Steps in Earthquake Proofing a Country - A Case Study of Myanmar

2010 NZSEE Conference

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ABSTRACT: In many countries around the world, building and bridge structures with close proximity to known earthquake faults have been constructed with little consideration to the effects of strong ground shaking. This paper discusses some of the infrastructure and systems required in a country to prevent structural collapse, and hence major loss, in a major earthquake. The modus operandi of one group which seeks to reduce earthquake loss in these countries, the World Seismic Safety Initiative, is described. Finally, a case study is carried out on Myanmar where extraordinary strides that have been made toward earthquake risk reduction in a relatively short period of time.

1 INTRODUCTION

Myanmar (formerly Burma), with its population of 56 million people has been known for many years as the Pearl of Asia. It is famous for many things, including Kipling's stories, and songs such as "The Road to Mandalay". It is a religious country with many Thervada Buddhists and their pagodas which are the centres of village and city social, religious, and recreational activities. What is less commonly known about Myanmar is that it is a land of earthquake shaking. There are many major faults. For example, the Sagaing fault has similar characteristics to the San Andreas fault, and it passes near a number of major cities including Yangon (formerly Rangoon) and Mandalay. Damage to pagodas over many hundreds of years has been recorded by the monks living around these pagodas, providing a valuable source of historical seismicity. Active faults are shown in Figure 1. Appendix 1 shows records of some Myanmar earthquakes.

While Myanmar is subject to large earthquakes, design of structures has traditionally been carried out without explicit consideration of earthquake effects. In Yangon, many of the structures are 8 stories or less. Governmental authorities have been asked to allow taller structures, up to around 30 stories, around the country and the government has mandated that earthquake design be required for these structures.

This paper describes some of the steps required to earthquake-proof any country. Then the World Seismic Safety Initiative (WSSI) and its efforts are discussed. The development of earthquake risk mitigation methods in Myanmar and the historical changes in building design and construction are described. Then, the steps undertaken by Myanmar are listed in terms of what it needed to earthquake proof a country.

