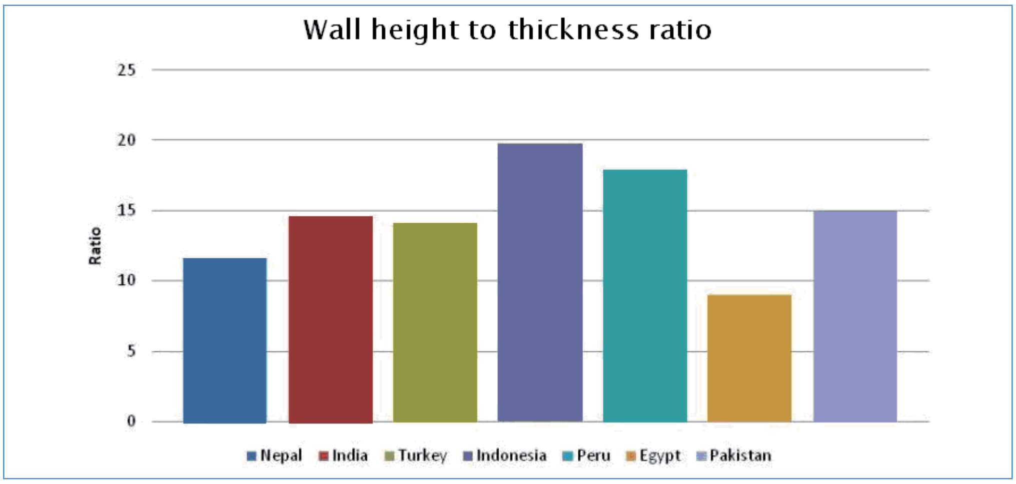


Figure 21 Wall height to thickness ratio

- Most non-engineered constructions use beams and few have columns. This depends on the structural system adopted in the surveyed country. In Indonesia, most of the surveyed sites use confined masonry, so both columns and beams are available. However, in Pakistan, Egypt and India, where most of the selected sites are unconfined masonry, the buildings only use beams or lintels.

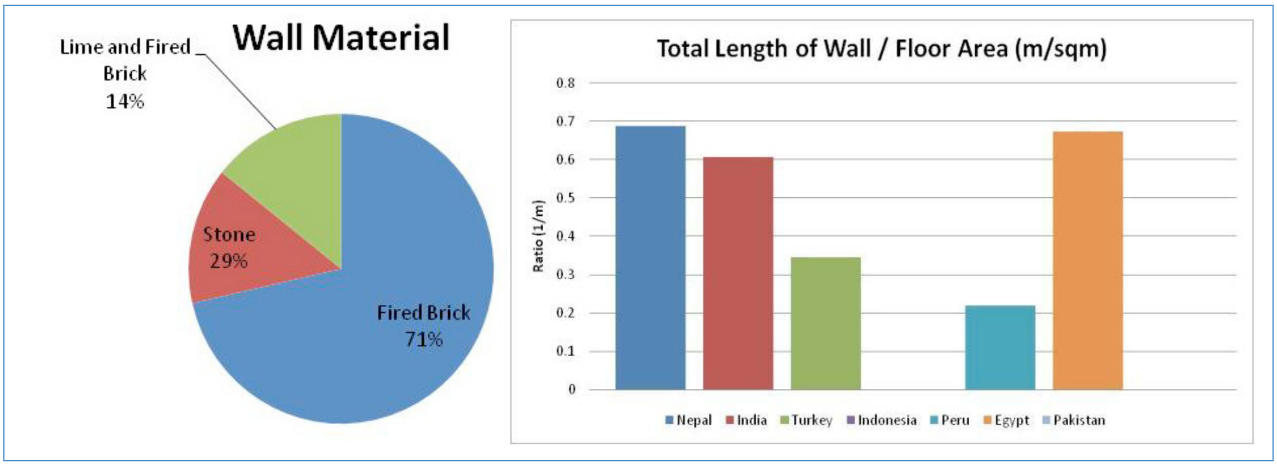


Figure 22 Wall materials (left), and total wall length and floor area (right)

- In all of the selected countries, most non-engineered constructions have poor detailing on the connection of structural elements.

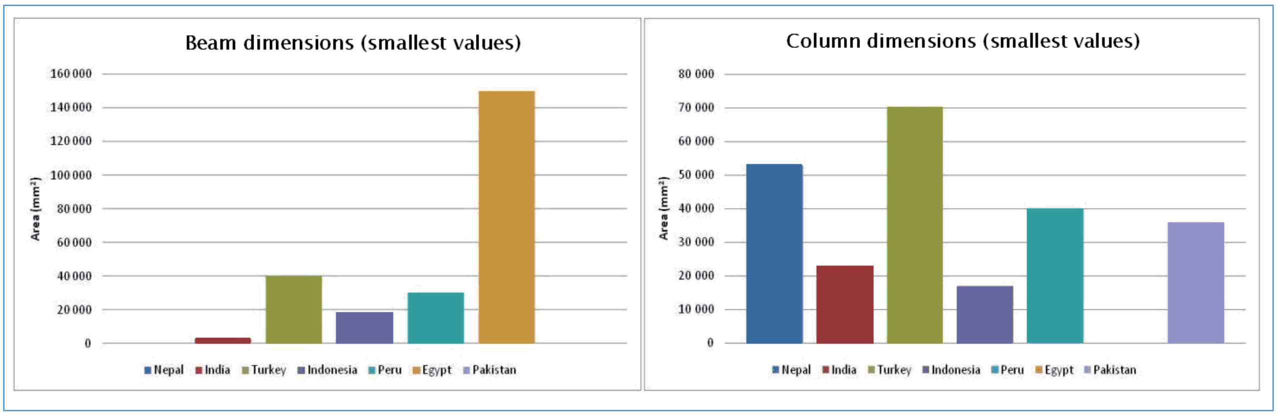


Figure 23 Beam dimensions (left) and column dimensions (right)

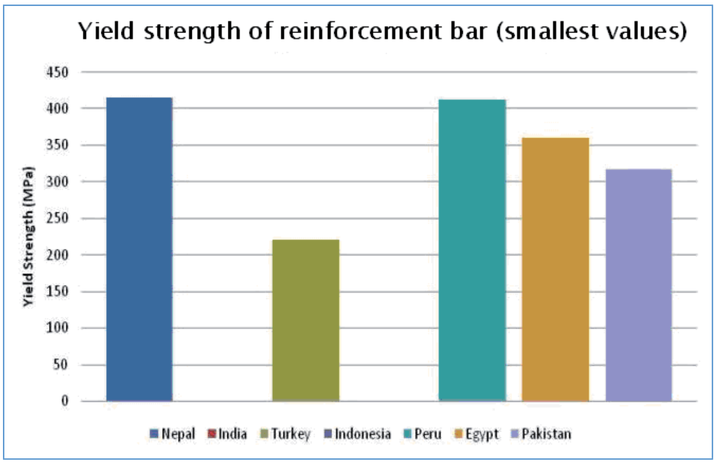


Figure 24 Yield strength of reinforcement bar

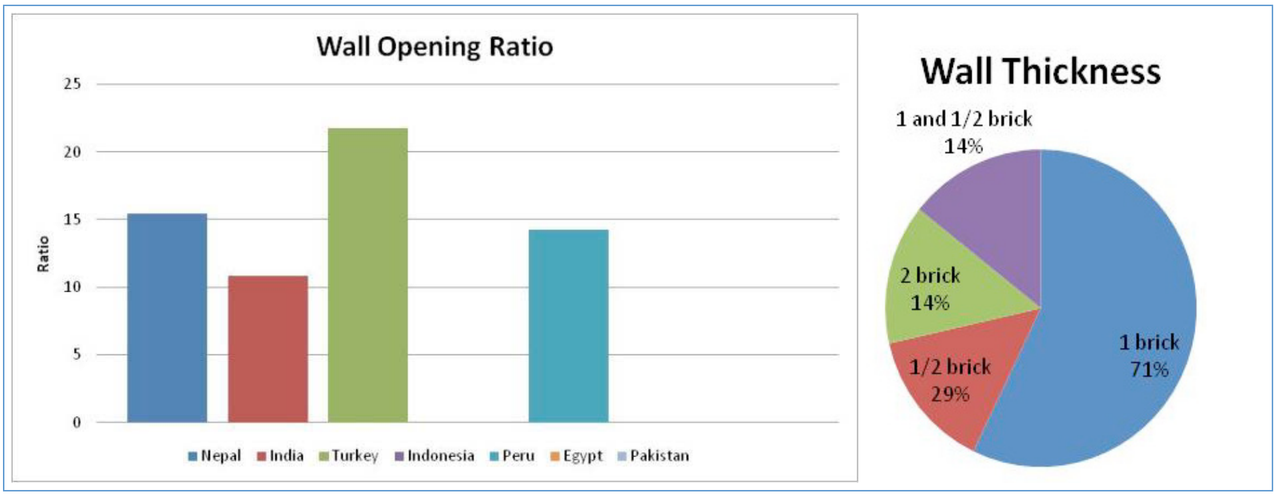


Figure 25 Wall opening ratio (left) and wall thickness (right)

Building information data – technical data on masonry materials

- Most non-engineered constructions in the selected countries use baked clay or stone masonry for the walls.
- Indonesia, Nepal, Pakistan, Peru and Turkey use the same brick size, while Egypt and India use a different size
- Peru has the highest brick compressive strength compared to the other countries, while Turkey has the smallest brick compressive strength.

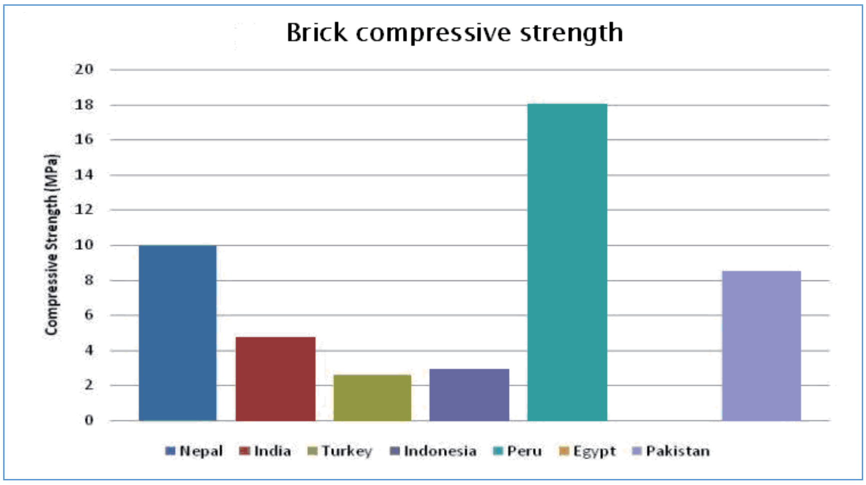


Figure 26 Brick compressive strength

- Based on the results of testing in each country, some selected sites have inadequate brick strength.
- Most of the countries use ordinary Portland cement as the plaster, and mortar as the cementing agent.
- Mortar strength is higher in Pakistan than other countries, even though they use the same composition. The exception is Peru, which uses a different mortar composition (1:02) but produces the same compressive strength.
- Egypt has the thickest layer between bricks (25 mm), while Turkey and Pakistan have the thinnest (10–20 mm and 11.45 mm respectively).

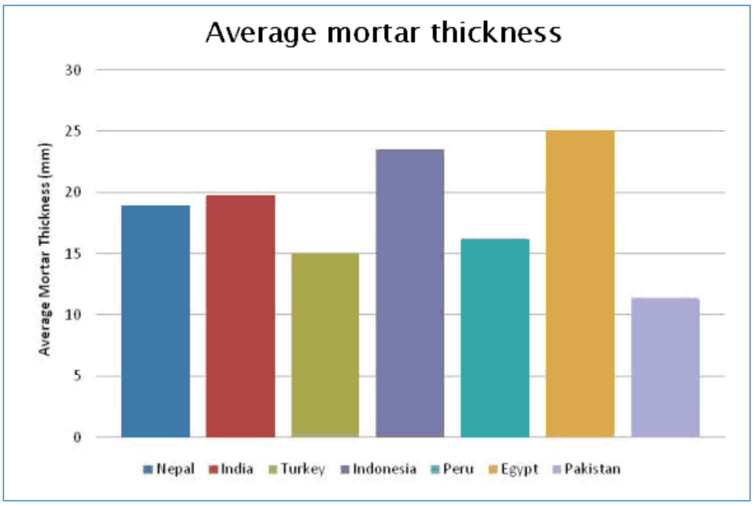


Figure 27 Average mortar thickness

- The common plaster composition is either 1:6 or 1:4, except in Peru where the composition is 1:1.
- Turkey has the thickest layer of plaster (20–30 mm), while Nepal has the thinnest (10 mm).

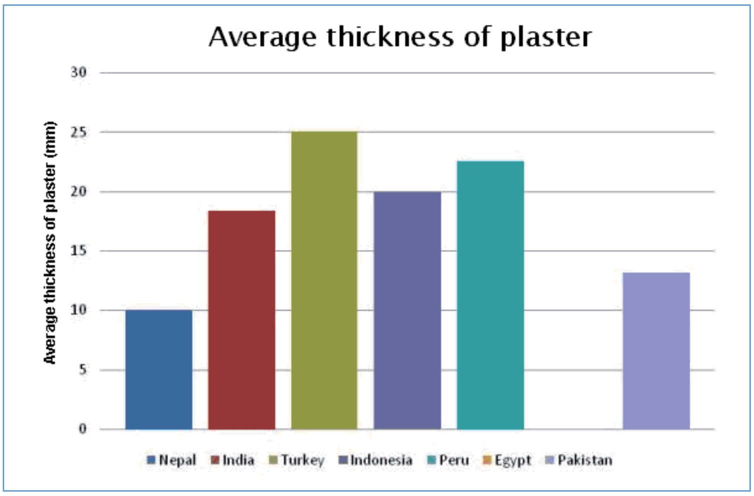


Figure 28 Average thickness of plaster

- The data gained from Egypt was rather strange, because the data sheet stated that the compressive strength of bricks was around 100 MPa, which is higher than the strength of high-performance concrete.

Building information data – technical data on concrete materials

- Based on the surveys conducted in selected countries, some of the non-engineered constructions use very poor concrete strength for the structural elements.
- Indonesia has the highest compressive strength concrete (21.75 MPa), while Turkey has the smallest (8–10 MPa).
- All of the countries use ordinary Portland cement in constructions.
- Most of the aggregates are taken from rivers and mountain quarries.
- India, Nepal and Pakistan use 1 part cement to 2 parts sand and 4 aggregates in the mixing composition, while Indonesia uses 1 part cement, 2 parts sand and 3 aggregates. Peru uses 1 part cement to 1.2 parts sand and 4 aggregates in the mixing composition. The mixing composition in Indonesia and Peru results in a relatively high compressive strength.
- In some countries, workers on some sites do not use any measurements when mixing concrete.

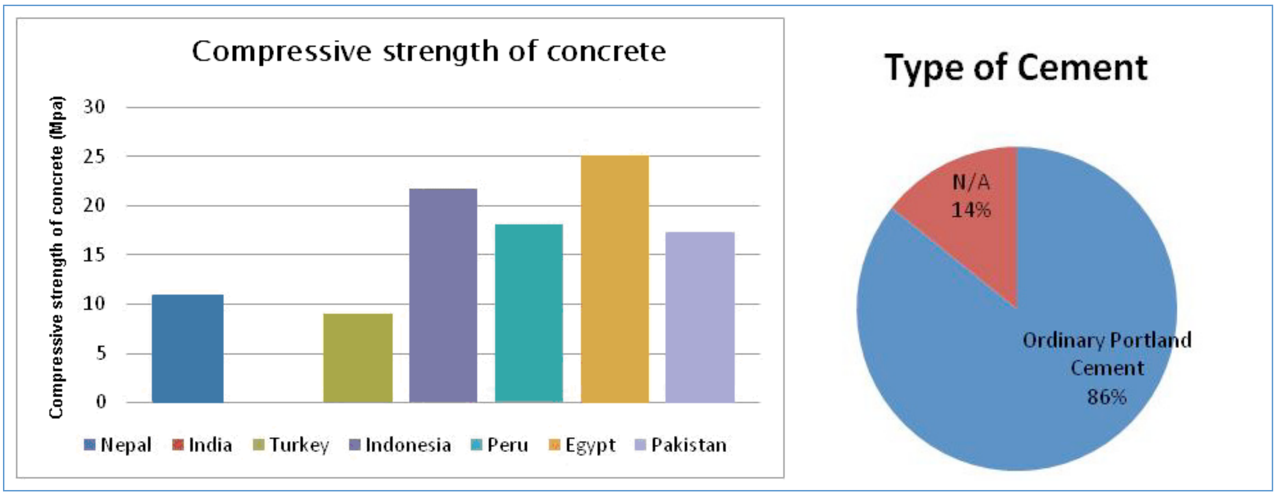


Figure 29 Compressive strength of concrete and type of cement

Contractor data

- In Egypt, most of the buildings are built by contractors with a site supervisor and workers.
- Most of the workers in the selected developing countries do not receive any training in construction.
- Most of the workers in the selected developing countries acquire their skills on the job. Indonesian workers have the most work experience and Egyptians the least.

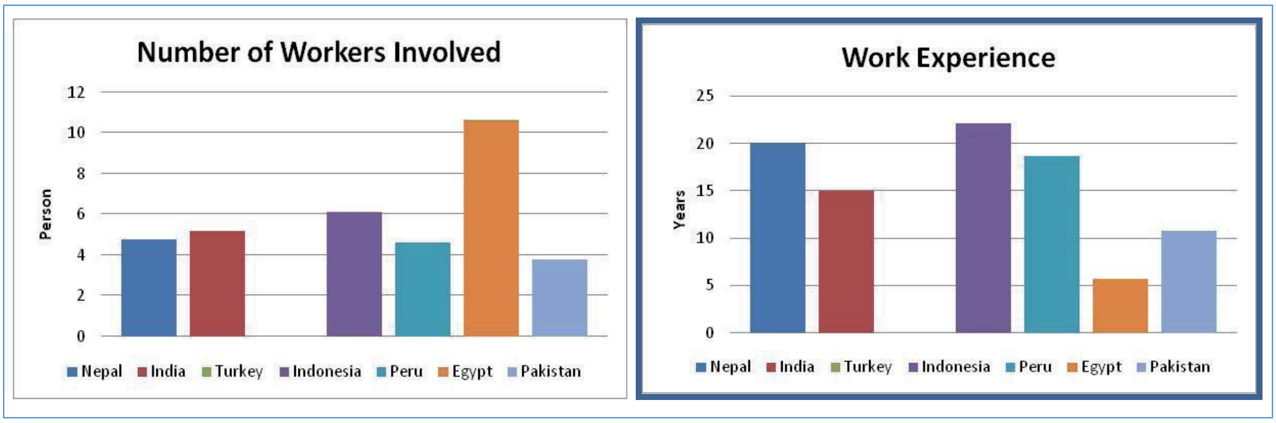


Figure 30 Number of workers involved (left) and work experience (right)

GENERAL ISSUES REGARDING NON-ENGINEERED CONSTRUCTION IN DEVELOPING COUNTRIES

Based on the survey information, some general issues regarding non-engineered construction in developing countries can be summarized as follows:

- Many building owners and construction workers have limited knowledge of proper construction methods and do not consider earthquakes as a potential hazard.

Most of the building owners do not consider earthquakes as a potential hazard. Most of the owners give more attention to construction costs than building safety. This may be one of the reasons why improper detailing occurred in structural elements.

Some of the construction workers have insufficient formal education or training on correct building techniques, and have acquired their skills from the guidance of their site supervisor and their own experience.

- Codes or guidelines for earthquake-resistant construction are not well communicated.

- All of the selected countries have a code or at least guidelines for earthquake-resistant construction. However, it is a shame that this information does not seem to be well communicated. Most workers are unaware of such codes or guidelines in their country. The quality of building work therefore cannot be assured.

- There is a lack of community awareness of earthquake-resistant construction. This might result from communities having limited knowledge of earthquakes or hazards that can harm them or their properties.

- There is a lack of integrity and improper detailing in structural elements, and construction materials are poor quality. As mentioned in the first point, this problem probably arises from workers not knowing how to build earthquake-resistant buildings, or having the knowledge but lowering the quality of building work to reduce costs, under the influence of the owners.

- No particular quality control system exists on a local or national level. Although some countries have a specific construction quality control system, construction workers are rarely, if ever, investigated or supervised by local or national authorities.

CONCLUSIONS

All of the selected countries have a specific code or at least guidelines for construction, but these codes seem to make a minimal impact on practices in the field.

The main types of non-engineered constructions are unconfined masonry, confined masonry and concrete frames with masonry infills. However, some sites use different structural systems, incorporating wooden elements (walls and columns).

Different countries have different non-engineered construction features. However some similarities were found on certain parameters, such as design intervention (by owners, except for in Egypt, where the government intervenes), building owners (private), availability of materials and workers (almost all types of materials and workers are available, except in Egypt where only sand is mostly available), supervision (by owners), construction tools (small concrete mixers), building function (residential, except in India, where non-engineered buildings also include schools), type of foundations (strip, or combination of strip and isolated pad), wall thickness (one brick, except in Indonesia, which uses a half brick, and Egypt, which uses two bricks), type of plaster/mortar for cementing agent (Portland cement), type of cement for concrete (Portland cement), and the training given to workers (never, except in Peru).

Some quantitative parameters have been derived from the surveys:

- Average area of non-engineered construction: less than 200 m2
- Average number of rooms: 5 (5.53)
- Average project duration: 11 (10.5) weeks
- Average wall height to thickness ratio: 14.54
- Average mortar thickness: 19.3 mm
- Average plaster thickness: 18.99 mm
- Average concrete strength: 17.16 MPa
- Average number of workers involved: 6 (5.87)

Most of the non-engineered constructions in developing countries are not properly constructed, technically speaking. From the survey results, most of the non-engineered constructions do not pay attention to the detailing, quality of materials, building configuration and quality of construction work.

Quick actions must be carried out to prevent the recurrence of such problems in non-engineered construction and avert huge losses in future disasters. In designing and implementing the strategies, all the relevant stakeholders should be involved, including the government, experts, community, builders and trades people.

RECOMMENDATIONS

Guidelines or codes on earthquake-resistant construction should be simpler and communicated widely and effectively to home owners, builders and trades people. The main objective is to encourage local or national authorities to provide easy-to-understand codes or guidelines to increase the chance that builders will improve their knowledge. Some methods that appear to be effective for disseminating a code or guidelines include small-scale workshops, conducted by local authorities, and random inspection of representative sites.

Programmes to raise community awareness need to be conducted. Some programmes that have already been conducted (e.g. community workshops) have effectively raised awareness of earthquake hazards.

Poor quality existing structures need to be reinforced. Some building elements, such as walls, connections, columns and beams, need to be strengthened in order to ensure correct building performance in the event of an earthquake.

Quality control or inspections carried out by local authorities are required to enforce the implementation of building guidelines or codes and ensure good building practices.

A certification programme for masons, trades people or foremen will ensure the quality of labourers. In addition, building owners should be more comfortable entrusting their buildings to qualified workers.

Experts should more often communicate safe construction methods and discuss them with workers and contractors. This should reduce the gap between experts and field practitioners. Periodical field surveys by experts may be an effective way to disseminate knowledge.

LIMITATIONS

Some selected sites may not be fully representive of the current state of non-engineered construction in certain countries, even though the selection was adjusted to be representative.

Not all of the selected countries had sites under construction at the time of the study. Some of the selected sites were chosen from existing buildings and may not be representative of current non-engineered construction practices in their countries if the sites were built a long time ago.

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RECOVERY OF DAMAGED SQUARE REINFORCED CONCRETE COLUMNS USING A STEEL PLATE JACKET

Cecep Bakheri Bachroni

Research Engineer, Research Institute of Human Settlements (RIHS),
Agency for Research and Development, Ministry of Public Works, Indonesia
Email: cecep_bch@yahoo.com

ABSTRACT

This paper presents an experimental study of the steel jacket method for recovering damaged reinforced concrete columns. The main purpose was to measure the effectiveness of steel plate in recovering the properties of damaged reinforced concrete columns. Two reinforced concrete columns were used in this experiment, both loaded in their original condition until failure and than repaired using a steel jacket. After 28 days, both specimens were reloaded using the same procedure. The scope of evaluation involved the failure mode, the pattern of cracks, and strain development of steel plate, longitudinal bars and hoops. The results reveal that the steel jacket repair method was able to recover the properties of the column specimens much more effectively than the original specimens. Steel plate is capable of effectively inhibiting the development of shear cracks, allowing the longitudinal bars and steel plate to achieve their strain hardening state and the column to achieve the expected capacity.