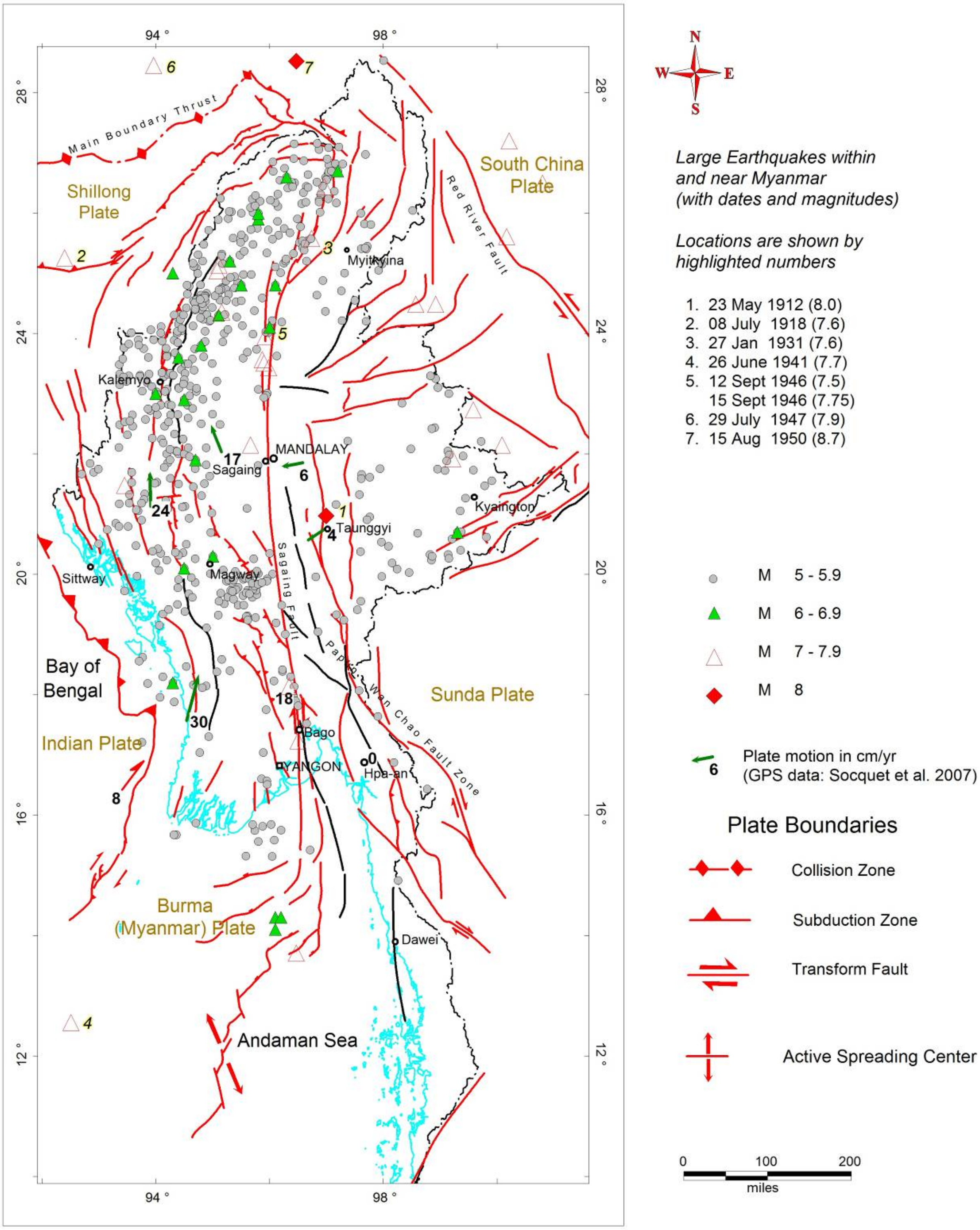

Figure 1. Seismotectonic map of Myanmar and surrounding regions (Active faults are shown in red lines) (Thein, 2009)

2 EARTHQUAKE-PROOFING A COUNTRY

Earthquake loss from ground shaking is the result of a process illustrated in Figure 2 below. It only occurs when there is (1) a fault rupture. After the rupture, a series of vibrations or waves travel through the rock (2a). If there is soft soil on top of the rock, then the waves travel through the soil to the structure. They are modified by the characteristics of the soil (2b). The shaking at the base of the structure causes the structure to respond (3). If the demands in the structure, such as rotations, extensions, accelerations, and displacements, are too large then there will be some damage. The resulting losses (4) are due to the direct damage to the structure and its components, the injuries or deaths, and business interruption (or downtime) losses. These three, damage, death and downtime are sometimes referred to as the 3 D's. They can be expressed in terms of dollars, at least by the insurance industry,

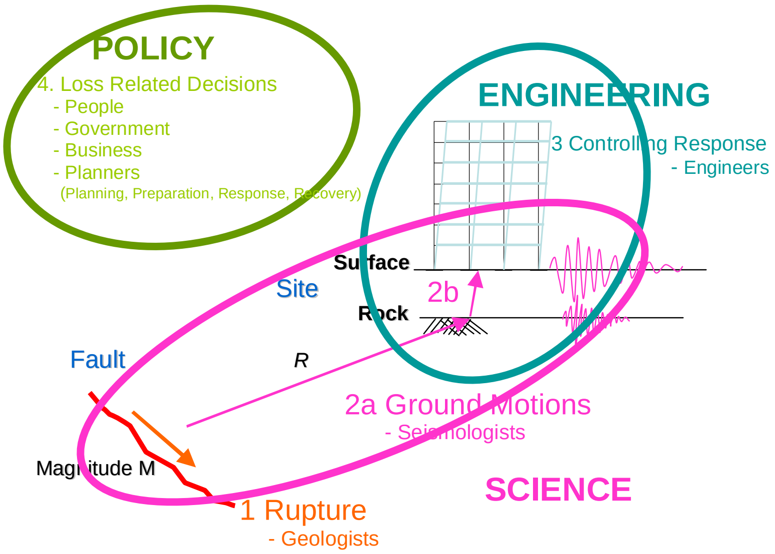

Figure 2. Losses Caused by Earthquakes (from MacRae 2009, based on PEER)

How do you earthquake proof a whole country? It can be done by breaking the chain of events leading to damaging response in Figure 2. However, it is difficult to prevent fault rupture or ground shaking. Since it is the buildings and structures which fall down and kill people, concentrating on building/bridge and structural performance, in addition to having response and recovery plans for very large events, is needed. Obtaining good structural performance is not as easy as it might initially seem. It is not achieved by only having good codes, as shown by the 1999 Turkey earthquakes (Youd et al. 2000). Neither is it a matter of some organizations retrofitting a school and showing locals how to do it, because this affects only a small region. Training engineers and builders to design and build better is also inadequate. And it is not enough to tell school children that earthquakes can cause damage and that they should be prepared. A government mandating that structures are to be earthquake resistant also does not result in safe structures. Earthquake proofing a country, generally involves all of these to be effective.

David Hopkins (2007) uses a variation of Figure 3 to illustrate what is necessary to develop earthquake resistant structures. Here structures, such as buildings are shown dangling above the citizens of a country. The building is supported by a rope made up of a number of links in series. Each link is needed to ensure that the building will not collapse in a tremor. If the rope does break due to even one of these links being weak, the building may collapse and kill the people below. The links of the rope are discussed below.

Political commitment is necessary to provide safe buildings over all earthquake prone regions within a country. A lack of political commitment will lead to other issues becoming important over time and emphasis on safe structures will be lost.

Legislation and a legal framework are necessary to express political commitment and provide a reference for enforcement. The legislation gives power to standards and codes which are used by practitioners. This results in minimum standards of earthquake resistance.

Designers and builders must have the appropriate skills to provide design and construction consistency and quality. This is developed through education and practical training.

Monitoring and quality assurance is necessary to maintain standards.

Effective enforcement procedures are necessary to develop a culture of quality, to ensure that standards are maintained, and to make examples of individuals involved in corrupt activities.

While it may be possible to perform all the activities as a result of a decree, it makes a significant difference if the battle for the hearts and minds of the owners is won. Owners must believe that there is a problem, and trust that the methods used will mitigate that problem. This means that owners should not see the enforcement of regulations as something undesirable, but as something to help them. Developing this trust, and establishing systems takes many years, but the benefits are enormous – a resilient society, rather than a potential disaster zone.

For an individual structure, the additional costs of providing earthquake resistance of a new structure are normally only a small percentage of the total cost. However, there are significant costs in developing the framework in order to ensure compliance with building standards.

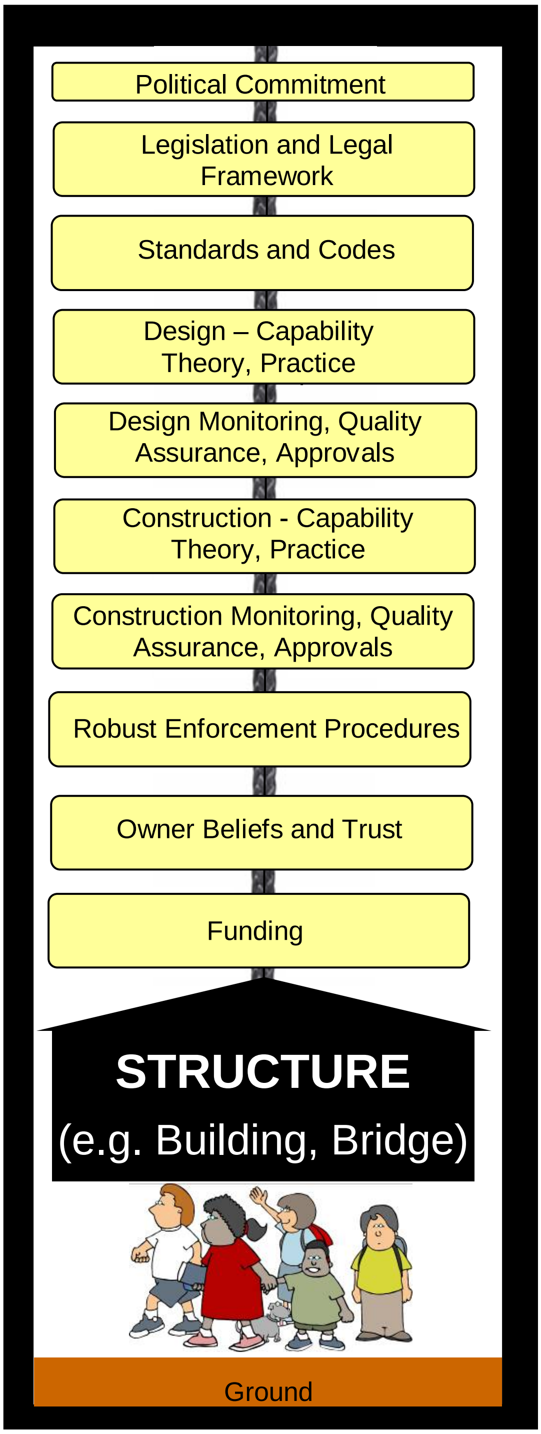

Figure 3. Requirements for Structural Earthquake Resistance
(Based on Hopkins, 2007, People Illustration from Cox 2010)