KEYWORDS

Reinforced concrete, column, damaged, repair, steel plate

INTRODUCTION

General

A steel plate jacket is one of the strengthening methods used to increase the capacity of reinforced concrete columns that are undergoing reduced shear. Encasing the hinge plastic area of a reinforced concrete column using steel plate inhibits the shear crack and allows the main bar to strain up until the actual capacity of the column is obtained. If the jacketing method is intended to increase capacity, the steel plate is only installed at the hinge plastic area of the column. However, if the method is intended to recover a column damaged by overload or an earthquake load, for example, the steel plate encases the whole of the column height. This means that in the lateral direction, the steel plate may work as web bars and additional web bars to resist the force of the concrete core that cracked due to axial and lateral load. In the longitudinal direction, the steel plate can become an additional main bar or substitute the main bars that failed to resist bending load. This was confirmed by the experimental study of the half-scale column applying constant axial load and cyclic loads.

In this steel jacketing method, a controlled increase in flexural strength enables a well-balanced enhancement of both the flexural strength and the ductility of reinforced concrete columns. A cyclic loading test using large-scale models constructed in the laboratory was intended to examine the improvements in strength and ductility of reinforced concrete columns using this retrofitting method.

Objective

The main purpose of this experiment was to measure the effectiveness of steel plate jackets for recovering damaged reinforced concrete columns.

EXPERIMENTAL PROGRAMME

Materials

Concrete. The original column specimens had a concrete strength of 250 kg/cm2 and tensile strength of its main bars of 2,400 kg/cm2. For repairing the damaged specimens, concrete with a compressive strength of 300 kg/cm2 and steel plate with a tensile strength of 2,292 kg/cm2 were used. A steel plate thickness of 1.9 mm was used to confine the column. 13 mm diameter deformed bars and 8 mm plain bars were used for the main and web bars respectively.

Polymer bonding aid. Nitobond SBR was used to enhance bonding between the existing and new concrete. The bonding properties were 62 N/mm2, 3.3 N/mm2, and 9 N/mm2 for compressive strength, tensile strength and flexural strength respectively.

Cement grout. Conbextra GP was used in this experiment. This type of multi-purpose cement grout can be used in reinforced concrete construction as well as in repair and retrofit works for concrete having experienced damage such as cracks. The properties of this cement grout were 64 N/mm2, 10 N/mm2, and 28 KN/mm2, for compressive strength, flexural strength and Young's modulus respectively.

Test specimens

Figure 1 shows the original and repaired column specimens, along with the repair process. The column section measured W 25 cm x L 25 cm x H 210 cm. The height from the base to the loading point was 280 cm. The shear span ratio was 4.2. 13 mm diameter bars were arranged as longitudinal reinforcements with a 3 per cent ratio. As hoop reinforcements, 6 mm diameter hoops were arranged at intervals of 9 cm, and the ratio of web bars was 0.25 per cent.

Two column specimens were tested, one subjected to an axial load of 35.5 Tf and the other an axial load of 69.4 Tf. This load was constantly applied together with a lateral load. After the first load had damaged the column specimens, a steel jacket was used to repair them, and both repaired column specimens were then reloaded using the same procedure.

When the steel jacket was applied to the specimens to be repaired, two steel plates, each with a thickness of 1.9 mm were bent into a channel shape. Both channel-shaped steel plates were set up around the column and than welded into a jacket. To avoid jacket from axial stress, a vertical gap of 1 cm was left between both ends of the steel plate and a stab of column specimen, as shown in Figure 1.

Loading method

The loading position of the specimens is shown in Figure 2. The specimen was fixed to the bottom beam of the steel reaction frame fixed to floor slab of the laboratory room. The upper end of the specimen column was attached with high tensile strength bolts 22 mm in diameter to the L-shaped beam of the loading apparatus.

The horizontal load on the test specimen was applied through the L-shaped beam by a 300 Tf capacity actuator. The vertical load was applied by a 300 Tf capacity actuator installed on the upper beam of the steel reaction frame. A 350-tonne capacity roller bearing was placed between the frame and actuator to follow the horizontal displacement of the specimen.

Force was applied horizontally with gradually increasing displacement according to the loading process shown in Figure 2. A constant axial load was applied, including the weight of the loading apparatus, to produce an axial stress.

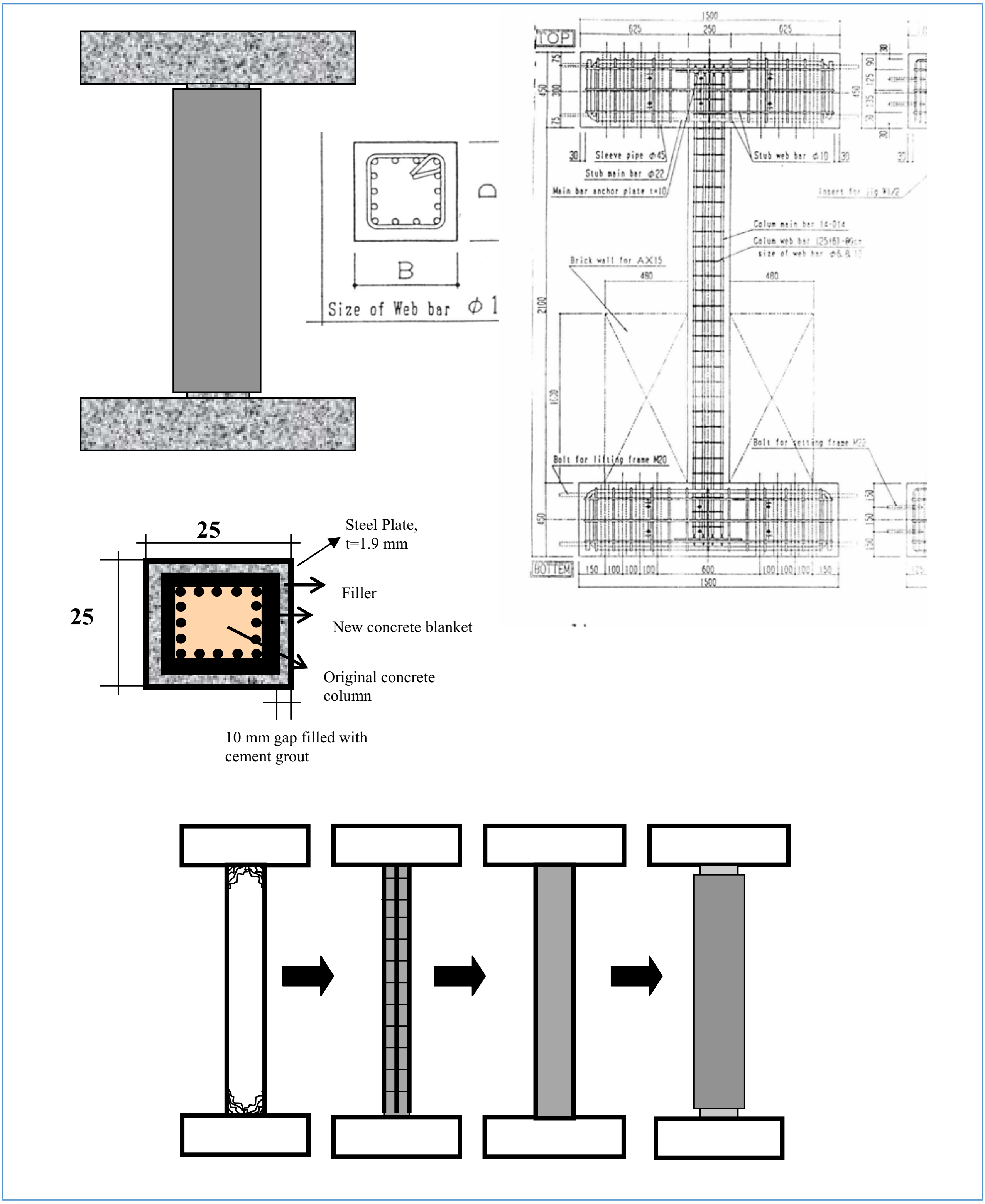

Figure 1 Specimens and repair process

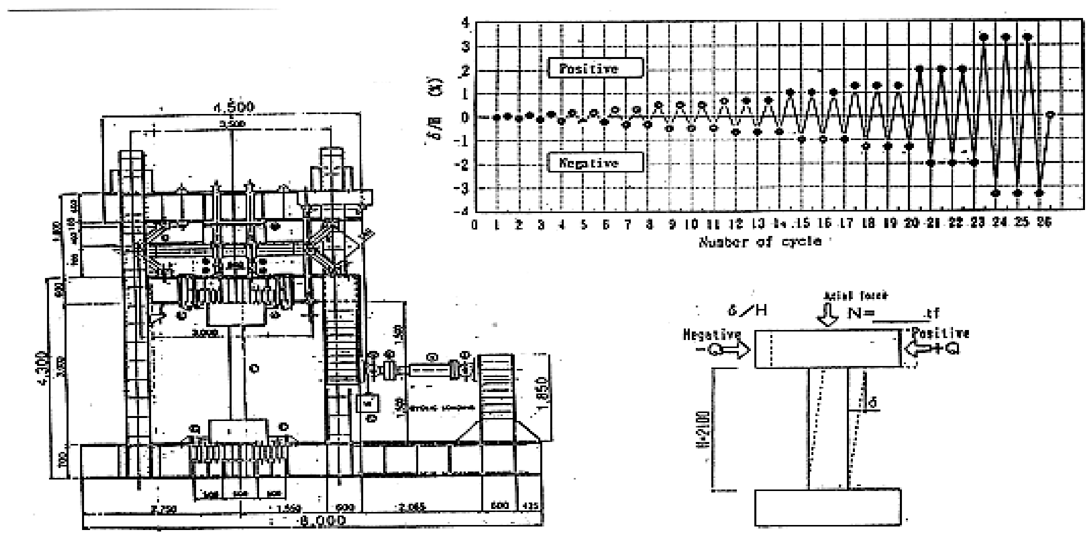

Figure 2 The loading position of the specimens and loading pattern

Measurement method

For the configuration of the force measurement system, shear load cells attached to the front end of the actuators acquired the data for horizontal and vertical loads. This data, together with jack-stroke data, was sent directly from the actuator control computer through an interface to the measurement control computer.

Displacement transducers measured the displacement of each part of the test specimen with a 25 mm capacity, placed in the measurement frame fixed to the surface of the test specimen. Also, to clarify the specimen failure mode, the strain in the axial direction at the top and bottom of the column's main bar causing the maximum bending moment was measured with a one-axis strain gauge (5 mm detection length). For the strengthened specimen, strains at the main point of the steel plate were measured with three-axis strain gauges. The strain measurement positions are shown in Figure 3. The displacement and strain data was obtained using a digital strain measurement device and recorded with online control by computer.

EXPERIMENT RESULTS

Crack patterns and failure mode

The crack pattern of the retrofitted specimen test is shown in Figure 6, with the original specimen in Figure 6a and the repaired test specimen in Figure 6b. For the repaired specimen, the steel plate and filler were removed after the test, and the cracking in the reinforced concrete column was observed.

The test results are summarized in Table 1. Yield displacement means the displacement of the specimen recognized as main bars achieved its yield strain. Yield load is a load noted when the yield displacement was achieved, and the ultimate displacement is a displacement of 80 per cent of the maximum loads taken after the peak load had been achieved.

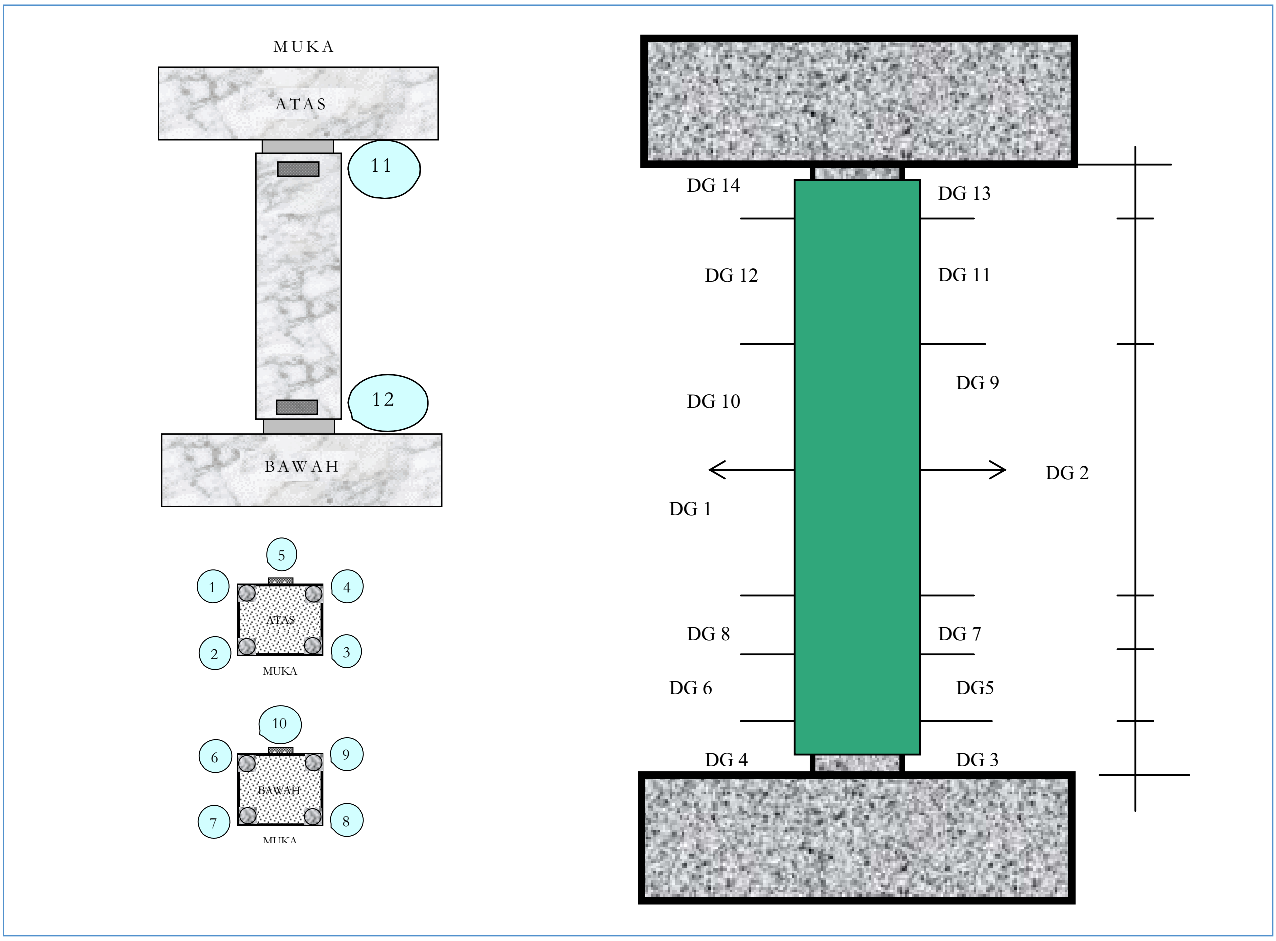

Figure 3 Location of strain gauge and dials gauge

Original specimen (BUK 1 and BUK 2). Initial cracks appeared in the second loading cycle as a flexible crack on the tension side at the top of the column at a load of 3.95 Tf and rotation angle of the member R=1/300 Rad. As the load increased, new flexible cracks appeared at the head and foot of the column, and these flexible cracks steadily extended in a 45° direction to axes of the column, appearing as flexible shear cracks. Shear cracks appeared in the bottom of the column in the 373rd loading step, and in the third cycle at a load of 5.52 Tf and rotation angle of the member R=1/150 Rad. Fracture of the concrete in top of column occurred at a load of 6.96 Tf as the horizontal displacement reached 21.1 mm or rotation angle R=1/100-Rad. The maximum load could be reached in the push direction of force of 8.45 Tf and the horizontal displacement at the maximum load was 40.1 mm or as rotation angle of member R=1/50 Rad. The maximum load could be obtained in the pull direction of force of 8.69 Tf with horizontal displacement 105 mm or as rotation angle of member R=1/20 Rad.

For specimen No. 2 (BUK 2), with the same steps of failure as specimen No. 1 (BUK 1), an initial crack appeared in the 161st step of loading, at a load of 3.52 Tf and horizontal displacement of 7.0 mm or rotation angle of member (R) reaching 1/300-Rad. In the 515th step of loading, a shear crack occurred, the load that could be reached on that step was 6.63 Tf and a horizontal displacement of 21.1 mm (R=1/100-Rad) was noticed. In the same step, a fracture occurred at both ends of the column at a load of 6.64-Tf. The maximum load of 9.86 Tf had been reached and the horizontal displacement at the maximum load was 38.1 mm.

Repaired column specimens (SJBU-1 and SJBU-2). In specimen No. 1 (SJBU-1), a flexible crack appeared at the boundary between the stab and column at the 420th loading step with a load of 8.93 Tf and horizontal displacement of 21.00 mm (R=1/100-Rad). The crack widened further up to the 555th loading step with a load of 4.62 Tf and horizontal displacement of 140 mm (R=10-Rad). In this step, the steel plate in the bottom part of the column was blowing. The maximum load that could be reached by the column at the end of the test was 9.22 Tf with a horizontal displacement of 69.6 mm. The ultimate displacement of 152.5 mm could be reached. (The ultimate displacement is a displacement that taken at a point of unloads 20 per cent of the maximum load.)

The first crack in specimen No. 2 (SJBU 2) was a flexible crack appearing at a load of 5.29 Tf in the 349th loading step, and the horizontal displacement of the member was 9.44 mm. In the 985th loading step, the concrete fractured in the bottom of the column, as the load reached 7.73 Tf with a horizontal displacement of 40.00 mm. The maximum load of 10.23 Tf was achieved at nearly the end of the test, where the horizontal displacement at maximum load was 42.44 mm and the ultimate displacement of 111.1 mm could be reached. The ultimate displacement was a displacement taken at a point of unloads 20 per cent of the maximum load.

Hysteresis loop curve

The hysteresis loop curve of the column test is depicted in Figure 4, which shows that the ductility and strength of the repaired specimens can recover much more effectively than the original specimens. The ductility capacity of repaired specimen No. 2 (SJBU 2), which was subjected to an axial load of 69.4 Tf, was lower compared with repaired specimen No. 1 (SJBU 1), which was subjected to an axial load of 35.5 Tf. In addition to the lateral load capacity, the lateral load capacities that could be achieved were lower for repaired specimen No. 2 than repaired specimen No. 1. The area of each hysteresis loop in each cycle of the repaired specimens was much larger than in the original specimens. The ultimate displacement was shorter for repaired specimen No. 2 than repaired specimen No. 1. In general, the enhancement effect of steel plate for recovering damaged columns can be seen through the deference of the hysteresis loops area, as shown in Figure 5.

DISCUSSION

Load-deformation curve

The curve in Figure 5 represents the load-deformation envelope curve for each test specimen. Figure 7a is a combination envelope curve showing the original and repaired column in specimen test No. 1, which was subjected to a load of 35 per cent of its axial load capacity. Figure 7b is a combination envelope curve showing the original and repaired column for specimen test No. 2 with a load of 50 per cent of its axial load capacity. The envelope of specimen BUK-1 and SJBU-1 shows the confinement effect of steel plate on the property improvement of repaired column specimen. This effect could be examined from increasing the load as first crack, yield point; maximum load and ultimate horizontal displacement were achieved.

When compared with the original specimen (BUK 1), increases of 56 per cent, 12 per cent, 8.4 per cent and 48 per cent were obtained for the first load, yield point, maximum load and ultimate displacement respectively. For specimens No. 2 (BUK-2 and SJBU-2), the confinement effect of the steel plate was slightly smaller than for specimen No. 1 (SJBU 1), since the axial load applied to the column of specimen No. 2 was much larger than the axial load applied to the column specimen No. 1 (SJBU 1). Examined from the test result of repaired specimen No. 2 (SJBU 2) and then compared with the original specimen No. 2 (BUK 2), increases of 33 per cent, 24 per cent, 19 per cent and 36 per cent were obtained for the first load, yield point, maximum load and ultimate displacement respectively.

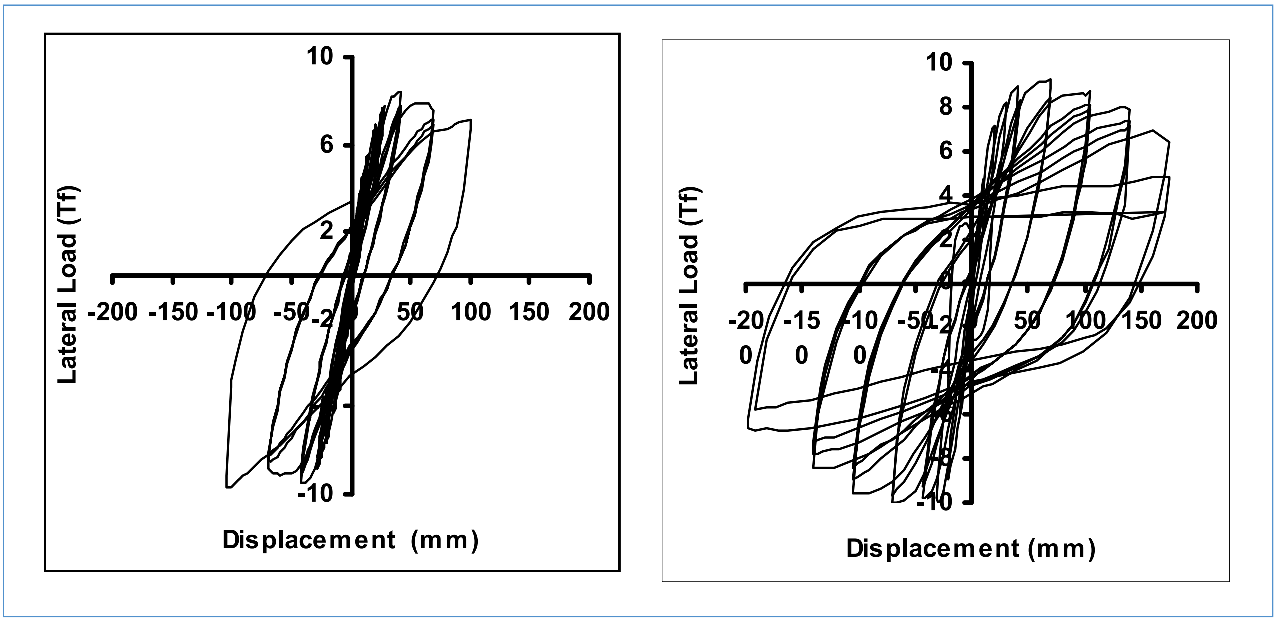

Figure 4 Hysteresis loop curve of original and repaired column specimens

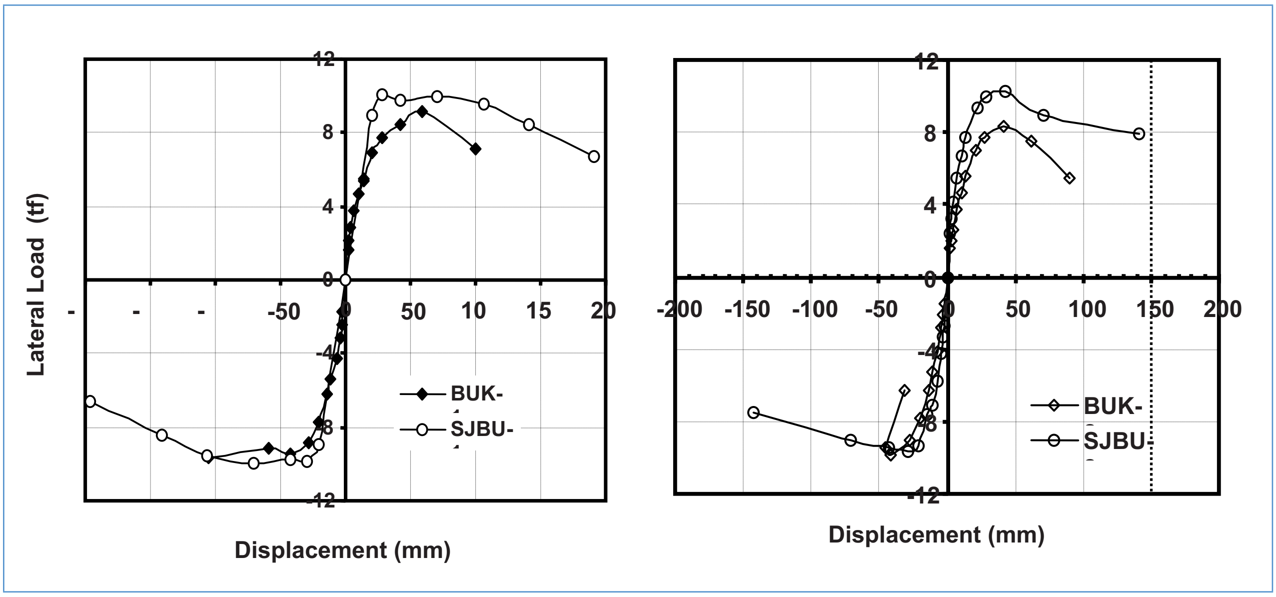

Figure 5 Load-deformation envelope curve

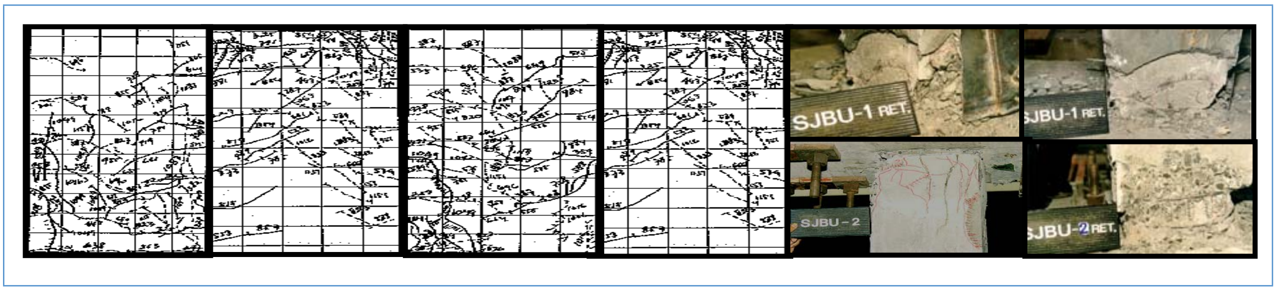

Figure 6 Crack pattern of the original and repaired column specimens after ultimate displacement

Specimen No.	Type of web bars (N/bD ratios)	Moment cracks			Shear cracks			Ultimate yields			Maximum load			Ultimate displacement		Ductility ratio	Condition of cracks
		Step	Q T.f	R Rad	Step	Q T.f	R rad	Step	Q T.f	R rad	Step	Q T.f	R rad	Q T.f	R rad		
BUK-1		161	3.95	1/300	373	5.53	1/150	659 587	7.09 -7.5	1/87 1/100	855 885	8.45 -9.43	1/500 1/500	7.09	1/21	4.75	Fracture by moment
SJBU-1	PELAT BAJA	420	8.93	1/100				410 560	8.09 -8.93	1/100 1/100	159 720	9.22 -10.06	1/302 1/73.9	6.73	1/11	9.07	Fracture by moment
BUK-2		161	3.52	1/300	515	6.63	1/100	513 536	6.63 -7.42	1/110 1/116	855 886	8.33 -9.83	1/53 1/55	6.632	1/23	4.75	Fracture by moment
SJBU-2	PELAT BAJA	349	5.29	1/200				513	8.73 -8.79	1/114 1/110	855 695	10.23 -9.69	1/50 1/74	7.93	1/15	7.71	Fracture by moment

Q = gaya geser, R = sudut defleksi, N/bD = rasio beban aksial.