To embark on building earthquake safety, it is necessary first to develop the political will and political commitment at all levels of society. Petak (2001) describes a framework for understanding how such a commitment is obtained. *First,* decision-makers must be made *aware* that there is a risk. This is usually the result of an experience which has involved some loss. *Second,* they must be made aware that there is a means of mitigating the risk. This may be the result of experience, or models (physical, analytical, sophisticated or simple) which are consistent with experience. *Third,* the stakeholders/responsible officials must choose to allocate resources, which could be used for some other purpose, to provide some risk mitigation. Figure 2, indicates that these 3 steps are related somewhat to different disciplines making the whole earthquake safety issue multidisciplinary. That is;

> The *awareness* of the problem is often developed based on *scientific* and historical observations from actual earthquakes. The scientific part of understanding earthquake loss generally centres around the geology, seismology, geomechanics, and physics of structural response.
>
> The development of earthquake loss *mitigation* procedures is related closely to structural design. Appropriate design to mitigate the demands is generally led by *engineers*.
>
> The resourcing and funding to develop appropriate methods of planning and preparation to mitigate earthquake loss before the earthquake, and for response and recovery after an earthquake, are a matter of *policy*. This political part of loss estimation involves the general public, planners, decision makers and planners at all levels.

Before the policy can be developed, policy makers need to describe to their employers/constituency why it is essential that something be done. This requires understanding problem, the means of mitigating the problem, and the costs of different mitigation options. This more easily said than done because the different scientific, engineering and policy groups involve different types of people who have become accustomed to talking to each other with their own language and culture. While there is some overlap in communication between scientists and engineers, due to their overlapping fields of interest as shown in Figure 2, there is less overlap of scientists and engineers with policy makers. For a society to be earthquake-proofed, these barriers must be broken down so that people in each group can effectively communicate with each other with a common language and understanding to develop the decisions and policies which they can justify to those they represent. It is possible, by realizing what makes each of these groups perform best, and to get them to work toward the same goal, to make great strides toward meeting the requirements for structural earthquake resistance in Figure 3 which are key elements of earthquake-proofing a country.

When a country has no expertise in earthquake engineering, understanding the likely problems, and the possible mitigation methods, may be difficult. For this reason, it is important to get outside advice from those who have dealt with earthquake loss over many years. WSSI is one of these groups.

3. THE WORLD SEISMIC SAFETY INITIATIVE (WSSI)

3.1. What is WSSI?

The World Seismic Safety Initiative (WSSI) is one of a number of groups seeking to bridge the gap between the knowledge of, and implementation of, disaster mitigation procedures for earthquake. The WSSI (http://www.wssi.org/) was established in 1992 as an undertaking for the International Association of Earthquake Engineering (IAEE) to promote the spirit and goals of the International Decade of Disaster Reduction (IDNDR). The mission of WSSI is*" to reduce the level of earthquake risk in the most vulnerable communities in developing countries to an acceptable level consistent with sustainability of these communities".* A number of publications related to WSSI's work are given in the references.

The WSSI is an independent not-for-profit organization incorporated in Singapore and governed by a Board of Directors. The 2009 directors, who are all volunteers, involve key people from different countries such as Prof. Mehedi Ahmad Ansari (Bangladesh), Prof. Mohsen Ghafory-Ashtiany (Iran), Prof. Joäo Azeveda (Portugal), Prof. Shel Cherry (Canada), Dr. David Hopkins (New Zealand), Prof.

Wilfred (Bill) Iwan (USA), Prof. Sudhir Jain (India), Prof. Tsuneo Katayama (Japan), Prof. Gregory MacRae (New Zealand), Prof. Kimiro Meguro (Japan), Prof. T. C. Pan (Singapore), Prof. Haresh Shah (USA) (Chair), Prof. Rajib Shaw (Japan), Prof. Adang Surahman (Indonesia), Prof. K. C. Tsai (Taiwan), Dr. Zifa Wang (China) and Prof. Andrew Whittaker (USA).

The emphasis is on developing countries because of their rapid population growth. That, accompanied by almost uninterrupted economic prosperity since World War II, has led to increase in the level and concentration of people and properties exposed to earthquake risk. Despite the roughly constant levels of worldwide seismicity from year to year, the spectacular growth in exposure has contributed to a dramatic increase in economic and life losses over the last four decades, especially in developing countries. Some estimate that 80% of the economic and life losses due to earthquake this century will occur in developing countries as shown in Figure 4.