Table 1 Failure pattern of original and repaired column specimens

Energy absorption

Figure 7 compares the specimens with regard to accumulated energy absorption. Energy absorption in each loading step was computed here by integrating the relevant hysteresis loop. Figure 7a shows that in the case of original specimen BUK 1, which was subjected to an axial load of 35.5 Tf, the energy absorption in each loading step began to decrease as the lateral displacement reached 50 mm. At this point, displacement tof he core concrete of the column started to suffer from damage. In the case of repaired specimen SJBU 1, the impact of the steel jacket for recovering column performance was shown by extending further and stable of the energy absorption up to the ultimate displacement reached. Figure 7b shows the impact of the steel jacket on improving the energy absorption of the reinforced concrete column, which was confirmed by repaired column specimen SJBU 2, which was subjected to an axial load of 69.4 Tf. The energy absorption of the original column started to decrease and radically drop when the displacement reached 50 mm. On the other hand, in the repaired specimen, the energy absorption rose in a stable manner until ultimate displacement was achieved.

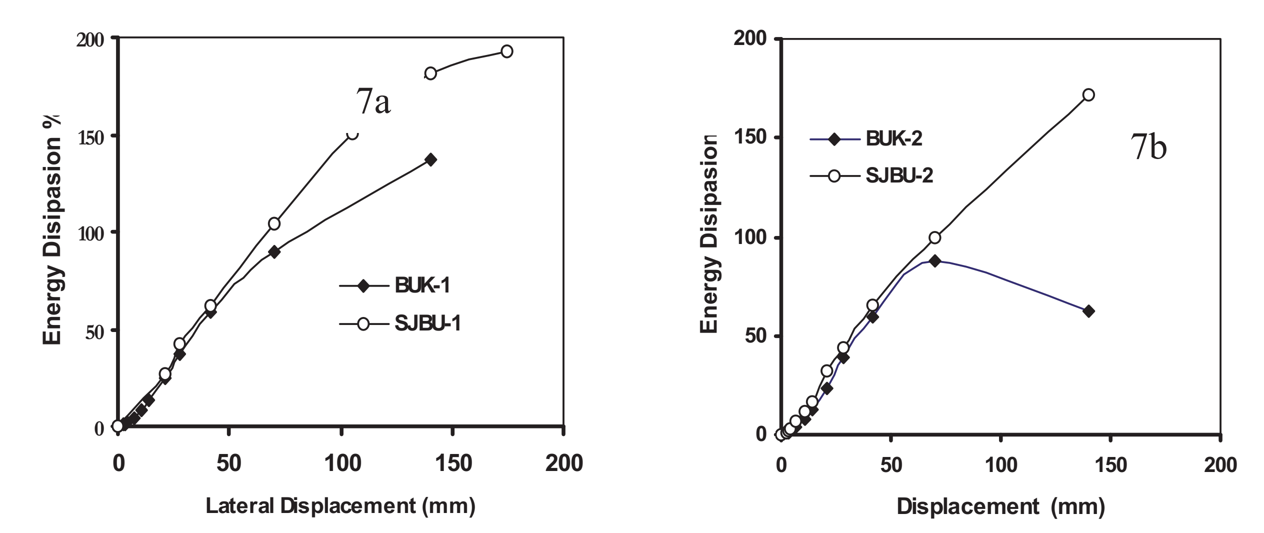

Figure 7 Impact of the steel plate jacket on energy absorption

Equivalent viscous damping factor

Figure 8 shows the impact of the steel jacket on the equivalent damping ratio. The ratio calculated was based on the hysteresis loop in the first loading cycle of each loading step. The ratio of the repaired column SJBU 1 and SJBU 2 rose constantly as lateral displacement increased, while the ratio of the original specimen began to decrease at the lateral displacement of 50 mm. This indicated that stable damping performance was obtained with the steel jacket method.

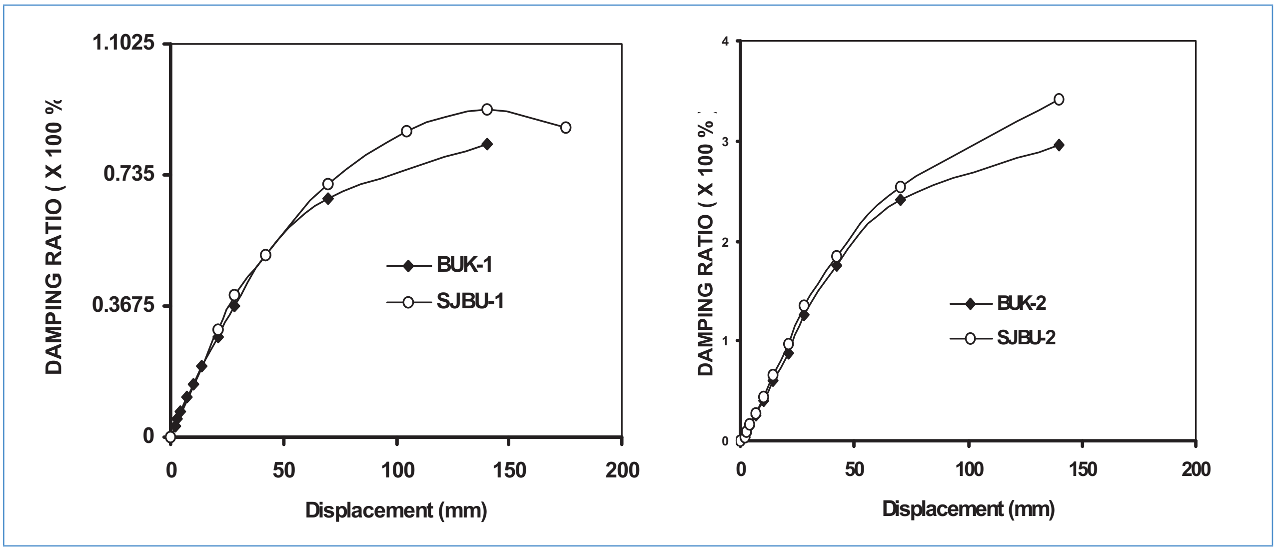

Figure 8 Impact of the steel plate jacket on equivalent damping ratio

Development of steel plate strain, main bar strain and hoop strain

The effectiveness of the steel plate confinement can be seen from the strain performance of the main bar and hoop in both the original and repaired columns. Figure 9a compares BUK 1 and SJBU 1 with regard to the strain of longitudinal bars, showing that the strain produced in the longitudinal bars of SJBU 1 was smaller at every loading step, with the steel jacket functioning as a longitudinal reinforcement. In addition to the web bars of the column, the steel jacket functioned effectively as a hoop reinforcement limiting the lateral deformation of the concrete column. This is shown in Figure 9b, in which the strain of web bar in SJBU 1 was much weaker than the strain in the original column.

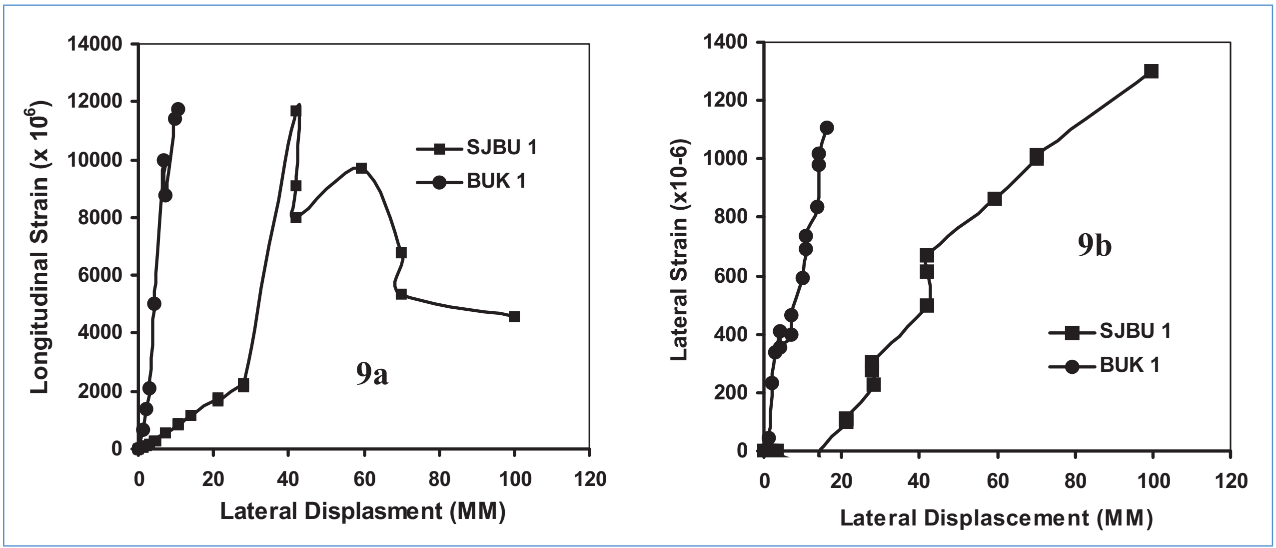

Figure 9 Impact of steel plate on hoop strain and longitudinal reinforcement

CONCLUSIONS

1. The test showed clearly that the ductility of reinforced concrete columns can be increased, as demonstrated by using a steel jacket.

2. Strain applied to the steel jacket and hoop reinforcement in the test confirmed that the steel jacket functioned effectively as a longitudinal and hoop reinforcement.

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LESSONS LEARNED FROM THE GREAT HANSHIN–AWAJI EARTHQUAKE AND OTHER MAJOR EARTHQUAKES IN JAPAN

Y. Katsumi

Director for International Building Codes Coordination, Housing Bureau
Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan
Email: y.katsumi@unesco.org

ABSTRACT

Japan has suffered many earthquakes, such as the Great Hanshin–Awaji Earthquake in 1995. We have learned lessons from the major earthquakes and have been taking measures for earthquake-resistant housing and buildings. One major example is that we have repeatedly revised the seismic requirements in the Building Standards Law of Japan (BSL) since it was enacted in 1950, reflecting what we have learned.

KEYWORDS

Recovery plan, building codes, reducing earthquake damage, retrofitting

INTRODUCTION

Japan has suffered many earthquakes such as the Great Hanshin–Awaji Earthquake in 1995. The aim of this paper is to describe the lessons learned from major earthquakes in Japan, including the Great Hanshin–Awaji Earthquake, and the measures taken for earthquake-resistant housing and buildings.

THE GREAT HANSIHIN–AWAJI EARTHQUAKE: RECOVERY PLAN AND LESSONS LEARNED FROM THE EARTHQUAKE

The Great Hanshin–Awaji Earthquake

Damage caused by the Great Hanshin–Awaji Earthquake

In the early morning January 17, 1995, the Great Hanshin–Awaji Earthquake hit the west region of Japan, including Kobe City, the prefectural capital of Hyogo Prefecture with a population of more than 1.5 million. The earthquake's magnitude was 7.3 and its maximum acceleration 818 Gal.

The earthquake made a considerable impact: 6,434 people killed, 111,123 totally-collapsed buildings, 144,274 partially collapsed buildings and about 320,000 evacuees. In total, the estimated cost of earthquake damage was approximately ¥10 trillion, including damage to buildings reaching ¥5,800 billion.

Table 1 shows the casualties, evacuees, damage to houses and the number of housing units that were demolished by local government order, as well as the number of temporary houses in the entire Hyogo Prefecture and Kobe City alone. The figures for Hyogo Prefecture include those for its capital city, Kobe.

Casualties, evacuees and damage		Total (incl. Osaka)	Hyogo Prefecture	Kobe City
Human	Dead	6,434	6,401	4,571
	Missing	3	3	2
	Injured	43,792	40,092	14,678
	Evacuees (peak)	320,000	316,678	236,899
Houses (units)	Totally collapsed	111,123	104,906	67,421
	(Households)	(191,617)	(186,175)	(-)
	Partially collapsed	144,274	137,289	55,145
Emergency response (unit)	Publicly demolished houses (Total)	108,672 (136,730)	87,289	61,392
	Temporary houses	49,800	48,300	32,346

Table 1

The population of Kobe City was about 1.52 million before the earthquake and decreased sharply soon after the earthquake to less then 1.45 million. It took about nine years for the population to return to the same level as before the earthquake.

Kobe City recovery plan

Kobe City spent more than ¥900 billion per year on recovery efforts in 1995 and made significant investments in reconstruction projects during the first three years after the earthquake. The total Kobe City budget from 1994 to 2004 reached approximately ¥2.7 trillion, of which about 46 per cent was covered by city bonds and one third by national funds.

The main objectives of the city bonds were to create a new disaster recovery fund, rebuild infrastructure, redevelop urban areas and build public housing. The national government provides subsidies, typically for half the costs, but in case of a large-scale disaster, they may increase to two thirds or more. The national government introduced 20 laws to apply exceptional measures to address the damage from the Great Hanshin–Awaji Earthquake.

Kobe City established an Earthquake Recovery Head Office in January 26, 1995, published the Kobe City Recovery Plan Guidelines in March 27 and formulated the Kobe City Recovery Plan in June 30, 1995.

The symbolic projects of the Kobe City Recovery Plan were as follows:

1. A quality-of-life restoration plan (for rebuilding houses)
2. Creating a safe and pleasant urban area (projects for land readjustment and urban redevelopment)
3. Creating a welfare-minded city (services for the elderly, etc.)
4. A safety network (safer communities)
5. A new eastern-city centre (HAT Kobe) (120 ha, population of 30,000)
6. The Kobe entrepreneurial zone concept (for start-up businesses)
7. The China and Asia exchange zone concept
8. Creating a port of registry in Asia
9. Promoting a cosmopolitan, modern culture in Kobe
10. Creating transportation systems (grid-system roads)
11. Infrastructure for next-generation information and communications technology (ICT) studies
12. Forming regional disaster-preparedness bases
13. Creating a city rich in water and greenery (river, greenery corridors and landscape areas)
14. Creating a memorial area within the city centre (parks commemorating the recovery with disaster bases)
15. Implementing disaster-resistant (utility) lifelines (joint-use ducts and large-capacity water supply pipes)
16. Recording the earthquake experience for posterity: Inheritance of the “Disaster Culture” (maintaining records of the earthquake experience)
17. Promoting the concept of a Natural Disaster Science Museum and a Twenty-First Century Museum Cluster

The Kobe City recovery projects included three major categories for restoring the daily life in communities: housing recovery projects, urban recovery projects and economic revitalization projects.

To promote the reconstruction of housing, Kobe City published an emergency three-year housing reconstruction plan for 1995–97.

Table 2 shows the target numbers of newly constructed housing units in the plan. For example, the target for new public housing was set at 10,000 units.

Target number of newly constructed units	
Public housing (for lower-income people)	10,000
Specially designated high-quality rental housing	10,500
Redevelopment-related housing	4,000
Housing built by the Public Housing Corporation (UR)	15,900
Private housing	31,600
Total (1995–97)	72,000

Table 2 Kobe City emergency three-year housing reconstruction plan (1995–97)

In a revised plan, called the Kobe Housing Recovery Plan (1996–97), the target for public housing was increased to 16,000 units as more were needed. The city government found that the elderly and low-income families accounted for many of the disaster victims. In the third plan, called the Kobe Three-year Housing Plan (1998–2000), a smooth transition from temporary to permanent houses was included. The national government provided financial assistance for public housing intended for lower-income people.

Many urban recovery projects, such as land readjustment projects and urban renewal projects were implemented to rebuild the quake-hit city areas. The national government also subsidized these recovery projects.

In addition to these infrastructure rebuilding projects, a number of industrial measures were carried out to revitalize the economy, and included measures for small- and medium-sized enterprises, business grants, reviving tourism, zones for new industries, job creation, agriculture and forestry, etc.

The earthquake caused plenty of evacuees and the local government provided shelters for them. The number of shelters in operation peaked to 599 on 26 January 1995 and the number of people using the shelter services reached 230,000. The community residents and many people from all over Japan, most of whom came from areas neighbouring the Hanshin–Awaji region, participated in volunteer activities such as classifying and distributing relief goods and materials, and taking care of elderly people and infants. The number of full-time days of volunteer work reached more than 1.2 million.

Lessons learned from the Great Hanshin–Awaji Earthquake

We can learn many lessons from the Great Hanshin–Awaji Earthquake Disaster. Some simple but important points for reducing the risk of earthquake disaster are as follows:

1. The earthquake disaster reminded citizens of the severity of nature.
2. Communities help to protect the lives of their members in the event of an emergency.
3. It is impossible to do something new, which citizens do not do on a daily basis, in a devastated situation.

We can also learn from the recovery efforts after the Great Hanshin–Awaji Earthquake:

1. The meaning of “recovery” changes as recovery activities proceed.
2. Cross-sectional and flexible approaches are required for recovery.
3. Communities are created by the autonomous efforts of individuals through daily cooperation and participation.

MEASURES FOR EARTHQUAKE-RESISTANT HOUSING AND BUILDINGS IN JAPAN

As mentioned above, many buildings collapsed during the Great Hanshin–Awaji Earthquake and buildings designed according to the old seismic code were severely damaged by the earthquake. For years, we have been learning greatly from analyses of the damage to buildings caused by several major earthquakes.

Analysis of the damage caused by the Great Hanshin–Awaji Earthquake

Buildings should protect human beings from natural disasters. When buildings are damaged by earthquakes, the impact on the lives of the occupants is enormous. Table 3 shows the causes of fatalities from the Great Hanshin–Awaji Earthquake. Eighty-eight per cent of fatalities were people killed under the weight of collapsed buildings, furniture or other objects.

	Number of fatalities
People who were probably killed under the weight of collapsed buildings, furniture or other objects	4,831 (88%)
People who were probably killed by fire	550 (10%)
People killed by other causes	121 (2%)
Total	5,502 (100%)

Table 3 Causes of fatalities from the Great Hanshin–Awaji Earthquake in 1995

Building codes are considered the most effective tools to safeguard the lives and property against major disasters, particularly earthquakes. Figure 2 shows the degree of damage to buildings by construction year. There are clear differences in the damage to buildings constructed before 1971, between 1971 and 1981, and after 1981.

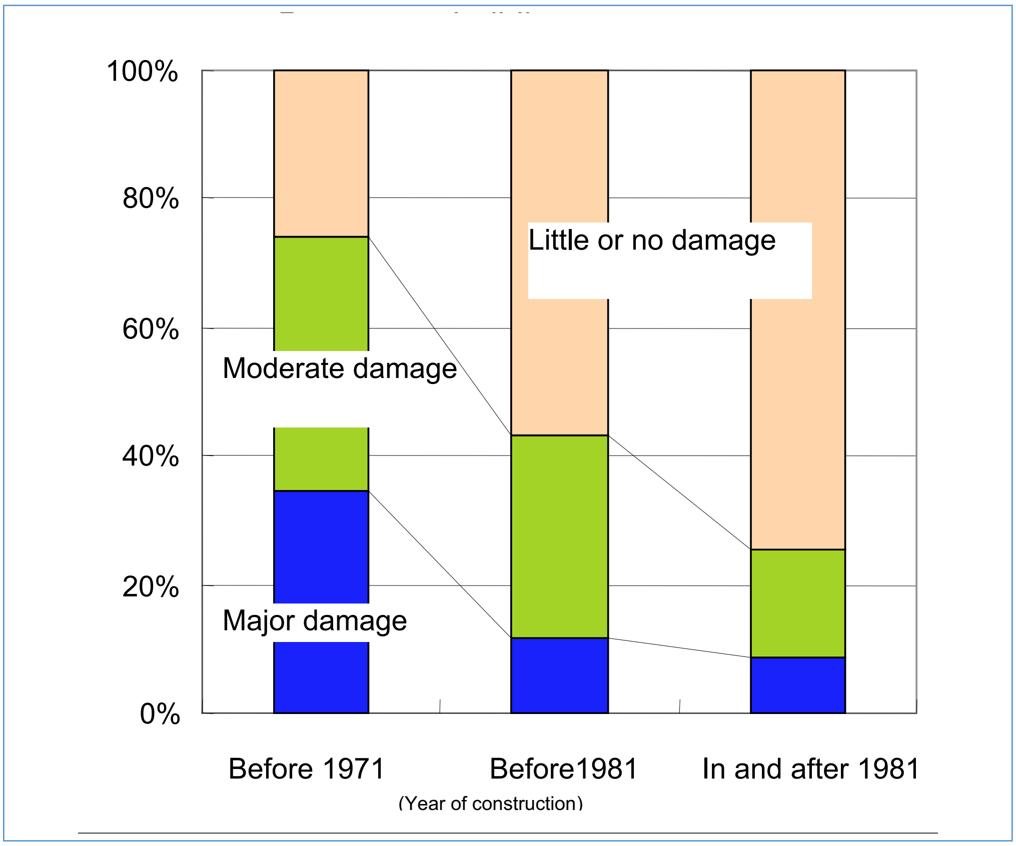

Figure 2 The degree of damage to buildings by construction year

The Building Standards Law of Japan (BSL) was amended to strengthen reinforced-concrete standards in 1971, and New earthquake resistant standards were introduced in 1981. This analysis provided an important fact: a strict building code is an effective means to reduce earthquake damage.

Since the BSL was enacted in 1950, Japan has experienced several major earthquakes and suffered severe damage. We have learned from experience, and repeatedly revised the seismic requirements in the BSL. For example, after the Tokachi offshore earthquake in 1968, the standards for reinforced-concrete structures were strengthened and the minimum stirrup space was reduced to improve ductility of reinforced-concrete columns in 1971.

After the Myagi offshore earthquake in 1978, the New earthquake resistant standards were introduced in 1981 and remain the current design principle.

Before the enactment of the New earthquake resistant standards in 1981, structural requirements were for buildings to suffer no damage from medium-sized earthquakes. It was believed that buildings would withstand even large earthquakes thanks to high ductility.

The new standards have a two-tier target for structural design. First, buildings should not be damaged by medium-scale earthquakes, or Intensity 5 quakes on the Japanese scale, which occur infrequently. Second, the building should not collapse or fall due to large-scale earthquakes, or Intensity 6–7 quakes on the Japanese scale, which occur very rarely. Simply put, the standard requires "no damage by medium load and no collapse by large load". According to this principle, provisions for the confirmation of horizontal load-carrying capacity were introduced in the seismic code.

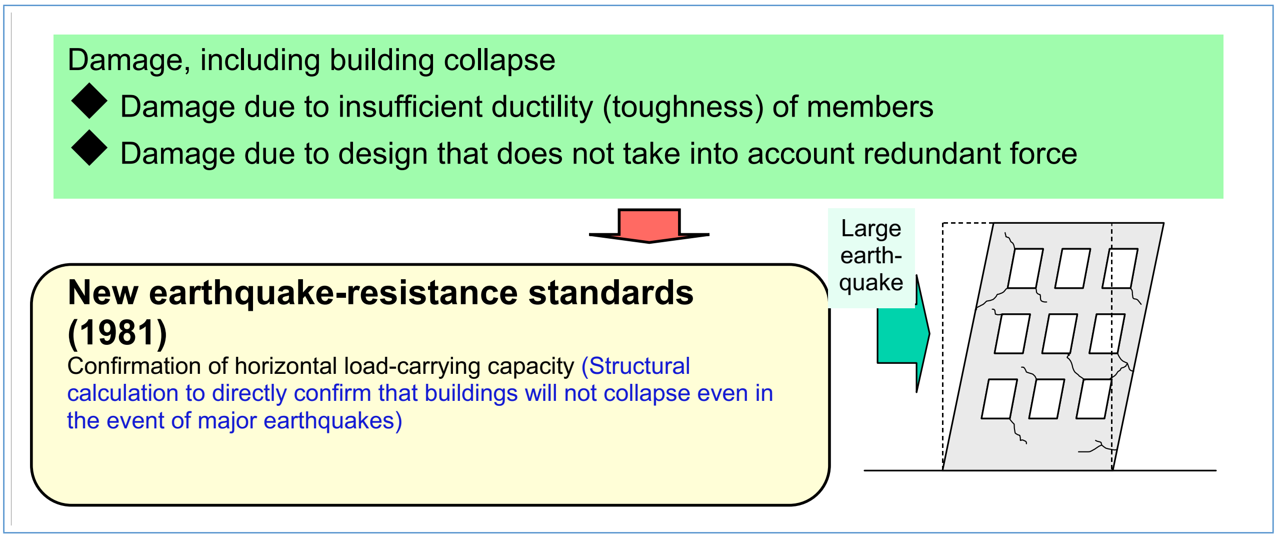

Figure 3 New earthquake resistance standards

After the Great Hanshin–Awaji Earthquake in 1995, a separate law for seismic retrofitting was enacted because we found that existing buildings that had failed to meet the current BSL were heavily damaged. In addition, an interim inspection scheme was introduced in the BSL because there was severe damage assumed to have been caused by inappropriate construction.

Measures for earthquake-resistant housing and buildings

Since the Great Hanshin–Awaji Earthquake, the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT), has enacted various measures for earthquake-resistant housing and buildings. The national government implemented the Act for Promoting Seismic Retrofitting of Buildings in 1995, and has provided assistance through subsidies, financing and tax breaks. MLIT has also promoted technical developments for seismic retrofitting.

Under the Act for Promoting Seismic Retrofitting of Buildings, the owners of buildings used by large numbers of people, such as hospitals, theatres and department stores, must have their buildings undergo seismic capacity evaluation and seismic retrofitting. In principle, when people carry out major repairs, they must comply with the current building code, the BSL. However, when they obtain certification for seismic retrofitting work, the provisions of the current law are not applied retroactively, except those related to earthquake resistance.

	Public buildings	Private buildings	Total
Number of certifications	4,857	684	5,541

Table 4 Certifications under the Act for Promoting Seismic Retrofitting of Buildings (1995–2008)

According to the Act for Promoting Seismic Retrofitting of Buildings, MLIT developed Basic Principles for Promoting Seismic Performance Evaluation and Seismic Retrofitting of Buildings, which included provisions for the promotion of seismic performance evaluation and seismic retrofitting, targets to increase the use of seismic performance evaluation and seismic retrofitting, technical guidelines for seismic performance evaluation and seismic retrofitting, raising public awareness and disseminating information, and the development of seismic retrofitting plans by prefectural governments.

On the basis of the principles developed by MLIT, prefectural governments must set plans for promoting seismic performance evaluation and seismic retrofitting of buildings in their jurisdictional areas. All prefectural governments have already made plans and set targets for increasing the percentage of housing and buildings with sufficient earthquake resistance.

Unfortunately, we cannot say that Japan is fully prepared for earthquakes. In 2003, 25 per cent of the country's 47 million housing units and 35 per cent of the 3.4 million non-residential buildings had insufficient earthquake resistance.

	Total stock	Stock with insufficient earthquake resistance	
Housing	47	11.5	(25%)
(million units)			
Non-residential buildings	3.4	1.2	(35%)
(million buildings)			

Table 4b Existing buildings with insufficient earthquake resistance

In 2006, MLIT set a target to raise the proportion of housing and specified buildings with sufficient earthquake resistance in the basic principles to 90 per cent by 2015 from the current 75 per cent.

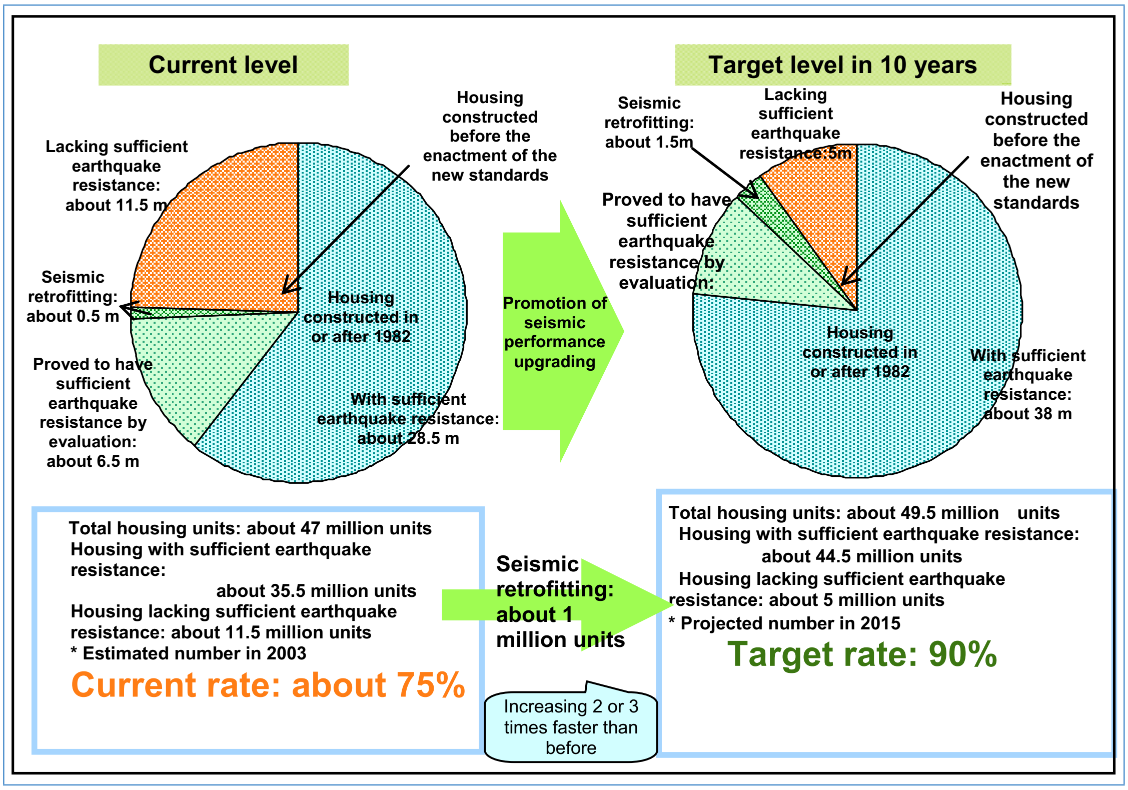

Figure 4 Target increase in the percentage of housing with sufficient earthquake resistance

Since the current seismic code is stricter than ever, it is certain that the percentage of housing units with insufficient earthquake resistance will decrease as housing is reconstructed. In addition, the Japanese government has been trying to accelerate seismic capacity evaluation and seismic retrofitting through the implementation of support schemes.

Subsidies are available for both seismic capacity evaluation and seismic retrofitting. For seismic capacity evaluation, the owner needs to pay only one third, and the rest is paid by the national and local government.

For seismic retrofitting, about 23 per cent is paid by the national and local government. There are also programmes to supply low-interest loans for the cost of seismic retrofitting. Tax breaks are also available and can deduct 10 per cent of the cost of seismic retrofitting from income tax (up to a maximum of ¥200, 000).

Through these measures, seismic capacity evaluation was conducted for about 545,000 housing units, and seismic retrofitting for about 31,000 housing units by March 2009.

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IMPLEMENTATION OF QUICK INSPECTION FOR DAMAGED REINFORCED-CONCRETE BUILDINGS DUE TO THE 2009 PARIAMAN EARTHQUAKE

Ferri Eka Putra

Structure Researcher, Research Institute for Human Settlements
Ministry of Public Works, Indonesia
Email: f3rri@yahoo.com

ABSTRACT

The earthquake in Pariaman on 30 September 2009 caused damage to public buildings and houses in surrounding cities. After an earthquake, a quick inspection of damage to buildings needs to be carried out as soon as possible to obtain preliminary data on the number of buildings damaged and to determine the level of damage to buildings so that decisions can be taken on the usage status of the building. Quick post-earthquake inspection was adopted, referring to the Quick Inspection Manual for Reinforced-Concrete Buildings Damaged due to Earthquake issued by the National Institute for Land and Infrastructure Management (NILIM) of the Ministry of Infrastructure, Land, Transport and Tourism (MILT) Japan in 2002. This inspection focused on government-owned buildings in the city of Padang, especially office and hospital buildings, and status stickers were used to classify inspected buildings in three categories: inspected (aman), limited entry (hati-hati) and unsafe (bahaya). This kind of inspection has provided preliminary data for further handling, and provides psychological benefits for building users.

KEYWORDS

2009 Pariaman Earthquake, Quick Inspection, Damaged Building.

INTRODUCTION

The Pariaman earthquake occurred on 30 September 2009 at 5:16 pm. According to news released by the National Agency for Disaster Management (BNPB), the earthquake reached 7.6 magnitude on the Richter scale and a depth of 71 km. Its epicentre was located at 0.84 longitude and 99.65 latitude, approximately 57 km southwest of Pariaman City, West Sumatra. The MMI intensity in West Sumatra Province ranged from III to VII, with VII in the city of Padang, the capital of West Sumatra Province. Earthquake shocks were therefore felt strongly in this region. According to data from the National Agency for Disaster Management (BNPB), as of 27 October 2009, the earthquake had caused as many as 1,195 people deaths, 619 serious injuries and 1,179 minor injuries. Moreover, hundreds of thousands of housing units were damaged, along with thousands of buildings and other public facilities.

After the 2009 Pariaman earthquake, quick inspections of damaged buildings were badly needed, not only to know the number of damaged buildings and the level of damage, but also to provide certainty for users on whether buildings were safe for use or in need of evacuation. This sort of examination must be completed quickly by a competent person and can be a concern because errors in decision-making can be fatal. A building that is in good condition but deemed unsafe only reduces the number of buildings that can be used as temporary shelters, as safe buildings are usually in very limited supply after a strong earthquake. But if the situation is reversed, and an unsafe building is deemed to be safe because of the survey officer's lack of knowledge, a second disaster can occur for the occupants. After the main quake, aftershocks – usually with a large enough magnitude and intensity – can exacerbate damage to buildings and cause them to collapse.

Problems during post-earthquake building inspection are due to a lack of competent human resources for assessing the extent of damage, because inspectors are limited to building researchers and academics. Meanwhile, the number of buildings that need to be examined is enormous and the available time for examinations is limited. Inspections need to be quick.

The purpose of quick inspections is to determine which buildings are still safe to use and which are unsafe. This is necessary to reduce the likelihood of casualties caused by aftershocks. The results of quick inspections can also be used as a basis for determining the number of temporary buildings required for evacuation.

Quick inspection priorities are public facilities such as hospitals, schools and government offices, and if more time is available, homes as well. Stickers are installed on inspected buildings to explain briefly their safety status. These stickers are essential because, in addition to providing information on building conditions, they can convince residents that a building is still safe for use.

THE POST-EARTHQUAKE INSPECTION PHASE

Post-disaster building inspection can generally be divided into three phases: the emergency phase, the quasi-stable phase and the stable phase.

1. Emergency phase

This is a quick visual inspection carried out during the emergency phase, generally from both outside and inside the building, although the inspection can be completed from outside the building if it is not possible to check the building from inside. The recommended level of damage to buildings may be divided into three: “inspected”, “limited entry” and “unsafe”. After determining the level of damage to the building, temporary reinforcement recommendations can be followed if necessary. It is important to reduce building damage or collapse due to aftershocks.

This stage is usually performed one to two weeks after the main earthquake event. Nevertheless, the time for this phase can be extended depending on the severity of building damage, the extent of damage to the area and the number of available inspectors.

2. Quasi-stable phase

In the quasi-stable phase, damage can be assessed more accurately and quantitatively, allowing for technical and financial recommendations to be made for inspected buildings. A decision can also be taken on whether buildings need to be reinforced or demolished. This stage usually lasts between two weeks and three months after the earthquake event.

3. Stable phase

Three months after the earthquake, the stable phase can begin, involving seismic capacity evaluation and retrofitting design.

METHODOLOGY

A quick visual check of the building for earthquake damage involves the following:

1. Building identification

The first step in a quick inspection is to identify the building, with the date and time of inspection, the name of the inspector, the name of the inspected building, the address of the inspected building, contact persons, the number of storeys, the functionality of the building and the type of partition walls.

2. General inspection of the entire building

The next stage is a general visual inspection of the building. Inspectors need to ascertain whether it has suffered total or partial collapse, whether there is extensive damage and/or remarkable offsetting of the superstructure forming the foundation, or a remarkable inclination of an entire or partial building storey and any other damage. This check is performed inside and outside the building. If a building appears dangerous to enter, the procedure can be stopped by deeming the building unsafe.

3. Structural component inspection

An examination of structural components includes hazards from damage to adjacent buildings, surrounding ground, settlement of the building due to ground failure, inclination of the building due to differential settlement and damage to level beams, columns and beam columns. Criteria for damage to the components of the observed structures are shown in Table 1.

	A	B	C
Hazard from damage to adjacent buildings or surrounding ground	No	Uncertain	Yes
Settlement of building due to ground failure	<0.2 m	0.2–1.0 m	>1 m
Inclination of building due to differential settlement	<1/60 rad	1/60–1/30 rad	>1/30 rad
Ratio of damage IV or V	1%	1–10%	>10%
Ratio of damage III	12.5%	12.5–25%	>25%

Table 1 Damage criteria in Stage 3

4. Non-structural component checking

Inspection of non-structural components includes: framed non-structural walls, unframed non-structural walls, roof, stairs, window frames and windowpanes, finishings, elevated water tanks, chimneys, signboards, etc. Table 2 shows the damage criteria in Stage 4.

	A	B	C
Framed non-structural walls	Little or no damage	Crack observed but no out-of-plane deformation	Extensive cracks penetrated, offset from boundary members or out-of-plane deformation
Unframed non-structural walls	No damage	Slight damage	Diagonal crack observed
Roof	No damage	Some damage but no falling hazards	Noticeable inclination, deformation or separation
Stairways	Little or no damage	Extensive cracks but stair rebars are anchored	Noticeable inclination or separation from connected members
Window frames and windowpanes	Little or no damage	Visible deformation or cracks	Likely to fall down
Finishings	No damage	Partial cracks or separation	Remarkable crack and/or separation
Elevated water tanks, chimneys, signboards, etc	No inclination	Slight inclination	Likely to fall down
Other	No damage	Damage observed	Life-threatening

Table 2 Damage criteria in Stage 4

5. Determining the level of damage

The last phase is to determine the level of damage to buildings in accordance with the highest rating of structural and non-structural damage. Three main conclusions are possible on the level of damage to buildings:

(a) Inspected (aman)

In general, buildings can be categorized as inspected if there is an indication that original lateral resistance has not been significantly degraded. This building can be used by building occupants, although it should be checked for long-term use. To ensure reliability, the building should be examined in comprehensive detail in the stable phase. The building can be categorized as inspected if only "A" critieria were found in Stage 3 and only "A" and "B" criteria in Stage 4.

(b) Limited entry (hati-hati)

When buildings are categorized as limited-entry, temporary occupancy is not allowed without retrofitting to prevent damage, repairs to remove life-threatening hazards and/or barricades around hazards and striking areas. Further detailed assessment may be needed. Buildings can be classified as limited-entry if more than one "B" criteria but no "C" criteria were found in Stage 3, and more than one "C" criteria were found in Stage 4.

(c) Unsafe (bahaya)

Buildings categorized as unsafe have suffered severe damage to structural and non-structural components. Here, retrofitting to prevent emergency sudden collapse is needed, building entry and temporary use are not allowed, and a detailed assessment may be needed. Buildings are classified as unsafe if more than two "B" criteria and more than one "C" criteria were found in Stage 3.

QUICK INSPECTION RESULT

A quick inspection of the buildings damaged after the 2009 Pariaman earthquake was conducted with government-owned buildings such as offices and hospitals. The inspection was carried out in 96 buildings having 1–5 storeys. A quick inspection was conducted over one week, beginning two days after the earthquake event and focusing on the city of Padang. Rapid test results can be seen in Table 3.

Use of building	Inspected	Limited entry	Unsafe	Collapse
Office buildings	32	15	12	7
Hospitals	20	7	1	2

Table 3 Quick inspection results

Building categorized as “inspected”

In the city of Padang, out of 96 buildings checked, 52 buildings were categorized as inspected, of which 32 were government office buildings and 20 were hospitals. Damage was generally non-structural damage. Concerning the components listed in the form:

1. Damage to partition walls

Wall damage occurred in the form of cracks in wall connections with columns or beams and shear cracks in the diagonal direction due to in-plane and out-of-plane force. Figure 1 shows damage to partition walls.

Figure 1 Damage to partition walls

2. Damage to floors

Floor damage occurred to ceramic floor coverings. Damage is usually at the dilatation covered with ceramic. Figure 2 shows damage to floors.

Figure 2 Damage to floors

Building categorized as "limited entry"

Buildings that were categorized as limited entry included 22 government office buildings, of which five were hospitals and 17 were other buildings. Damage occurred to the structure and non-structural components. The typical damage included:

1. Damage to the structural columns, beams and beam-column joints.

Damage occured in the form of cracks in structural components or spalling of the concrete cover. Figure 3 shows this condition.

Figure 3 Structural damage to beams and columns

2. Damage to partition walls

Partition walls showed a fairly high level of damage in both out-of-plane and in-plane directions. Examples of this damage are shown in Figure 4.

Figure 4 Damage to partition walls

3. Damage to ceilings

Damage to ceilings included the release of the cover of the ceilings due to the use of insufficiently strong lack bolts or nails at the time of installation. This damage occured in ceilings with wood or light steel frames. In the case of light steel framed ceilings, failure did not only occur at the cover of the ceiling but also in the the connection frame or in the hanger frame of the floor plate. Figure 5 shows damage to ceilings.

Figure 5 Damage to ceilings

The defects mentioned above must be fixed before the building can be used.

Buildings categorized as "unsafe" or collapsed

Buildings categorized as "unsafe" included 12 government offices and a hospital building. At the same time, seven office buildings and two hospital buildings collapsed. Damage to buildings in this category was caused by several conditions, including:

1. Non-fulfillment of the "strong column, weak beam" principle

The "strong column, weak beam" principle must be respected in the design of earthquake-resistant structures, but the structural failure of many buildings in Padang after the 2009 Pariaman earthquake showed that this principle was ignored. Instead, the common situation found was "strong beam, weak column", where capacity and stiffness is greater for the beam than the column. In this case, buildings usually experienced quite severe damage to the column although the beam was still in one piece or only slightly damaged. Figure 6 shows examples of this condition.

Figure 6 "Strong beam, weak column"

In this case, plastic hinges should be placed on the beam, as well as a switch to column components, especially in areas close to the beam column connections. The column shown in Figure 6 suffered a stress concentration high enough to cause severe damage to the fracture, which later led to the building's collapse.

2. Short column effect near to opening

The short column mechanism was one of the common causes of damage occuring after the Pariaman earthquake. This mechanism most often occurs in columns adjacent to windows or door openings. The column's effective length is shortened to just the open height of the window adjacent to the column, while the part adjacent to the wall has added stiffness. The column, which is expected to encounter a large shear in the pedestal region, experiences a change in position of shear stress concentration towards the centre (area of opening windows) due to the reduced effective column length. Yet planned capacity at this position is generally lower shear. The high shear stress causes damage to the concrete cover columns to the point of destroying the concrete core. The location of the damaged column then becomes a weak point that can lead to the total destruction of buildings. Figure 7 shows examples of short column mechanisms that led to building collapse.

Figure 7 Short column effect

3. Lack of mass distribution and stiffness

Mass distribution between storeys can affect the stiffness of a floor. Extreme differences in mass between storeys will lead to one having less stiffness than the others so that soft storey mechanisms may occur during the earthquake. Figure 8 shows an example of this. The mass of the third floor is much larger than the first floor, which led to the building collapsing on the first floor after the earthquake.

Figure 8 Poor distribution of mass

A rigid partition on a floor may also affect differences in stiffness of a floor. The large difference can also cause the soft-storey mechanism, which is one cause of severe damage or collapse in the 2009 Pariaman earthquake. Figure 9 shows examples of buildings that collapsed due to the soft-storey mechanism.

Figure 9 Damage to buildings due to the soft-storey mechanism

4. Beam-to-column eccentricity

Adoption of Minangkabau traditional house architecture in modern high-rise buildings in West Sumatra creates new problems, particularly eccentricity of the main beam-to-column connections. This condition is prone to failure in shear and torsion if poorly planned. This problem is evident with considerable damage found in buildings that use traditional architecture after the 2009 Pariaman earthquake. Beams with eccentric main columns experience shear and torsion failure that may reduce the reliability of the building. Figure 10 shows examples of buildings that were damaged in this way.

Figure 10 Damage to beams

Stickers showing building damage

Examined buildings have a sticker placed on the front door to show the extent of damage. The stickers contain data such as: name of building, location of building, number of floors, building function, level of damage, inspectors' name and status of the building, categorized as inspected (aman), limited entry (hati-hati) or unsafe (bahaya). Figure 11 shows examples of stickers placed on examined buildings.

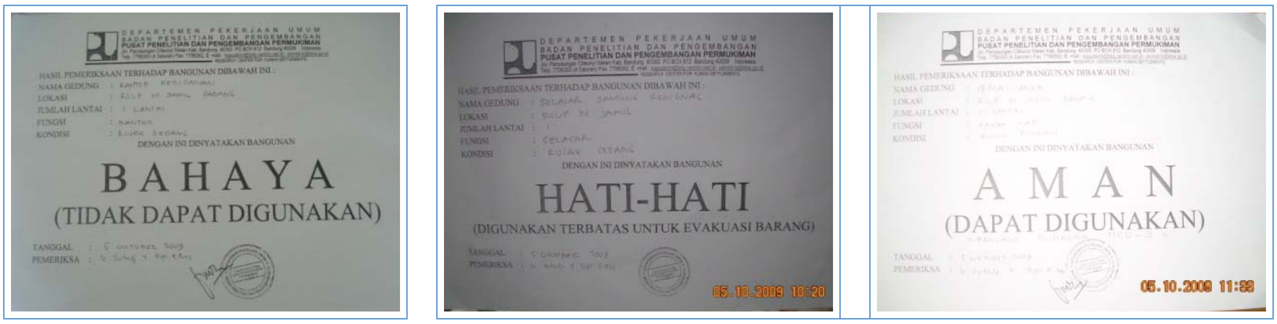

Figure 11 Stickers showing building damage

Installation of this sticker should be made to:

1. Give confidence to owners and users on the status of buildings

Users and owners often do not want to enter and use their buildings after the quake in case they collapse due to aftershocks. Yet many buildings can still be used after non-structural components are cleaned and repaired. The building status sticker helps people to feel more confident about using their buildings, especially those that have received “inspected” status.

2. Warn building users

Buildings with limited-entry or unsafe status should not be entered or used. However, users often continue to enter buildings that have experienced severe structural damage because they feel they should retrieve their belongings. With this status sticker, people know whether or not they can enter.

CONCLUSIONS

After the 2009 Pariaman earthquake, a quick inspection was carried out to determine the level of damage to 96 buildings, comprising government office buildings and hospitals in the West Sumatra Province, especially in Padang City. Stickers showing the extent of damage were fixed to buildings, enabling owners to feel confident about the safety status of their buildings.

ACKNOWLEDGMENTS

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THE MEXICAN EXPERIENCE OF POST-QUAKE RECONNAISSANCE

Oscar A. Lopez-Batiz[1] and Leonardo E. Flores[2]

[1]Subdirector of Structural Risk, National Center for Disaster Prevention, Mexico,
Email: olb@cenapred.unam.mx

[2]Researcher, National Center for Disaster Prevention, Mexico,
Email: lfc@cenapred.unam.mx

ABSTRACT

The paper describes a procedure and protocol for massively screening the structural safety of buildings, to determine both the possibility of use after a severe earthquake and vulnerability in the event future earthquakes, based on a previous scenario.

KEYWORDS

Remaining earthquake resistance, post-earthquake seismic evaluation, vulnerability evaluation.

INTRODUCTION

During the second half of the twentieth century and the first decade of this century, various procedures have been proposed to evaluate the safety level of buildings, in order to respond quickly, efficiently and safely to a major disruptive event such as an earthquake. Similar to design and construction regulations after an earthquake, the approach to reviewing building safety has changed since the first proposals in the 1960s. In addition to studying and reviewing buildings damaged by earthquake, considering the knowledge emerging from analytical research and in particular experimental studies, this research suggests a number of procedures to assess building safety, regardless of whether a disturbing event has occurred. These procedures enable a building's level of vulnerability to earthquakes of a maximum probable magnitude to be determined.

This paper considers various proposals for assessing buildings, regardless of whether they have been subjected to the effects of strong ground motion.

OBJECTIVE

Our aim is to create a single form that suits overall assessment needs in an emergency. This involves reconciling criteria to suit the greatest number of cases that may occur and inspectors with different types and levels of training. This proposal aims to provide a framework and a reference tool for the inspector (evaluator) responsible for carrying out assessment in the first instance and collecting the minimum required information to determine building safety using a systematic, uniform procedure.

BACKGROUND

There have been many proposals, surveys, evaluation forms, assessment manuals and technical papers on the inspection and assessment of the structural safety of buildings, especially before the occurrence of seismic events. Typically, authorities and professional groups representing disaster victims have designed, adapted or adopted a number of forms and questionnaires to assess the damage and structural safety of buildings. This data is used in the first instance to identify severely damaged buildings for evacuation and to prohibit or restrict their use. It is also used in databases for estimating overall losses and for resource planning.

While there are already many proposals, manuals and related questionnaires or evaluation forms, they do not all contain all the required information. In most cases, they are too short (half a page), and in a few cases, they are very extensive and difficult to use in emergency situations (e.g. a questionnaire of 10–20 pages or more). Moreover, the required data may cover other aspects (e.g. legal or financial aspects or damage to finishes) and even omit structural damage.

Some questionnaires are well designed but require additional information. Therefore, the National Center for Disaster Prevention in México (CENAPRED), as a technical institution of the Ministry of the Interior, was tasked with coordinating the development of technical procedures for assessing the safety of buildings as part of a general strategy for earthquake disasters, entitled "The Earthquake Plan".

FORM DESIGN

To design a form for structural assessment, a series of documents, manuals and various forms were reviewed and in particular, the general outline of the work of Rodríguez and Castrillón (1995) and the Mexican Society of Seismic Engineering (SMIS, 1998), as well as the following documents and forms (all in Spanish):

- Standard for assessing the level of earthquake damage to structures and technical guide for rehabilitation (Jumonji, 2001), National Center for Disaster Prevention
- Form for the inspection of structures, National Center for Disaster Prevention, August 2007
- Form for housing typology (Flores et al, 2006), National Center for Disaster Prevention
- Form for seismic performance evaluation of existing hospitals, Acapulco Minutes (Hospitals), National Center for Disaster Prevention
- Opinion technical assessment of buildings, Federal District General Secretariat of Works
- Form for damage inspection, UNAM Engineering Institute
- Forms for post-seismic inspection: Rapid Assessment and detailed evaluation, College of Civil Engineering of the State of Colima AC, 2003
- Evaluation of post-earthquake damage to physical infrastructure, General Directorate of Civil Protection, National System of Civil Protection, March 2010
- Protocol inspection department, Survey of the Mayor of Providencia, Santiago de Chile
- Damage assessment form, Department of Architecture, Ministry of Public Works in Chile, February 2010, Santiago de Chile
- Inspection and testing of buildings to determine their structure and capacity under seismic action, Oscar de la Torre Rangel

We decided to include as much information as possible in the smallest space, using the entire page. One key consideration for the final format was easy, economical reproduction on paper. It was suggested that the page should be the letter-size paper (21.6 cm × 28 cm) commonly used in Mexico, which is easy to print from a digital file or photocopy in shops, and more manageable than the legal size. The form would include an extension of one, two or four pages.

The form for detailed (Level 2) inspection was produced on three pages and a free page with a grid of thin lines for adding sketches or diagrams of the building, details or notes.

The size and style of the text was kept simple and legible, to take into account the use of mediocre-quality photocopies and black and white prints. Charts were included to clarify important concepts.

Another important consideration in form design was keeping data collection as concise as possible. Instead of entering free text, the inspector is asked mostly to check one or more boxes, or to write concise numerical data (number of floors, distance between columns, etc.).

The purpose of gathering data in a more objective way is to be able to feed the data into a database after the inspection work, whether each inspector does so at the end of the day, sends the data by email to the data collection centre, or delivers it on paper to a team of people entering data into the computer system. A variant in the near future could be a web-based form, enabling information to be captured by inspectors directly using laptops or handheld mobile devices, and sent in real-time over a wireless connection.

A multiple-choice questionnaire enables easy data capture and analysis, especially when considering that a may disaster may require hundreds or thousands of forms to be processed within a few hours.

A proposal has already been made for automatic data capture using an Excel spreadsheet. Finally, like the algorithm developed to perform quantitative analysis of the structural safety of buildings, the assessment form includes most types of systems and structural materials commonly used in Mexico. This form is showed in Figure 1.

NATIONAL NETWORK OF INSPECTORS (RENE)

A fundamental part of Mexico's earthquake plan is the creation of a database of civil engineering and architecture professionals who can join a group of inspectors in the event of a large-scale disaster. These members must have in-depth knowledge of the use and scope of the form for structural assessment, for which a manual has been prepared. In addition, inspectors must follow training with courses of varying scope and duration (from 1–2 hours up to 20 hours) and inspection levels (Level 0, 1 or 2), depending on the required specialization and detail in assessing the structural safety of buildings.

To this end, four inspection levels have been proposed, depending on the required depth and detail for the evaluations: three main levels (Levels 1–3) and a more basic Level 0. Figure 2 outlines the different assessment levels serving two basic objectives: 1) emergency post-quake analysis after a earthquake of great magnitude and damage potential, and 2) analysis of the vulnerability of existing buildings to mitigate the impact of major earthquakes in the future.

FORM FOR STRUCTURAL ASSESSMENT

February-2010

Date: | Time: | Duration: | Bldg code:

Inspector name: Engineer or architect: ☐ Student ☐ Graduate ☐ Other

GENERAL INFORMATION OF PROPERTY

Property name:

Building/division/area name: *(one form for each building/division/area)* Coordinates: (___________ , ___________ , _____ msnm)

Street and No.:

Suburb/neighborhood: ZIP Code:

Locality *(town/city)*:

District/Municipality/County: State/Province:

Points of reference: *(between streets "A" & "B", notable site, etc.)*

Owner / contact person: Responsibility of contacted person:

Phone number: +( ) Fax: E-mail:

BUILDING USE *(Give % area for each use, must sum 100%)*

1- Housing: ☐ One-family ☐ Multifamily ☐ Hotel ☐ Dormitory

3- Educational: ☐ Kinder ☐ Elementary ☐ High school ☐ University ☐ Library ☐ Museum

5- Meeting: ☐ Social center ☐ Church ☐ Gym ☐ Dance hall ☐ Cinema/Theater/Aud. ☐ Stadium

7- Communication and transportation: ☐ Passengers terminal ☐ Cargo terminal ☐ Parking place ☐ Airport / Harbour ☐ Mail / Telegraph/ Telephone ☐ Radio / TV ☐ Communication antenna

Importance GROUP: ○ A ○ B1 ○ B2 ○ C

2- Offices/ Trade: ☐ Offices ☐ Shoping ☐ Market ☐ Restaurant

4- Health /Social: ☐ Hospital ☐ Clinic ☐ Retirement home ☐ Nursery

6- Industrial: ☐ Factory ☐ Workshop ☐ Store ☐ Electric generation ☐ Combustible station

Other ☐ ____________________

Occupancy status: ☐ Occupy/in use ☐ Abandon/not occupy ☐ Not used by damages Number of occupants or people capacity: _________

LAND AND FOUNDATION

Topography: ☐ Flat terrain ☐ Hillside ☐ Riverside ☐ Valley ☐ Lake deposits ☐ Coastline

Subsoil type: ☐ Very soft clay ☐ Fine soil (clay / lime) ☐ Loose granular ☐ Compact granular ☐ Rock

SOIL: ○ Soft ○ Intermediate ○ Hard

Superficial (sallow): ☐ Single-column footing ☐ Continuous strip footing ☐ Stone footing ☐ Slab ☐ Mat foundation

Deep foundation: ☐ Pile ________ ☐ Other ________

subsoil water level: ________m Terrain slope: ________% Distance to lake / river / sea: ________m

STRUCTURE CHARACTERISTICS

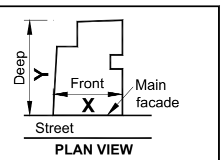
No. of stories, n = ________ Construction year: ___________

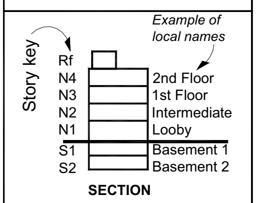
No. of basements: ________ Rehabilitation year: ___________

☐ Roof appendix (*staircase / elevator*)
☐ Mezzanine (*intermediate slab*)
☐ Slab level at middle of type-stories
☐ External staircase
☐ Street level at the middle of first basement

Total property area: ___________ m²
Green area (rain infiltration): ________ %
Average-story area: ___________ m²

General Dimensions:
X = Front: ________ m
Y = Deep: ________ m
First story (N1) height: ________ m
Average-story height: ________ m
No. of parking places:________ .
No. Elevators:________ .
No. different staircase:________ .





Facilities
☐ Elevator ☐ Electrical
☐ Drinking-water ☐ Waste water
☐ Gas ☐ Other: ____________________

<<logos of institutions>>

Figure 1 Form for data capture

VULNERABILITY

Location in block: ☐ Corner ☐ Middle ☐ Aisle

Plan irregularities
- ☐ Asymmetric (storey torsion)
- ☐ Floor openings > 20 % *(length or area)*
- ☐ Concave perimeter line > 20 %
- ☐ "L" plan or another irregular shape

Vertical irregularities
- ☐ Soft story
- ☐ Frames or walls don't reach foundation
- ☐ Short columns
- ☐ Area reduction in upper floors
- ☐ Foundation at different level (in hillside)
- ☐ Inclined floor systems
- ☐ Higher weights in upper floors
- ☐ Random opening pattern in facade

Another vulnerability sources
- ☐ Eccentric beam-to-column joint
- ☐ Weak col-strong beam
- ☐ Inverted pendulum/only one line of columns
- ☐ One element resist more than 35% of EQ

Critical next-building

No. of storyes: ____________
Gap separation : __________ cm
Use no: ☐ : ________________

- ☐ Frames ☐ No damage
- ☐ Walls ☐ Medium damage
- ☐ Other ☐ Severe damage
- ☐ Different slab level

STRUCTURAL SYSTEM

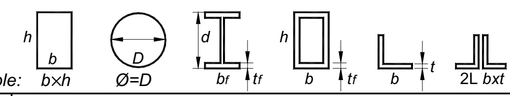
Material in walls
- ☐ Reinforced concrete (RC)
- ☐ Precast concrete
- ☐ Solid concrete block
- ☐ Concrete block *(20x40 cm)*
- ☐ Solid clay brick
- ☐ Hollow clay brick
- ☐ Panels covered with mortar
- ☐ Wood
- ☐ Stone
- ☐ Adobe
- ☐ Bahareque *(branches/mud)*
- ☐ Weak material *(metal sheet/cardboard/waste)*
- ☐ Other: ____________

Reinforcement in masonry walls
- ☐ Unreinforced *(plan)*
- ☐ Confined masonry
- ☐ Poorly confined masonry *(no reinforced around openings)*
- ☐ Interior reinforced
- ☐ Other: ________________

Shape in predominant elements

	Shape: Rectangular	Circular	Circular pipe	H / I Section	Box	L Section	Truss	Material: Concrete	Steel	Precast	Wood	Section
Columns	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	________
Main Beams	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	________
Secundary Beams	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	________
Bracing *(diagonals)*	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	________

Example:



MAIN VERTICAL STRUCTURE

		First story X	First story Y	Average story X	Average story Y	Basement	Apendix	Vertical access *(stairway / elevator)*
Frames	Steel	☐	☐	☐	☐	☐	☐	☐
	Concrete	☐	☐	☐	☐	☐	☐	☐
	Precast concrete	☐	☐	☐	☐	☐	☐	☐
	Flat floor & columns	☐	☐	☐	☐	☐	☐	☐
	Wood	☐	☐	☐	☐	☐	☐	☐
Braced	Steel	☐	☐	☐	☐	☐	☐	☐
	Concrete	☐	☐	☐	☐	☐	☐	☐
	Several stories	☐	☐	☐	☐	☐	☐	☐
	Cables	☐	☐	☐	☐	☐	☐	☐
Walls	Load bearing, masonry	☐	☐	☐	☐	☐	☐	☐
	Infill, masonry	☐	☐	☐	☐	☐	☐	☐
	Concrete walls	☐	☐	☐	☐	☐	☐	☐
	with coupling beams:			☐	☐			

Frame in typical story

Number of frames paralel to: X:________ to Y: ________
Average span: X =________m Y = _______m
Total number of columns: ________ *(in the story)*
Num. of braced spans: at X:________ at Y:_______
Num. of infill wall spans: at X:________ at Y:_______

Walls in typical story

Sum of wall length, and thickness (t):
Concrete walls: ΣLx =_______m, ΣLy = _______m, t = _____cm
Masonry walls: ΣLx =_______m, ΣLy = _______m, t = _____cm

FLOOR / ROOF SYSTEM

Floor System
- ☐ Two-way slab
- ☐ Flat slab *(no beams)*
- ☐ Beams and floor of wood
- ☐ Beams and clay brick deck *(Catalan vault)*
- ☐ Beams, joist (rafter) and deck
- ☐ Trusses and deck
- ☐ 3D Truss
- ☐ Masonry arc

Distance between axes of:
Secundary beams: ______cm
Beams, joists or ribs : _______cm
Rafters/stringers: _______cm

Reinforced Concrete Slab
- ☐ Solid
- ☐ Grid slab *(two-way joist)*
- ☐ Precast, concrete system
- ☐ Precast joist slab *(one-way)*
- ☐ Composed metal sheet and concrete cover

Total slab thickness: _____ cm
Solid cover thickness:_____ cm

Trusses
- ☐ Steel ☐ Wood
- ☐ Variable depth

Span:_____m, Tot. depth:_____m
Trusses separation:_____m
Shape of cords:__________
shape diagonals:__________

Roof Deck
- ☐ Same as floor system
- ☐ Corrugated metal sheet
- ☐ Asbest / plastic sheet
- ☐ Cardboard
- ☐ Panels
- ☐ Wood
- ☐ Grass
- ☐ Clay tile

Deck Geometry
- ☐ Flat and horizontal
- ☐ Inclined, slope = _____%
- ☐ Cilindric vault Ø=_____m
- ☐ Spherical dome Ø=_____m

Fastener type and separation: ______________________________

Plans: ☐ Architectural ☐ Structural ☐ Design documentation ☐ Self-build (no design) Specify: ______________________

REHABILITATION

Type
- ☐ Architectonic
- ☐ Repair
- ☐ Strengthening
- ☐ Restructuring

Used techniques
- ☐ New Foundation
- ☐ Concrete jacketing
- ☐ Steel jacketing
- ☐ Wall mesh and mortar
- ☐ Add braced
- ☐ Add concrete walls
- ☐ Add masonry walls
- ☐ External buttress
- ☐ Carbon fiber jacketing
- ☐ Other

Brief description:

2/3

Figure 1 (cont.). Form for data capture

DAMAGE ASSESSMENT

Geotechnical problems

- ☐ Cracks in surrounding terrain
- ☐ Differential settlements
- ☐ Land slide
- ☐ Socavation or Erosion
- ☐ Soil liquefaction
- ☐ Settlement (-) or uplift (+) general = _________ cm
- ☐ Building inclination: _________ %

Structure

- ☐ **Collapse**

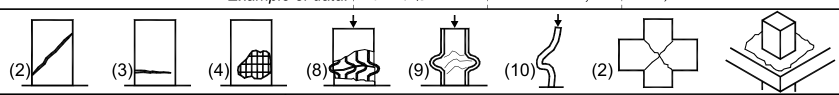
Parcial collapse

- ☐ Roof
- ☐ First story
- ☐ Other story
- ☐ magnitude ______ %
- ☐ Building pounding

Maximum visible damage

Give story key (N1, N2, ..., S1...)

Type and characteristics	Columns	Beams	Walls: masonry	Walls: concrete	Bracing	Beam-column Joints
1- Collapse / general damage	☐	☐	☐	☐	☐	☐
2- Inclined cracks (*shear cracks*)	☐ ______mm	☐ ______mm	☐ ______mm	☐ ______mm	☐ ______mm	☐ ______mm
3- Normal to axis cracks (*flexion cracks*)	☐ ______mm	☐ ______mm	☐ ______mm	☐ ______mm	☐ ______mm	☐ ______mm
4- Concrete crushing and exposed reinf.	☐	☐	☐	☐	☐	☐
5- Fracture of longitudinal reinforcement	☐	☐	☐	☐	☐	☐
6- Fracture of transversal reinf. (hoops)	☐	☐	☐	☐	☐	☐
7- Compression bar buckling	☐	☐	☐	☐	☐	☐
8- Plate buckling	☐	☐	☐	☐	☐	☐
9- General buckling	☐	☐	☐	☐	☐	
10- Wedge failure	☐	☐			☐	☐
11- Fasteners failure (screw/ribets)	☐	☐			☐	☐
12- Steel corrosion	☐	☐	☐	☐	☐	☐
Reinforcement (for concrete section)	______	______	______	______	______	______
Distance between hoops / stiffeners	______cm	______cm	______cm	______cm	______cm	______cm
Shape	______	______	______	______	______	______
Example of data:	*b×h / Ø*	*b×h / d×bf,tf*	*t, hc×bc*	*t*	*b×h / d×bf,tf*	*b×h*



Roof / floor system

- ☐ Collapse
- Cracks:
  - ☐ around columns
  - ☐ midspan
  - ☐ on beams
  - ☐ slab corners
- thickness: _________ mm

Porcentage of damaged elements at critical story

	Severe	Moderate	Story key
Columns	☐	☐	☐
Beams	☐	☐	☐
Concrete walls X	☐	☐	☐
Concrete walls Y	☐	☐	☐
Masonry walls X	☐	☐	☐
Masonry walls Y	☐	☐	☐
Bracing	☐	☐	☐
Beam-column joints	☐	☐	☐

	Severe damage	Moderate
Columns, beams concrete walls	Collapse Shear cracks > 2 mm Flexion cracks > 5 mm General buckling Plate buckling Reinforcement buckling or fracture	> 1 mm > 2 mm
Masonry	Shear cracks > 5 mm Inclined cracks in tie-column	> 2 mm ---

NON STRUCTURAL DAMAGE

Exterior

- ☐ Windows
- ☐ Structure for publicity
- ☐ Ornaments
- ☐ Facade
- ☐ Balcony
- ☐ Parapets
- ☐ Water deposits
- ☐ Fence wall
- ☐ Others:___________

Interior

- ☐ Partition walls
- ☐ Ceilings
- ☐ Lamps
- ☐ Stairways
- ☐ Elevators
- ☐ Line services (Gas, Elec., Plumb...)
- ☐ Chemical substances

Drawings

(Locate North direction) N

3/3

Figure 1 (cont.). Form for data capture

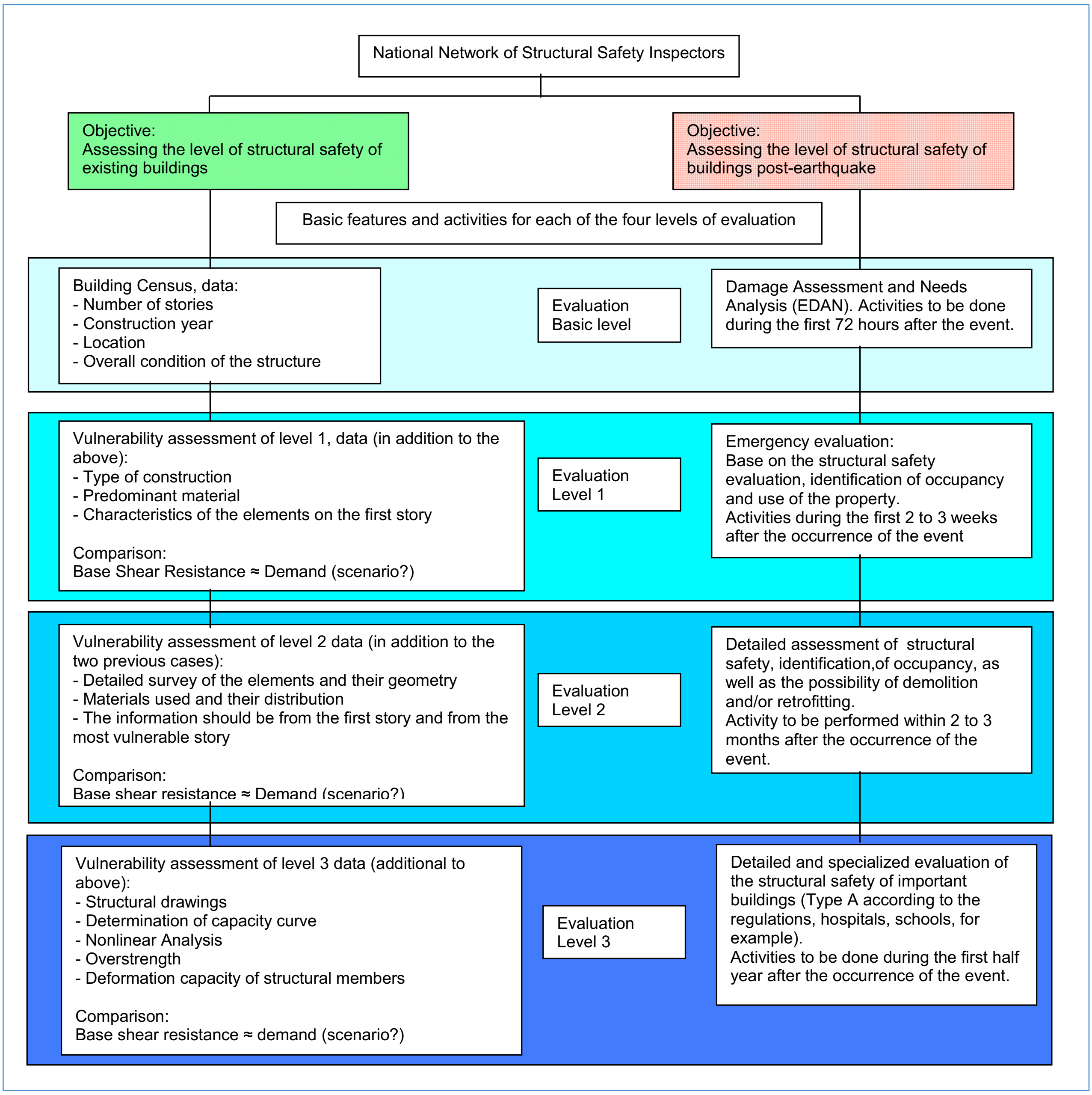


Figure 2 Global technical response network for natural disturbance events

Response procedure

1. The General Coordination of Civil Protection, through a letter of invitation sent to local universities and professional associations (engineers and architects), in conjunction with the local Management of Civil Protection, has asked professionals to join the National Network of Structural Safety Inspectors (RENE), in accordance with the requirements for the different levels of assessment.

2. Once the RENE participants have been identified, CENAPRED staff will conduct a training course. At the end of the course the participants will replicate the training for other localities and municipalities within the state.

3. A response protocol has been proposed to identify the level of structural safety of existing buildings, as well as their structural stability following a disruptive event causing damage and requiring an assessment of urban infrastructure. This protocol is shown in Figure 3.

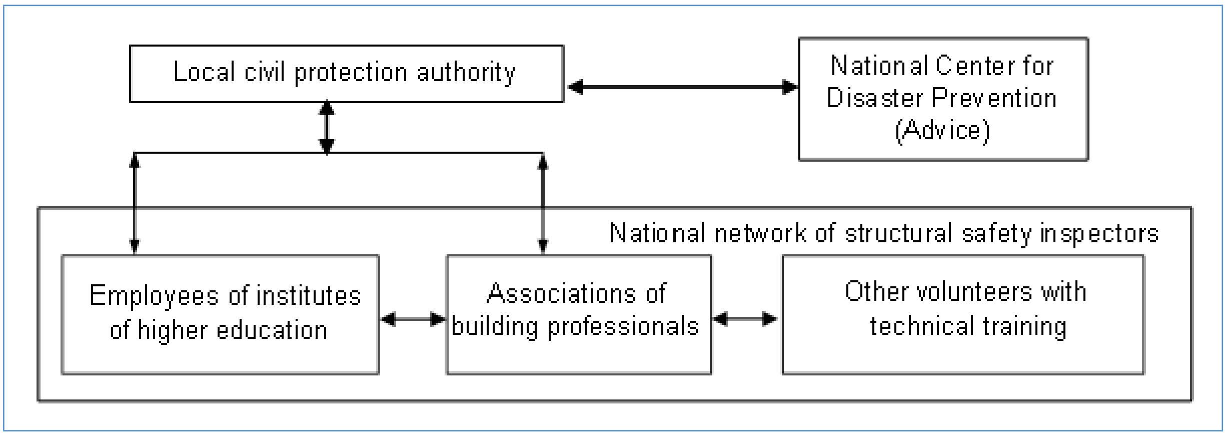


Figure 3 Scheme of the protocol of response for RENE

4. Based on survey information, the National Center for Disaster Prevention (CENAPRED), obtains the results for structural safety and/or vulnerability. These results are obtained using an algorithm of the first approach on structural safety levels. These assessment processes can be carried out in the same locations.

PREPARATIONS FOR FIELD INSPECTIONS OF STRUCTURES

Usually, structural assessment requests are filed after moderate to severe earthquakes. The use of human and material resources should then be weighed against the various priorities that require attention. Similarly, the inspected elements must be defined carefully in order to generate uniform data.

In the case of visiting a disaster zone, generally there is no specific plan at the beginning, but after arriving at the site, the inspection team must identify which structures or areas have been affected and make a tour of the damaged structures. This is the case for a moderate or severe event, where the process starts automatically according to the severity of damage, without requiring official notification.

There are two levels of preparation for conducting a structural review visit: 1) permanent provisions, and 2) preparations just before each visit. It is suggested that the following measures and equipment be available permanently:

- Technical and support staff (e.g. students) who can lead the inspection, and a team leader or manager (usually a member of RENE), all of whom should be familiar with the form, manual and other documents before emergencies
- Logistical support for the prompt designation of vehicles, economic resources and other support for emergency trips
- Sufficient photocopies of the form for structural assessment to meet the potential demand for inspections: normally 10–20 forms should be sufficient per day since each building can be reviewed in 0.5–2 hours depending on the size, complexity and level of damage presented
- Helmets, flashlights, shoes suitable for walking on rubble, a compass, measuring tapes and maps of the country and major citiesy maps of major cities.
- High-resolution digital cameras with flash for capturing closer details or for indoor pictures (at least 2 megapixels) and, in some cases, video cameras

In addition, specific equipment must be prepared for field trips:

- Map of the region where the visit will take place, with the route identified
- Data on the person or authority to contact
- Special shoes for walking on rubble or difficult areas
- Flashlight with good batteries

- Cracking measure and tape measure (5 m or longer)
- Clipboard to write on the form
- Form for structural evaluation and additional sheets for diagrams or notes

EVALUATION ALGORITHM

Assessment procedures, such as the simplified processes associated with Levels 0–1, are based on quantitative determination, using simple and generally conservative procedures, of the lateral resistance of structural systems in the first storey (base shear force). For example, with moment-resiting frame systems in structural walls, resistance is determined by considering a shear mechanism in the first storey. The calculated resistance value is compared directly with the base shear force demand obtained from a predefined scenario earthquake, or the value of base shear resistance according to current regulations applicable to the study site. This is summarized as:

Lateral resistance (base shear) < base shear force demand (1)

In the case of the Levels 2–3, the evaluation process requires accurate information on the geometry of structural elements and reinforcing steel bars in concrete or masonry structures. Based on this, the buildings' capacity curves and lateral resistances are obtained to compare with base shear force demand from the scenario or current regulations.

To estimate the remaining strength and deformation capacity of buildings assessed after a severe earthquake, information is used from experimental research to establish a relationship between the level of observable damage and remaining strength, as shown in Figure 4.

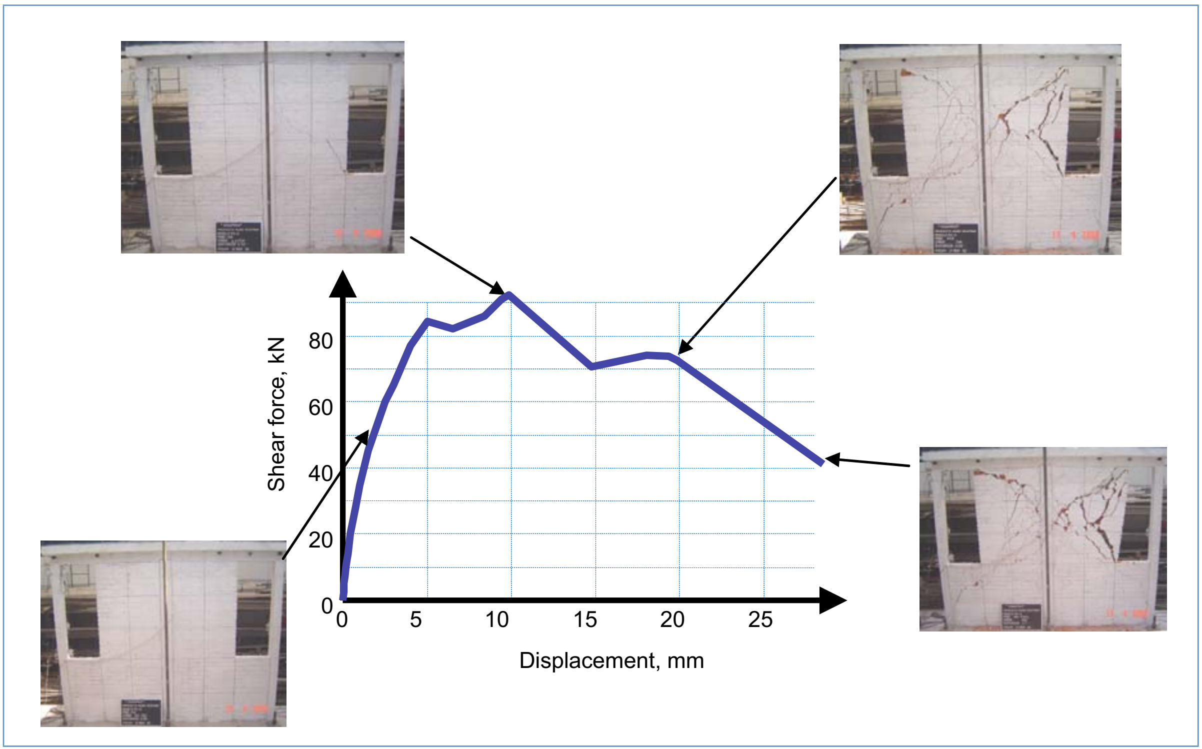


Figure 4 Relationship between observable damage and remaining strength

Based on the information and concepts above, criteria and benchmarks are established, as indicated in Figure 5. This information is necessary to define the remaining strength and therefore the structural safety of buildings.

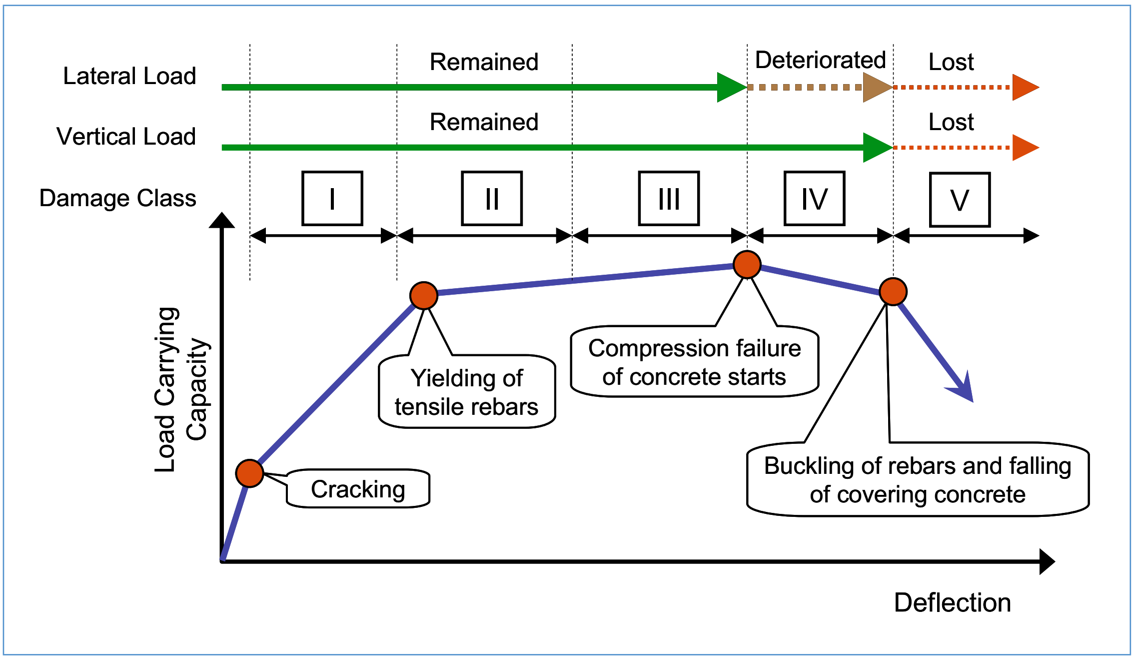


Figure 5 Relationship between observable damage and remaining strength

The remaining strength of the entire structural system can be determined, based on the resistance of individual structural elements, taking into account resistance deterioration due to irregularities in plan and/or elevation, as well as the location of the damaged elements within the structure.

CONCLUSIONS

To respond to a social need and take into account studies and research from the last three decades in Mexico and worldwide, a general approach has been taken to collect information on buildings in order to evaluate their remaining strength after a severe earthquake or assess the level of expected damage (vulnerability) in an intense earthquake scenario.

The procedure proposed in this paper is based on the following precepts:

- Uniform criteria and coordinated cooperation between CENAPRED, academics and government teams are necessary for post-earthquake inspections.
- Mexico is developing the necessary technical resources in terms of a form, a manual and training courses.
- A global strategy must be developed for all countries facing seismic hazards.

ACKNOWLEDGEMENTS

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SEISMIC PROTECTION AND PREVENTION OF THE DEMOLITION OF BUCHAREST HERITAGE BUILDINGS

D. Lungu, C. Arion, A. Aldea and R. Vacareanu

Technical University of Civil Engineering, Bucharest, Romania, 124 Lacul Tei, Bucharest, Romania
Email: arion@utcb.ro

ABSTRACT

This paper presents: (1) a history of earthquake damage and learned lessons, (2) the reinforcement of fragile tall reinforced concrete buildings in central Bucharest, (3) international projects for seismic risk reduction in Romania and (4) present-day challenges for the conservation of Bucharest heritage buildings.

KEYWORDS

Romania, earthquakes, Vrancea, damage, protection, heritage buildings

INTRODUCTION

With more than 2 million inhabitants, a population with a mean density of about 11,000 persons per km2 and more than 110,000 buildings, Bucharest can be ranked as the megacity with the highest seismic risk in Europe due to (1) soft soil conditions in Bucharest characterized by a long predominant period (1.4 ÷ 1.6s) of ground vibration during the strong Vrancea earthquakes and (2) the considerable fragility of tall reinforced-concrete buildings built in Bucharest before the Second World War and before the 1977 Vrancea earthquake disaster. The Vrancea region, located at the bend of the Carpathians Mountains Arc, at an epicentral distance of about 130 km from Bucharest, is a source of subcrustal seismic activity, which affects more than two thirds of the Romanian territory and an important part of the Republic of Moldova, Bulgaria and Ukraine. The city is located in the Romanian Plain, between the Danube and the Carpathian Mountains, in the meadow area of two rivers, Colentina and Dambovita, which cross the city from northwest to southeast.

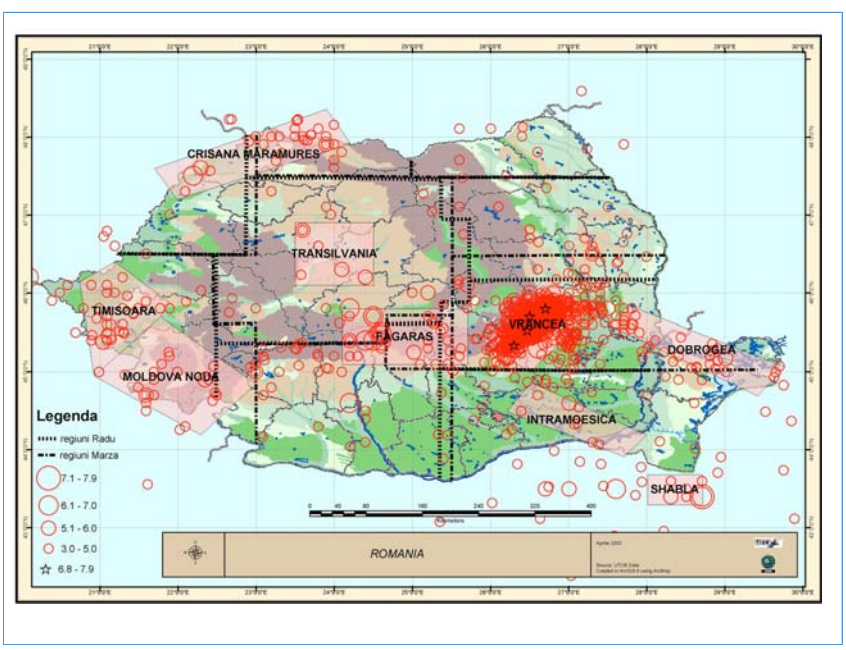


Figure 1. Romania: location of seismic regions and epicentres from 984 to 2003

Bucharest is the capital city of Romania and the country's main administrative, economic and cultural centre.

The first written record of the city comes from the fifteenth century. Placed at a confluence of civilizations, Bucharest has assimilated European and Oriental influences, displaying a natural capacity for integration that has supported its vocation as a city between the Eastern and Western worlds.

BUILDING DAMAGE DURING MAJOR HISTORICAL EARTHQUAKES

1802 earthquake

The 26 October 1802 earthquake (MG-R = 7.4 ± 0.3) is considered to be the strongest Vrancea subcrustal event. No precise information is available on causalities, although there is some on damages.

During the 1802 earthquake, many bell and church towers collapsed in Bucharest and several churches were destroyed there, including the Cotroceni monastery and Saint Spiridon Church. Half of Coltea tower collapsed and the remainder was seriously damaged (Figure 2). Most wealthy residences were heavily damaged and some collapsed. In Brasov, many chimneys collapsed, and houses and churches were damaged. The earthquake was felt in Transylvania, Sibiu, Sighisoara and Banat in Timisoara, as well as in Poland, Bulgaria, Turkey and Russia. In Cernauti, some houses were damaged. In Lvov, the Armenian church cracked and the bells rang by themselves, while light damage occurred even in Moscow.

Figure 2. Coltea Tower (photo © Szathmary, 1869)

1829 earthquake

"On Wednesday night […] a strong earthquake happened in our capital, […] no house in Bucharest remained without damage; all walls were cracked and in some cases fell down; rooves and chimneys were destroyed", Curierul Român, Bucuresci, No.15/27 November 1829.

During the earthquake of 26 November 1829 (Ms = 6.9), Bucharest suffered the most, with documents indicating that 115 houses became unsafe, 15 of which were heavily damaged and later demolished. In

Campina, a church collapsed. In Sibiu and Lasi, many walls were cracked. The earthquake was felt across a large area: Transylvania, Banat, Bulgaria, Poland and Ukraine.

1838 earthquake

The following description of the effects of 1838 earthquake effects in Bucharest was given in Travels in Southern Russia and The Crimea: Through Hungary, Wallachia and Moldova, by M.A. Démidoff: “Every year the soil of Wallachia receives two or three shocks of earthquake, of greater or less violence, and every ten years really disastrous effects unfortunately occur from this visitation. The earthquake of 1802, which overthrew the monastery of Koltza, is still remembered, as well as that of 1829, which violently shook the majority of buildings in Bukharest. Since this was written, a more violent shock than any yet remembered with sorrow in the country, very nearly destroyed Bukharest. On the evening of the 23rd of January, 1838, the city shook, the most solid monuments tottered, several houses fell to ruins ; all were damaged, and several individuals lost their lives”.

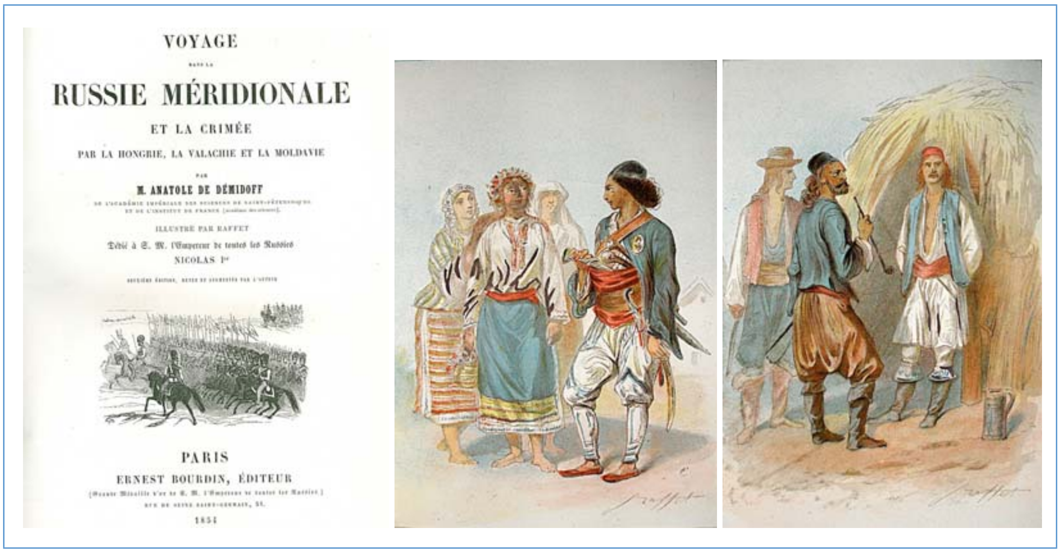


Figure 3 Travels in Southern Russia and The Crimea: Through Hungary, Wallachia and Moldova, M.A. Démidoff (Paris, 1841)

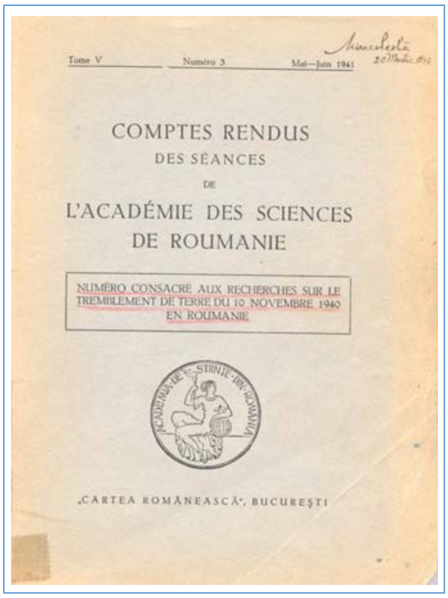
In Bucharest, the police report mentioned 8 deaths, 14 injuries and 36 collapsed buildings. Many other buildings were heavily damaged, especially the larger ones, including the Royal Palace.

The engineer Gustav Schuller, advisor to the Grand Duke of Saxa in Romania at the time, was asked by the Romanian Government to investigate the epicentral area. He indicated a maximum intensity of IX in the area of the Vrancea mountains, Focsani and Ramnicu Sarat, where many villages had been completed destroyed. Schuller concluded that “all the stone masonry buildings were heavily damaged and some of them became unusable, especially the churches and other large buildings.”

The earthquake was felt across an extended area in Europe: from Ukraine, Poland and Bulgaria to Constantinople and northeastern Italy.

1940 earthquake

“On 10 November 1940, an earthquake caused damage throughout Romania and threw people into mourning” (Comptes Rendus des Séances de l’Académie des Sciences de Roumanie, 1941).



Tome V Numéro 3 Mai—Juin 1941

COMPTES RENDUS
DES SÉANCES
DE
L’ACADÉMIE DES SCIENCES
DE ROUMANIE

NUMÉRO CONSACRÉ AUX RECHERCHES SUR LE TREMBLEMENT DE TERRE DU 10 NOVEMBRE 1940 EN ROUMANIE

„CARTEA ROMÂNEASCĂ“, BUCUREŞTI

Figure 4 Comptes Rendus des Séances de l’Academie des Sciences de Roumanie (1941)

Figure 5 The Carlton building in Bucharest, which collapsed during the 1940 earthquake

In Bucharest, the most significant loss was the complete collapse of the famous Carlton building, the highest reinforced-concrete building (47 m, 12 storeys) in Romania at the time. Between the earthquake and 24 November, 136 people were found dead in the rubble of the building. Several high-rise reinforced-concrete buildings in Bucharest were very severely damaged: the Belvedere, Wilson, Lengyel, Pherekide, Brosteni and Galasescu. Other important Bucharest buildings suffered important damage: the Justice Palace, Romanian Atheneum, Opera, National Theatre, CEC Bank, and Postal Palace.

Two zones of maximum seismic intensity were identified: one in the Focsani and Panciu area and one in the area from Campina to Bucharest. There, the seismic intensity was close to IX on the Mercalli–Sieberg scale. In Panciu, no buildings were left standing after the earthquake (Timpul newspaper, 12 November 1940).

In Lasi, every building was damaged, the City Hall presented large cracks and the Faculty of Medicine became unusable.

Since the earthquake was a deep event (about 140 km) it was felt on a radius of about 2 million km2: to the east in Odessa, Cracovia, Moscow, to the north up to Saint Petersburg, to the west up to Tissa river, and to the south up to Istanbul.

1977 earthquake

The earthquake on March 4, 1977 (Gutenberg Richter magnitude MG-R = 7.2, moment magnitude Mw= 7.5) was the most destructive in Romania’s history. This earthquake:

- Killed 1,578 people including 1,424 in Bucharest
- Injured 11,221 people including 7,598 in Bucharest and 3,723 in the rest of the country

- Destroyed or seriously damaged 33,000 housing units in high-rise apartment flats and conventional-type dwellings (35,000 families and more than 200,000 persons homeless)
- Caused lesser damage to 182,000 other dwellings
- Destroyed 374 kindergartens, nurseries and schools and badly damaged 1,992 others
- Destroyed 6 university buildings and damaged 60 others
- Destroyed 11 hospitals and damaged 2,288 other hospitals and 220 polyclinics
- Damaged almost 400 cultural institutions (theatres, museums, etc.)
- Damaged 763 factories
- Directly affected more than 200,000 people (Fattal, Simiu, Culver, 1977)

Figure 6 Typical collapse of pre-war tall reinforced-concrete buildings

International experts dispatched to Romania in the aftermath of the earthquake reported as follows:

(i) The Wilson building, buit in the 1930s (ii) The Lizeanu building, built in the 1960s

Figure 7 Soft-storey collapse of the building at ground level

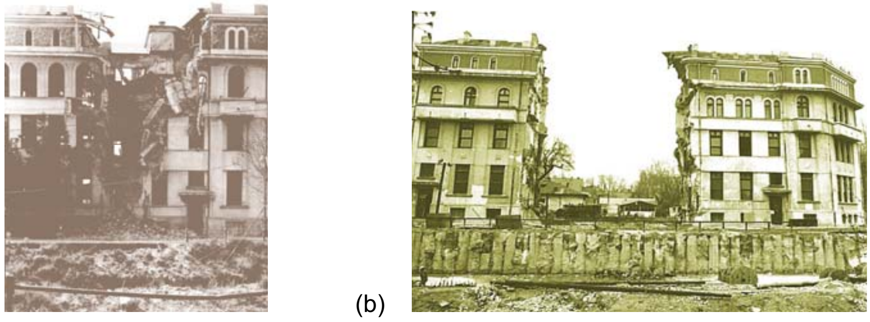


Figure 8 Bucharest, 4 March 1977: heavy damage to two University buildings built at the end of the nineteenth century. (a) Effect of bombing during the Second World War – (b) 1977 earthquake impact on the Faculty of Chemistry (photo © UTCB D. Lungu)

"The unusual nature of the ground motion and the extent and distribution of the structural damage have important bearing on earthquake engineering efforts in the United States." Jennings & Blume, NRC&EERI, Washington.

"It was felt on an area of 1.3 million km and caused damage over an area of about 80,000 km2 within which the most frequently occuring intensity did not exceed VII (MM). Much of the damage was caused to old reinforced-concrete buildings of 6–12 storeys. These structures have a fundamental period of 0.7–1.6 s, which places them on the ascending branch of the Bucharest spectrum. Progressive damage during the earthquake should have caused a lengthening of their period and an increase in the lateral forces acting on them. In contrast, little damage was experienced by rigid structures of large panel or frame construction with shear wall, of the same height, as well as 1–3 storey masonry dwellings." (Ambraseys, N.N., 1977)

"About 108 people died and three multistorey reinforced-concrete apartment buildings (having natural period of vibration of 0.8–0.9 s) collapsed completely in the town of Svistov, northern Bulgaria, approximately 270 km to the south of the epicentre."

(S.S. Tezcan, V. Yerlici and H.T. Durgunoglu, 1978).

VULNERABILITY OF BUILDINGS IN CENTRAL BUCHAREST

Reasons for Vulnerability

The explanation for the city centre location of the most fragile or vulnerable tall reinforced-concrete buildings in Bucharest as well as 29 (of 32) tall reinforce-concrete buildings that collapsed during the 1977 earthquake comes from the Urban Development Plan issued in 1935 by the Municipality of Bucharest. The plan recommends the city centre for the tallest buildings (i.e. buildings with 6–7 full storeys plus 2–3 setback storeys, with a roof height smaller or equal to street width). The collapse of buildings in the centre of Bucharest is clearly explained by the lack of mass vertical-symmetry, lack of structure horizontal-regularity, accumulated damage during the 1940 earthquake, low-strength concrete (mean compressive strength of ≤200 daN/cm2), soft ground floor due to commercial use (no in-filled masonry walls) and dynamic characteristics. Presently, 127 tall reinforced-concrete buildings built before the Second World War were randomly identified by authorities and structural engineers as "Seismic Risk Class 1" buildings (i.e. buildings likely to collapse or be very severely damaged during the next earthquake similar or larger to the 1977 event, as shown in Figure 9). The number of fragile high-rise reinforced-concrete buildings in the centre of Bucharest is probably double the existing number of buildings identified as Seismic Risk Class 1, as many of the most vulnerable buildings in the city centre are still not yet identified as being very vulnerable. In spite of the high cost of adequately retrofitting the fragile reinforced-concrete high-rise buildings located in the centre of Bucharest, there are architectural and historical heritage constraints – after the Bucharest demolition large campaign of 1980 – suggesting that more demolition should be not allowed in the city centre.

Unfortunately even today, the lessons learned in 1977 are still understood only partially. Examples of the lessons still to learn are given below.

Lesson 1:

> “A systematic evaluation should be made of all buildings in Bucharest erected prior to the adoption of earthquake design requirements and a hazard abatement plan should be developed.” (G. Fattal, E. Simiu and C. Culver, 1977).

Lesson 2:

> “Tentative provisions for consolidation solutions should be developed, preferably urgently” (Japan International Cooperation Agency, June 1977).

Lesson 3:

> “Bucharest is sited on deep alluvium. [...] Much of the damage was due to soil amplification associated with deep layers of silty clay, loess [...]Such sites would provide sufficient chances of dangerous amplifications in the shaking of such buildings.” (H. Tiedemann, 1992).

Lesson 4:

> “Bucharest had been microzoned as part of UNESCO’s Balkan Project, with microzones denoting three levels of risk. The worst destruction occurred in the lowest-risk microzone.” (G. Berg, B. Bolt, M. Sozen and C. Rojahn, 1980).

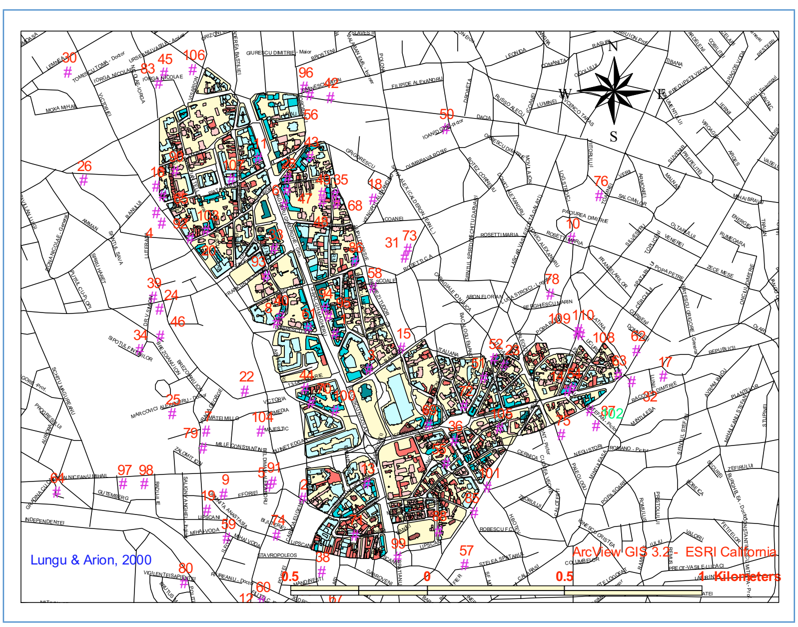


Figure 9 Map of central Bucharest with vulnerable buildings built prior to 1945 and identified as having the highest risk of collapse in the event of a strong earthquake (Mw≥7.5)

Lesson 5:

"Ground motion spectrum should be provided corresponding to each soil condition. A considerable number of strong motion seismographs will be required for the above purpose." (Japan International Cooperation Agency, June 1977).

On 30 March 1977 the national strategy for strengthening buildings damaged by the 1977 earthquake was established by the Romanian government in a letter to the Municipality of Bucharest sent by the General Inspector for Construction of Romania: "The retrofitting of buildings must provide: (i) for old buildings – the same resistance as before the 1940 earthquake (when they survived!), (ii) for new buildings – the same resistance as when they were designed". The above Governmental Order was further explained in the letter to the Technical University of Civil Engineering in Bucharest from Romania's General Inspector for Construction and the General Director of the Central Institute for Research Design and Coordination for Construction on 11 July 1977:

"Retrofitting of the buildings damaged by the 1977 earthquake will consist of strict local repairing of damaged elements. Additional measures for seismic protection are not permitted." The 1977 Romanian government's strategy for repairing damaged buildings proved to be a regrettable mistake.

SEISMIC RISK-REDUCTION STRATEGY AND PROGRAMMES

The present day national programmes for seismic risk reduction in Romania are focusing on the following three objectives: (1) strengthening fragile buildings in Bucharest, (2) upgrading the code for seismic design of buildings and structures, and (3) the seismic instrumentation of Romania. In Bucharest, about 20 per cent of the present building stock was constructed before the Second World War, less than 40 per cent before the major Vrancea earthquake in 1977, and more than 40 per cent after the 1977 event.

Currently, the list of buildings considered to have Class 1 seismic risk by the Ministry of Development, Public Works and Housing contains 392 entries or addresses that could be grouped as follows (percent of total buildings having undergone technical evaluation):

(i) Tall buildings	$\geq$ 9 storeys	under 3 per cent
	$\geq$ 7 storeys	16 per cent
(ii) Low buildings	$\leq$ 4 storeys	57 per cent
	$\leq$ 1 storey	17 per cent

Ten years after the creation of the consolidation programme for Class 1 seismic risk buildings, 19 of the initial 127 entries on the list (buildings over four storeys) are located on the Calea Victoriei and Magheru and Bălcescu boulevards (Figure 10). Most of them are considered part of the city's architectural heritage:

- 10 buildings (5 above 7 storeys) are fully consolidated
- 6 buildings (4 above 8 storeys) are under consolidation
- 12 buildings (7 above 7 storeys) have prepared plans for consolidation

Balcescu 25 (Wilson)

Magheru 20

Magheru 27

Calea Victoriei 2_4

Calea Victoriei 101 A–B

Calea Victoriei 124

Figure 10 Architectural heritage buildings in central Bucharest: examples of tall RC buildings built before 1940 in the city centre

Taking into account the risk matrix in Table 1, even Seismic Risk Class 2 buildings but importance and exposure (Class 1 buildings must be considered Seismic Risk Class 1 buildings, for example those shown in Figure 11).

Seismic vulnerability/ fragility class	Importance and exposure class			
	I Essential facilities	II Hazardous buildings	III General buildings	IV Minor buildings
1	1	1	1–2	3
2	1–2	2	3	3
3	3			

Table 1 Matrix of seismic risk classes 1–3


Figure 11 (a) National Romanian Television building, and (b) a reinforced-concrete flexible building built in the 1960s and the Ministry of Transport, Construction and Tourism, built in the 1930s

The Historical Monuments List (prepared by the National Institute for Historical Monuments – INMI, 2004), contains 26 cultural heritage palaces in Bucharest. Among these, the following Seismic Risk Class 1 palaces might be considered for priority strengthening: (1) Multistorey steel structures: the Ministry of Transport, Construction and Tourism, (2) Multistorey reinforced-concrete structures: Romanian Government Palace and City Hall of Sector 1, Bucharest, (3) Masonry and reinforced concrete buildings: the Royal Palace or National Museum of Art of Romania (central building), etc. Only the Justice Palace and Telephone Palace are now fully retrofitted (Figure 12).


Figure 12 Retrofitting of (a) the Justice Palace, 2006, and (b) the Telephone Palace, 2002

There are more than 200 orthodox churches in Bucharest, of which almost half are listed as architectural heritage buildings (Figure 13). Most of the old churches need structural strengthening and immediate rehabilitation.

In the case of seismic upgrading of architectural heritage buildings, the central role of the state must be replaced by new partnership models with the private sector, international donors such as UNESCO, the Council of Europe and the World Monuments Fund, and civil society at large. One major issue is the deterioration and/

or loss of a number of historic buildings and cultural assets due to the lack of financial resources to prevent further deterioration.

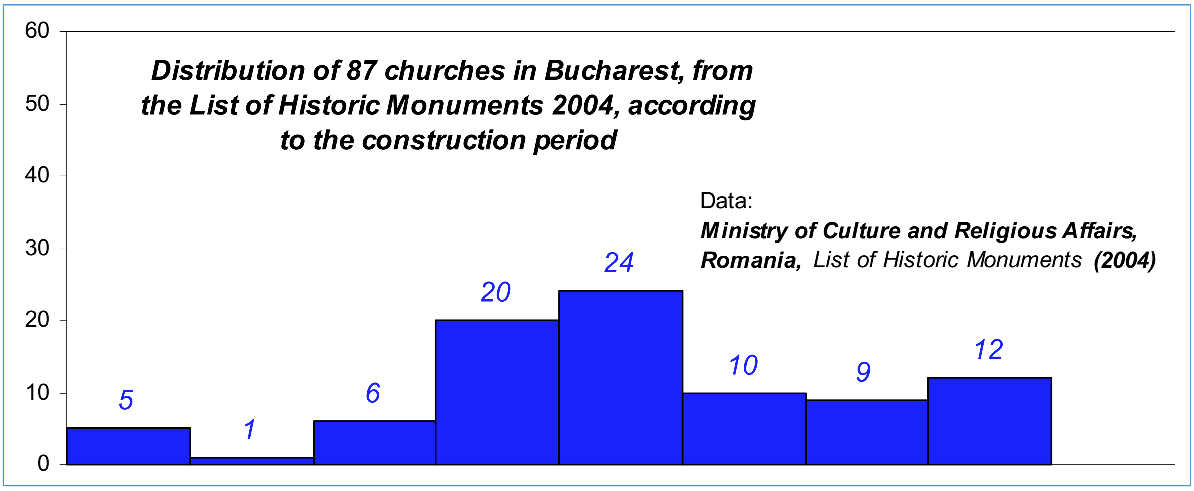


Figure 13 Distribution by age of the churches considered architectural heritage according to the list of Historical Monuments, Bucharest 2004

PRESENT-DAY CHALLENGE OF CONSERVING BUCHAREST HERITAGE BUILDINGS

Unfortunately for Bucharest's cultural, historic, architectural and urban heritage, it has been proven that the most important contributing factors in the disappearance of beautiful buildings in the city's protected areas are very deliberate architectural ambitions and, above all, current speculation in real estate. The applicable legislation for the protection of historic monuments (under the authority of the Ministry of Culture and Religious Affairs), the protection of buildings located in "protected areas" (under the authority of the Ministry of Development, Public Works and Housing with the the Ministry of Transportation, Construction and Tourism), and the city planning managed by the local administration, have led to a protection level close to zero for buildings that are located in these areas, and which are generally referred as "protected". The protection of these buildings seems to be a pure formality without any concrete action.

The present-day picture of Bucharest is of (1) overnight demolitions of historic buildings that have not experienced seismic damage, located in downtown, elegant, unpolluted areas, combined with (2) sky scrapers emerging without apparent logic (despite being approved by local and central authorities) all over the city including in historic protection areas, mixing with low-level buildings and causing traffic problems and irresolvable parking problems (now or in the future). This alarming picture indicates the utter destruction of Bucharest, the gravity of which will far exceed the damage experienced during communism.

The examination of available information on buildings in Bucharest leads to the following conclusions:

1. The initial purpose of the technical and seismic assessment programme for buildings in Bucharest damaged during the 1940, 1977 and 1990 earthquakes, was to make a Priority List for consolidating and ensuring the safety of inhabitants with respect to buildings showing serious bearing-structure damages.

2. In recent years, the list has been updated with a very large number of low buildings, with only a few levels, generally of bearing or mixed structure (brick walls and concrete) and boards sometimes made of wood or metallic profiles and brick bolts. Such buildings could be included in the same seismic vulnerability class as the tall, multi-level concrete buildings that collapsed on 4 March 1977, but they cannot be placed definitively in the same seismic risk class for the simple reason that their collapse in the event of a major earthquake similar to the 1977 quake would have completely different human, economic and structural consequences.

3. Since more than 50 per cent of the list of buildings in Bucharest falling under Seismic Risk Class 1 are low buildings below four storeys (17 per cent are buildings with one storey or a ground floor only) and only 6 of the

392 listed buildings are in Priority Group 2, we can infer that the initial purpose of the priority list for seismic consolidation has been altered and deviated to other obscure intentions.

Currently, the "red spot" signifies an "invitation" to eliminate many Class 1 buildings located mainly in Bucharest's central areas or residential neighbourhoods in the northern area of the city, (1 m2 of land costs €3000–7000 per m2). Unfortunately, the various Class 1 low-rise buildings are systematically planned to be demolished, not retrofitted. Such buildings have a fragile brick bearing structure that is easy to tear down, making them very attractive for real-estate speculation aimed at offering free land for future investment in tall buildings 3 to 8 storeys above the general height of the neighbourhood.

BUILDINGS SUBJECT TO DEMOLITION OR DEMOLISHED IN "PROTECTED AREAS"

Visarion 8 building

This building was completed in 1911, and the urban renewal plan for Lascar Catargiu Boulevard between Piata Romana (the Roman Square) and Piata Victoriei (Victory Square) was implemented in 1895–1899 in the French Academy spirit, according to a design by the architect I.D. Berindei. The building is also part of the same protected area as Dinu Lipatti House at 12 Lascăr Catargiu Boulevard, which figures on the List of Historic Monuments 2004, entry no. 615/B-II-m-B-18330. The building is located in a "protected area" but has benefited from no protection at all. The roof burnt at the beginning of 2007 and the building has been vandalized systematically, up to its present state of utter ruin (Figure 14). The "Collapse Hazard" sign placed on the facade of the building in March 2007 made a clear statement with respect to the destined end of this elegant building in the very heart of Bucharest. The application to declare the building a historic monument filed by the National Institute for Historic Monuments (no.351/23.03.2008) was rejected by the National Commission for Historic Monuments. Unfortunately, the existing law on protected areas in Romania cannot legally prevent the demolition of buildings located in such areas.

Figure 14 A Bucharest heritage building in the city centre, intentionally prepared for demolition

TALL BUILDINGS LOCATED IN THE "PROTECTED AREA" OF HISTORIC MONUMENTS

Tall building next to Saint-Joseph Cathedral

Saint Joseph Cathedral in Bucharest was started in 1875 and finished in 1884 during the reign of King Charles I. The famous Viennese architect, Dr.Friedrich Schmidt, planned the cathedral. Mayer from Munich made cathedral's paintings and stained-glass windows, while the altar was sculpted in Rome. The tall building under construction next to the cathedral is a building with 4 underground levels and 18 storeys and a height of 75m, POT=53 per cent, area: 1,059 mp (Figure 15).

The procedures for obtaining permits, developing a city planning file, locating and erecting the tall building situated at 11-15 general Berthelot, sector 1 commenced in 1999 and the circumstances surrounding the start of construction work in 2006 have been shrouded in controversy. Legal proceedings have started to provide a resolution regarding the building's legitimacy. In the meantime, work has been interrupted. The huge Sfântul Iosif building by the cathedral demonstrates a lack of common sense in city planning and makes a mockery of the neighbouring historic monument.

The tall building next to the head office of the Ministry of Internal Affairs and Administrative Reform

The bearing structure of the tall building located near the head office of the Ministry of Internal Affairs and Administrative Reform is GF+12E and exceeds by approximately five storeys the height of the adjacent monumental building, the Senate building. Although the Senate has not yet been declared a historic monument, it is representative of the inter-war period, as it was built in 1938–1941 under the coordination of engineer Emil Prager according to plans drawn by architect Emil Nădejde. The building lies within the "protected area" of: (1) Hotel Continental, code LMI 2004, B-II-m-B-19858 (end of the nineteenth century) and (2)the former Hotel Negoiu, code LMI 2004, B-II-m-18421.

Figure 15. Saint Joseph Cathedral in Bucharest (left) and House of Senate in Bucharest (right)

BUILDINGS WITHIN PROTECTED AREAS OR HISTORIC MONUMENTS SUBJECT TO DEMOLITION AFTER TECHNICAL EXPERTISE AND LISTED IN SEISMIC RISK CLASS 1

Victoria Arcade, Academiei St.

Approximately 10 years ago, the Ministry of Public Works and Territorial Planning (MLPAT) under Minister Nicolae Noica promoted the concept of "buildings subject to technical expertise listed under Seismic Risk Class 1" (symbolized by the "red spot") to underline the need for urgent consolidation of reinforced-concrete buildings built before the Second World War in uptown Bucharest, which caused more than 1,400 deaths during the tragic earthquake on 4 March 1977. At present, the symbol for "buildings subject to technical expertise listed under Seismic Risk Class 1" has become one of the most irrefutable reasons to demolish buildings in the capital's downtown and "protected areas", completely disregarding its primary meaning: a priority for seismic consolidation and security. The deliberate use of the "Seismic Risk Class 1" symbol to demolish old buildings may result in the total extermination of some of the capital's beautiful historic architecture.

BURNT AND DAMAGED INDUSTRIAL BUILDINGS LOCATED ON LARGE AREAS OF LAND

Asan Mill (Moara lui Asan), Obor, Bucharest

Asan Mill, built in 1853, is the first steam mill in Romania. It is an industrial architectural monument in category A, the 2004 List of Historic Monuments, code B-II-m-A-19692. The building is made of bearing walls with wooden boards. The mill was lewd on 14 May 2008 for a thorough and rapid extermination of the wooden boards and roof ridge. The walls show signs of vandalization of bearing walls (Figure 17).

Figure 16. MICM building demolished in 2007, Calea Victoriei, Bucharest

Figure 17. Arson and vandalism precipitated the self-collapse of the Asan Mill, industrial heritage, Bucharest, 1853

DETERIORATION OF THE CITY'S GENERAL APPEARANCE BY ADVERTISING POSTED ON THE FACADE OF BUILDINGS LOCATED IN "PROTECTED AREAS"

George Enescu 27 Street Building

The facades of such buildings should be protected and not aesthetically mutilated. Unfortunately Romanian legislation is not very strict.

An excerpt from Law 554/20 "For the preservation of the aesthetic appearance of the capital and other localities" is as follows: "The marking or posting of unauthorized inscriptions on the walls or facades of public or private buildings, on historic and architectural monuments or on any other type of buildings [...] will be fined a minimum L500 to a maximum L2,500 (€120–600) and will be liable for the costs of returning the respective buildings to their rightful aesthetic appearance."

Figures 14–18, which show typical examples of vandalism to Bucharest's heritage buildings, call for an urgent amendment of the protection legislation and the real-estate policy of demolishing historic monuments or buildings located in "protected areas". Beautiful historic buildings have been lost for good, either with approval from the Department for Culture, Religious Affairs and National Cultural Heritage in Bucharest, (e.g. the building on Str. G. Clemenceau 8-10), or the National Commission of Historic Monuments (e.g. the building on Str. Visarion 8, on the corner of L. Catargiu Boulevard).

Figure 18. Façade of a historical building

INTERNATIONAL PROJECTS FOR SEISMIC RISK REDUCTION IN ROMANIA

JICA PROJECT

The Japan International Cooperation Agency's (JICA) Technical Cooperation Project on the Reduction of Seismic Risk for Buildings and Structures started in Romania on 1 October 2002. The project was signed in 2002, when Japan and Romania celebrated 100 years of diplomatic relations. The aim of the project was to strengthen efforts to prevent earthquake-related disasters in Romania, and its duration was 5.5 years. The implementing agency was the National Center for Seismic Risk Reduction (NCSRR), a public institution of national interest subordinated to Romania's Ministry of Transport, Constructions and Tourism.

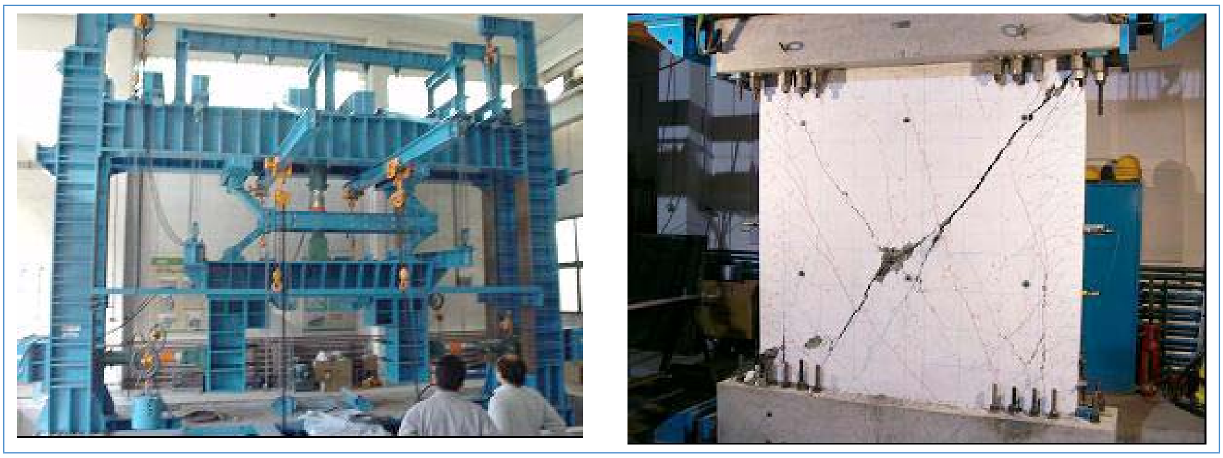


Figure 19. (a) Reaction frame donated by JICA, and (b) CNRRS tests on RC shear wall

The activities were carried out by NCSRR in partnership with the Technical University of Civil Engineering (UTCB) and the National Institute for Building Research (INCERC) in Bucharest. During the project period, 29 young Romanian engineers were trained in Japan, while Japanese experts worked in Romania (7 experts for a long-term period and 37 for a short-term period). Equipment for seismic instrumentation, and dynamic characterization of soil and structural testing required approximately ¥260 million (US$2.17 million), donated by JICA to the NCSRR. The total cost of the project was roughly US$7 million.

WORLD BANK PROJECT

The World Bank "Hazard Risk Mitigation and Emergency Preparedness" project for Romania (HREM Project) has several components: (A) strengthening disaster management capacity, (B) earthquake risk reduction, which accounts for US$71.2 million (about a third of the project's total cost) and (C, D and E): Flood, Pollution and Project Management, respectively. Component B has the following subcomponents: strengthening high-priority buildings and lifelines; design and supervision; reviewing the building code review and studying code enforcement; and professional training in cost-effective retrofitting. The project management unit (PMU) for Component B is located at MTCT.

The World Bank Report entitled "Preventable losses: saving lives and property through hazard risk management – a comprehensive risk management framework for Europe and Central Asia", in (October 2004) concludes that Romania is one the most seismically active countries in Europe and that Bucharest is one of the 10 most vulnerable cities in the world. The following recommendations from the report concern Romania: (1) upgrade the legal framework for hazard-specific management, (2) review the existing building code for retrofitting vulnerable buildings, (3) conduct a comprehensive public awareness campaign for earthquake risk, (4) invest in hazard mitigation activities to reduce the risks related to earthquakes, and (5) develop a financing strategy for catastrophic events.

CONCLUSIONS

The urban development of historic and protected areas of Bucharest within the European Union cannot be achieved by more storeys, demolitions or skyscrapers. The capital urgently needs the support of the population, as well as a new political strategy by central and local administrations to preserve, repair and develop the city for the benefit of its inhabitants and to respect its cultural and historic value, along with its identity as a European city.

ACKNOWLEDGMENTS

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RECOVERY SCENARIO AND NATIONAL LAND-PLANNING STRATEGY FOR MAJOR NATURAL AND MAN-MADE DISASTERS IN EASTERN JAPAN

H. Sazanami[1] and T. Kano[2]

[1]Representative, Sazanami Regional Study Office
5-43-3 Jingumae, Shibuya-ku, Tokyo 150-0001, Japan
Email: h.sazanami@mbr.nifty.com

[2]Assistant Professor, Faculty of Modern Life, Teikyo Heisei University, Japan
4-1 Uruidominami, Ichihara-city, Chiba 290-0193, Japan
Email: tomoko.kano@gmail.com

ABSTRACT

Great natural and man-made disasters destroyed cities, towns and villages in eastern Japan from 11 March 2011. This paper summarizes the situation in disaster areas, especially in Miyagi Prefecture through basic recovery program policy, temporary housing, evacuation facilities and space, volunteer activities, topography and public facilities, local communities, and municipality and government interviews on restructuring plan. Recovery strategies related to housing policies and national land policies are examined. A national housing policy is strongly recommended to meet demand for housing for refugees in the public and private sectors in eastern Japan. In terms of national policies, a master plan for future national land development is emphasized in relation to the size, function and structure of cities and towns.

KEYWORDS

Great East Japan Earthquake and Tsunami, temporary housing, housing strategy, National Land Planning, local community, sustainable towns and community

INTRODUCTION

A massive earthquake of 9.0 magnitude struck eastern Japan on 11 March at 2:46 pm. The ensuing tsunami (on a once-in-a-century scale) wreaked a 400 km trail of destruction along the Sanriku coast. The statistics underline the horrific extent of the natural disaster that struck the region: 14,238 fatalities, 12,228 missing individuals, and 330,237 destroyed buildings (Tokyo Metropolitan Police Department report, 23 April 2011).

Despite government deployment of 100,000 Self-Defense Force troops and 12,500 police officers to assist in rescue operations, the rescue of survivors buried beneath the rubble has proven extremely problematic, with many people still missing.

Docks, breakwaters and even urban districts have been completely destroyed. Vast piles of rubble still remained in the affected urban areas more than a month later. Fallout from the explosions at the Fukushima Daiichi Reactor continues to diffuse into the atmosphere, soil and ocean. The Japanese government imposed a no-entry zone around the reactor, and on 12 April, raised the severity of the Fukushima situation to Level 7 on the International Nuclear Event Scale, considering this to be the most serious nuclear incident. This is the first incident of this magnitude in the quarter-century since the Chernobyl disaster in the former Soviet Union, with the Three-Mile incident in the United States declared at Level 5. The Fukushima Daiichi incident was initially considered the same level as the Three-Mile disaster, although efforts to control the release of radioactive matter have proven futile. Under such circumstances, no feasible proposals are likely to emerge from the discussions of the East Japan Coastal Reconstruction Plan, and the government must inevitably take preliminary steps to ensure that the situation does not deteriorate further.

The Kan cabinet intends to set up the Recovery Initiative Council by June 2011 in order to present a primary restoration budget, but insufficient bureaucratic mobilization leaves doubts as to whether any specific proposals will emerge.

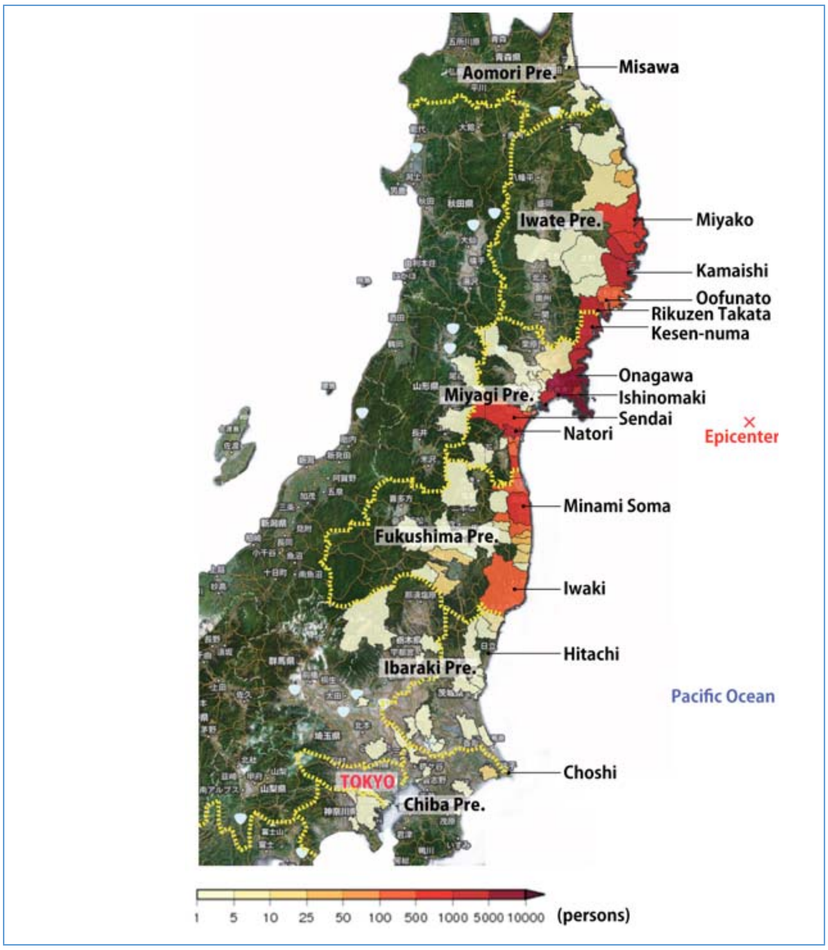

Figure 1 Map of dead and missing people

ADDRESSING THE ISSUES

The scale of devastation and the effects of radioactive contamination confronting the Eastern Japan Restoration Project are enormous. Compared with the Hanshin–Awaji Earthquake Restoration Project that made considerable progress within a decade, the progress of recovery we can reasonably expect from the Eastern Japan Restoration Project is questionable, even in two decades.

On the other hand, as Japan moves from the industrial to the information era, a drastic restructuring of the 1955 system established after the Second World War is now called for.

The premise of this paper is that Japan is on the cusp of a third breakaway from national isolation. The decade of the second breakaway (after the Second World War), saw the emergence of a new system in 1955, as the famous slogan “no longer post-war” suggests. Within the housing sector, Japan’s basic housing policy was introduced, leading to the creation of housing loan corporations (1950), housing projects (1951) and the Japan Public Housing Group (1955). One issue here is how a housing policy so closely linked to the Japanese public will unfold amidst the third breakaway from national isolation.

Despite a previous housing shortfall of 10 million homes in 1945, the rate of unoccupied homes reached 13.1 per cent in 2008. The private sector replaced public sector housing provision after the bubble burst in 1990, and this system continues.

Similarly, the construction of the Tomei Expressway, financed by the World Bank in 1955, helped improve Japan's infrastructure. Previously, a visiting specialist from the United States had expressed shock at the poor state of road maintenance in Japan. Today, the road networks have changed significantly with improved freeways and national highways, and the paving of agricultural roads throughout Japan. Moreover, roads have been paved and surrounding waterways have been improved rapidly in rural villages affected by the Chuetsu-oki earthquake, such as Yamakoshi.

Such housing construction and infrastructural improvement were implemented when Japan's GNP was second only to the United States. This raises questions regarding the kind of strategies Japan should adopt to respond to the developing new world economy with competition from emerging BRIC nations (e.g. China) that dominate the twenty-first century market.

The Great East Japan Earthquake and Tsunami has devastated the agriculture and fishery industries. Questions are being raised regarding how to implement strategies for these industries at the juncture of the third breakaway from national isolation, since existing restoration activities offer no resolutions.

Without a doubt, disasters of this magnitude are witnessed only once in a century. The previous equivalent disaster endured by Japan was the Great Kanto Earthquake on 1 September 1923, which had a massive effect on Japan's political and economic development and prefaced major historic incidents in the build-up to the Second World War, such as the early Showa Period financial crisis (around the 1920s), the colonization of Manchuria, the Independence of Manchukuo, Sino-Japanese entanglements and the Second World War. The aftermath of the Great East Japan Earthquake will certainly unfold very differently to the circumstances in the early to mid Showa period. Nevertheless, Japan is undoubtedly facing a period of great urgency where the paramount issue will be how to respond to major socioeconomic and political change.

RECOVERY FROM THE GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI

Fieldwork was conducted by the authors in Miyagi Prefecture from 9–11 May 2011, exactly two months after disaster struck the area. Through fieldwork and interviews with local authorities, government branch offices, volunteer centres and Tohoku University, the current situation of the prefecture was identified, along with disaster management measures for sustainable towns and communities.

Miyagi Prefecture is located approximately 300 km north of Tokyo in the central part of the Tohoku region, which is bordered by the Pacific Ocean on the east and noted for its rich fishing grounds, as well as famous sightseeing spots such as the Matsushima Islands. As a result of the Great East Japan Earthquake and Tsunami, a large but unknown number of people lost their lives, and many more lost their homes, jobs and workplaces.

Damages		Total (5 May)	Miyagi Pref(20 May)
Human	Dead	14,786	8,896
	Missing	9,982	5,359
	Injured	5,428	1,121
	Evacuees	more 150,000	17,666
Houses (buildings)	Totally collapsed	83,586	63,481
	Partially collapsed	304,861	37,584

Table 1 Damage caused by the Great East Japan Earthquake (Total, Miyagi Prefecture)

Recovery activities began with the reconstruction of key transportation infrastructure, including the Tohoku Expressway, the main north-south thoroughfare in the inland area of Tohoku region, and the east-west routes that connect the Tohoku Expressway with the fishing ports along the coast. After these key transportation routes were restored, rescue and recovery teams (e.g. Self Defense Forces, doctors and nurses) were able to reach the areas of the coast most seriously affected by the Tsunami, where gas and water infrastructure were completely destroyed. Self Defense Forces and social welfare corporations have been primarily responsible for the distribution of basic supplies to the coastal areas.

Basic recovery programme for Miyagi Prefecture

The Miyagi prefectural government drew up a basic recovery programme for one month after the disaster. The programme shows the direction of the prefectural reconstruction targets, clarifying basic principles and actions that are both urgent and essential. The basic concepts are as follows;

1. Prefectural residents as the core of reconstruction efforts
2. Not just restoration but restructuring
3. Drive regional development toward modernizations
4. Create a reconstruction model for catastrophic damage

Temporary housing

On 20 May, 30,647 affected people were accommodated in 404 refugee units. Temporary houses were built across 16,300m2 in Sendai City (Asuto Nagamachi), consisting of 38 blocks (one block for six housing units), with the standard housing type consisting of 3K with a bath and toilet (two rooms to sleep six and one to sleep eight). Here, the temporary houses are quite industrial and not particularly personal.

In Ishinomaki, temporary housing was built in the elementary school playground for refugees who had been staying in the gymnasium and classrooms. Here, the temporary houses are similar to those in Sendai City. There is a danger that some residents remain isolated in these houses. A crucial issue is how to provide space for communal recreational and leisure activities in these temporary housing estates.

Figure 2 Temporary housing (Asuto Nagamachi), Sendai (9 May 2011)

Evacuation facilities and space

Evacuation facilities were provided in the gymnasiums and classrooms of elementary and middle schools located in the upland areas that the Tsunami did not reach. Refugees who find neither temporary nor public housing (in other prefectures) and want absolutely to remain in their original living areas prefer to stay at the evacuation facilities. These refugees can obtain various information such as missing families' addresses, reconstruction and recovery activities in the disaster areas, and announcements of available medical care by doctors and nurses. In addition, relief materials are stocked and delivered there.

In these facilities, the refugees construct living spaces using cardboard boxes. The children use bus services to go to school. Some of the elderly people forced to live in such unhealthy environment have suffered from illness and died.

Figure 3 Kesennuma gym (10 May, 2011)

Figure 4 Onagawa elementary school (9 May 2011)

An urgent issue is how to provide a healthy living area in the large open space of the evacuation facilities.

Volunteer activities

Volunteer relief activities are managed mainly by the public authorities and social welfare corporations. The social welfare corporation is based on the priority of the original area's corporation and promotes coordinated activities by public and private organizations. Employees of the social welfare corporations in other prefectures have been mobilized to assist corporations in the disaster areas. In particular, they are coordinating demands and the supply of volunteers to the disaster areas.

Figure 5 Volunteer centre, Ishinomaki (10 May)

Topography and public facilities

The coastal areas in Tohoku Region afflicted by the Great Disaster are divided into the three areas by topography:

1. Plain areas in Sendai City
2. Plain areas and upland areas between Sendai City and Ishinomaki City
3. Coastal areas from Ishinomaki City to Kesenuma City, including Onagawa Town, a fishing port built into the Rias-typed coast.

Fortunately, the municipal hospital, located on a hill, was able to maintain operations, even though its first floor was inundated. The town hall was flooded, however, and debris remains on the roof, while its reinforced concrete building still stands. The fishing port near the creek was completely destroyed.

The Second Onagawa elementary school located on the high plateau was saved from the Tsunami and resumed school work in May. Children use the school bus operated between the school and the evacuation facilities.

The general public widely accepts the principle of building the town hall and other public facilities such as schools and hospitals on high plateaus. However, it is not easy to find suitable places in these coastal regions. Issues related to topography and public facilities should be fully examined in a country like Japan.

(a) Onagawa Town hospital

(b) Onagawa fishing port facilities

(c) Topography of Onagawa Town

Figure 6 Rias-type port area, Onagawa Town (9 May 2011)

Local communities

Specific customs has been fashioned in each of the coastal areas in the Touhoku Region and residents' daily lives are assisted by their communities.

For example, sea urchins and abalone are collected by community members every year and the profit is divided between them.

The residents of these business communities generally accept their community leaders' opinions and some of these coastal communities could evacuate entirely into neighbouring communities in the upland area following their leaders' decision.

This community-based approach will be quite useful for making an effective recovery plan, creating a new vision for life and building hub harbours.

Earthquake aftershocks of a 4–7 magnitude have occurred almost every day since the Eastern Japan earthquake. Therefore, we should thoroughly examine disaster risk in order to make a comprehensive recovery plan.

Municipality and government interviews on the restructure plan

In Ishinomaki City, the ground has sunk more than 70 cm as a result of the earthquake. In addition to the problem of sunken land, reconstruction activities must also address a range of other issues, including 1) centralization of fishing villages, 2) marginal villages, 3) population outflow, and 4) population ageing and low birth rates.

Considering all these issues, it is essential to not simply create a restoration plan but a plan for reconstruction. In addition, interviews and workshops with the local community will be essential to take local residents' opinions into account.

Figure 7 Recovery task force, Kesennuma (10 May 2011)

At the restoration activities office in Kesenuma City, two civil engineering experts have arrived from Ministry of Land, Infrastructure, Transport and Tourism (MLIT) offices in neighbouring prefectures. The most urgent problem is basic infrastructure, particularly roads and bridges, but nearly two months after the 11 March disaster, reconstruction plans were not yet finalized. Volunteers are actively working, often by hand, to remove mud and debris from areas hit by the Tsunami. The Self Defense Forces' heavy machinery has been crucial to recovery efforts, and there is a continuing need to coordinate recovery efforts between the government and civilian groups.

HOUSING STRATEGIES

According to estimates, 60,000 temporary dwellings need to be constructed in the affected areas.

While the required building materials have been secured, construction is not yet underway as suitable sites have yet to be found within the municipalities of the earthquake-struck region. The current disaster requires a grand plan that responds to the third breakaway from national isolation rather than mere recovery strategies. According to estimates, vast funding is required for strategies both to address the aftermath of the earthquake and tsunami and control radioactive fallout from the Fukushima Daiichi Reactor explosions, and the thorough consideration of a comprehensive national cross-sector plan should include the utilization of readily available facilities. For example, within the housing sector, the use of unoccupied homes throughout the country (40,000 buildings in total) as temporary public dwellings is strongly advocated.

If housing projects outside the disaster area are used as temporary dwellings, the receiving prefectures must first be encouraged to coordinate with the authorities of the three affected prefectures, and then use public housing allocated to nearby communities to accommodate displaced survivors.

Moving displaced survivors to nearby communities enables effective communication possible by facilitating the dissemination of specific information to those who require it. It is important to consider that the required information depends on the community. For example, the area affected by the East Japan earthquake and tsunami was a 400 km stretch of coast, home to many fishing and agricultural communities.

Likewise, the use of existing housing projects will allow funds earmarked for temporary housing construction to be diverted to other areas, and make other forms of aid feasible, such as payments to cover monthly travel costs from the refugee areas to the housing projects in the affected areas. This proposal would encourage the use of facilities and equipment that surround the housing projects such as hospitals and supermarkets, and survivors would visit the disaster area monthly and witness regeneration over two to three years while rebuilding their lives.

Professor Nishimura of Tokyo University voiced the opinion that it is crucial to involve specialists such as architects in this proposal. He suggested that recovery will undoubtedly be accelerated if specialists outside the disaster area support survivors in specific areas.

The scale of devastation and the effects of radioactive contamination confronting the Eastern Japan Restoration Project are enormous. Hence, compared with the Hanshin–Awaji Earthquake Restoration Project that saw considerable progress within a decade, the progress of recovery we can reasonably expect from the Eastern Japan Restoration Project is questionable, even in two decades.

NATIONAL LAND PLANNING

Topography and the level of disaster risk

For many, the East Japan Disaster underlined the close relationship between topography and disasters. Nothing has so clearly highlighted the importance of acquiring appropriate topographical data when drawing up disaster prevention schemes.

Topography could be divided into the following categories: 1) mountainous or hilly areas, 2) foothills, 3) plateaus/terraced hills, 4) valley floors and lowlands, 5) low-angle alluvial fans, 6) floodplains, 7) deltas, and 8) coastal lowlands. Each category has its own unique topography, which can be divided further into high- and low- risk areas in relation to potential disasters, such as land and mud slides, inland and river flooding, storm surges, tidal waves and liquefaction. Examples of information that can be acquired relatively easily include the various charts from the land classification survey. The charts display landform classification/land conditions, landslide topographical distribution, urban active faults, flood-control/landform classification, and volcanic land conditions.

Such topographical data and past disaster records are essential for national land planning. Based on the experience of the Great East Japan Earthquake, constructing a basic quake response system will be necessary in future.

This disaster caused widespread destruction on the coasts of Tohoku and northern Kanto. The explosions that erupted from the Fukushima Daiichi Reactor building continue to emit radioactive fallout into the surrounding environment with no foreseeable solution. In response, countermeasures that address the future shape of Japan's national land planning must be implemented urgently, and there is particular debate over how these should be formulated to cope with future anticipated earthquakes in the Tokai, Tonankai, and Nankai areas.

Plans to improve the Tokyo Metropolitan Area and form a New Osaka Metropolitan Government

The Tokyo Metropolitan Area presents a major challenge to disaster prevention plans in the national territory. Previously, there were two vast metropolitan areas in Japan, Tokyo and Hanshin, and the elimination of excessively concentrated political, economic and social functions has been raised as a fundamental measure to respond to major earthquakes in the Tokai, Tonankai, and Nankai areas. Governor Hashimoto has called for an Osaka Metropolitan scheme to merge Osaka Prefecture with Osaka City, and the majority of political parties in Osaka Prefecture support his proposals. Despite being a former commercial hub, Osaka remains dependent on Tokyo both politically and economically. A second metropolitan political system must therefore be established to support Tokyo, with the Osaka Metropolitan Area assuming political and economic powers to ensure that domestic and international policies are not disrupted even during a massive disaster affecting the Tokyo Metropolitan Area.

The Chukyo Metropolitan Area

While areas such as Toyohashi, located within the Chukyo Region (principally Nagoya), were formerly preferred for the capital's relocation, proposals to construct a Chukyo Metropolis must be treated with utmost caution since the region faces the risk of a major Tonankai earthquake. The area requires considerable improvements in disaster prevention as it is home to major manufacturing groups such as Toyota. Examples should be drawn from the experiences of the Ise Bay Typhoon (1959), which wreaked considerable coastal damage, and Tonankai earthquake strategies undoubtedly present a crucial challenge for disaster prevention in the Ise Bay area, as well as the Mie Prefecture's coastal region, which adjoins steep hills at many points. Lessons must be learned from the Great East Tokyo Earthquake to direct efforts towards strengthening disaster prevention schemes.

Figure 8 Minamisanriku (18 May) (photo by the Geospatial Information Authority of Japan)

The Metropolitan Areas of Fukuoka and Kitakyushu

New developments in the wide-ranging urban areas of Fukuoka and Kitakyushu must be encouraged to follow Osaka and Nagoya. Fukuoka City is the prefectural capital and functions as a hub city for the entire Kyushu district, while Kitakyushu is known worldwide as a city for environment and industry. Such characteristics must be fully exploited in the creation of a new urban hub.

"Plateau" cities

Japan's past history of disasters should be examined. In particular, low-risk disaster-safe areas should be selected and developed as information hubs, and transformed into "twenty-first century eco-cities and smart regions". According to past data, Okayama in the Chugoku region presents an option for a wide-ranging metropolitan area; it is thus recommended that past disaster reports be closely analyzed and the region developed as the site for a sustainable twenty-first century metropolis.

CONCLUSION

The third breakaway from national isolation may determine Japan's fate in the same way as the first and second breakaways (the Meiji Reformation and the formation of the Showa Constitution).

This paper presents options for nationwide strategies to respond to major earthquakes in Tokaido, Tonankai, and Nankai; advocates the early dispersion of excessive concentration in Tokyo; and recommends the creation of a second metropolis in Osaka, as well as improvements in the third and fourth regional metropolitan hubs in the Chukyo district and Fukuoka/Kitakyushu.

These are all approaches to forming regional urban hubs that could be followed by, for example, regional strategies on a large-scale level involving areas with Shinkansen tracks; express-motorways; and national mainline railroads and roads. The regions affected by the Great East Japan Earthquake of Tohoku and northern Kanto fall into this category, and such a "once-in-a-century" major natural disaster and the most serious nuclear reactor incident, at Level 7, have created an abnormal situation that calls for a national response. Although such strategies focus on a wide area within a nation, the explosions at the nuclear reactor present a major global challenge, and containment strategies may take a decade to implement. In such abnormal circumstances, the required strategies must be implemented urgently to assist those living or working in regions contaminated by radioactive fallout.

One reference case is Miyake Island (2000), where toxic gas emissions from volcanic eruptions forced island dwellers to evacuate en masse and live in long-term separation from their island homes. The reconstruction plan for the affected regions in eastern Japan must be sustainable and realistic.

The plan must be based on an investigation into the future 10-year socio-economic and environmental strategies for Japan and the wider world, as well as a consideration of developments within related global administrative and financial institutions.

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SURVEYS AND ACTIVITIES ON POST-EARTHQUAKE DISASTER

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United Nations
Educational, Scientific and
Cultural Organization

For further information, please contact:

Section for Disaster Reduction
Natural Sciences Sector
UNESCO
1, rue Miollis
75732 Paris cedex 15 France
Phone: + 3392 38 68 45-1-
Fax: + 3321 58 68 45-1-
E-mail: y.katsumi@unesco.org

9 789231 042225