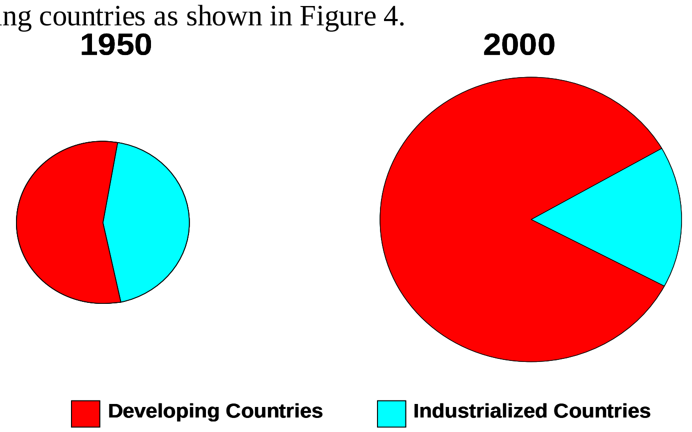

Figure 4. Urban Earthquake Loss (GeoHazards International)

WSSI follows the following guiding principles in order to fulfill its mission of reducing loss in these vulnerable communities. It aims to:

(i) *Act as a catalyst and facilitator rather than implementer of large projects.*
(ii) *Focus on development of regional and local awareness, capacity, and leadership.*
(iii) *Emphasize low cost high benefit strategies to address its mission.*
(iv) *Emphasize strategies that span the "last mile" to affected communities.*
(v) *Cooperate with organizations having similar goals on a non-competitive basis.*

3.2. What does WSSI do?

WSSI has the following activities consistent with the mission and guiding principles:

(a) High Level Meetings

High level meetings (HLMs) are organized by local host organizations such as a university or governmental ministry or agency. Participants include representatives of the academic and scientific communities, civic and business leaders, people from social and cultural institutions, the media, etc. These are long range educational projects. Objectives of HLMs are to:

- Trigger local high-level efforts;
- Build on, and encourage, local resource mobilization;
- Sensitize people – professionals, administrators and politicians;
- Help identify and prioritize local actions;
- Assist in developing local sustainability through local efforts
- Assist in adding credibility to local efforts;
- Assist in local efforts for fund-raising activities; and
- Assist in national networking

More than 10 HLMs have taken place in such locations as Colombo, Sri Lanka; Dhaka, Bangladesh; Hanoi, Vietnam; Kampala, Uganda; Katmandu, Nepal; Kuala Lumpur, Malaysia; Singapore; Yangon, Myanmar.

(b) Workshops, training courses and conferences

(i) WSSI International Earthquake Risk Management Workshops have been held approximately every 5 years in Bangkok, Thailand. The aims of these workshops are:

- To learn from countries where WSSI programs have made some positive difference in terms of earthquake risk mitigation and management
- To learn from countries where WSSI programs have not made any major impact
- To develop plans in consultation with all attending countries about what WSSI would like to do for the next five years and where they should develop their human and financial resources

Generally, each country reports their earthquake risk mitigation efforts, strategies, responses and assessment measures. By sharing some common needs, opportunities for future collaboration are defined.

(ii) Other WSSI workshops and courses have been held in Alma Ata, Kazakstan; Beijing Workshop, China; Black Sea University, Romania; Chile; Costa Rica; Hanoi, Vietnam; Hydrabad, India; Indonesia; Okinawa, Japan; Russia; Singapore; Suva, Fiji; Tokyo, Japan; Vienna, Austria; and Yangon, Myanmar. WSSI has sponsored 24 Workshops around the world and 5 courses. The aims of these courses are:

- To increase awareness of earthquakes
- To train managers and engineers to prepare for earthquakes
- To promote efforts toward implementation

(c) Special Projects

(i) *Safer Cities Project*
The SAFER Cities Project was initiated by WSSI in partnership with the Consortium of Organizations for Strong-Motion Observation Systems (COSMOS). Older Strong-motion Accelerographs For Earthquake loss Reduction (SAFER), which are still in good working order, are redistributed to qualified non-profit agencies in cities with high seismic risk that would otherwise have little or no means of recording the next damaging earthquake. The SAFER Cities Project is an initiative to create awareness, to educate, and to accelerate earthquake hazard mitigation efforts in urbanized high seismic-risk regions of the world.

(ii) *Myanmar Project*
The Myanmar project, initiated by WSSI and Oyo Corporation, Japan, has involved in the deployment of 10 strong-motion accelerographs. Readings have already been obtained from a number of recent earthquakes. This information will be used in the development of hazard maps.

(iii) *Earthquake and Megacities Initiative*
WSSI was a founding organization of the Earthquakes and Megacities Initiative (EMI), 1997. EMI is an international not-for-profit scientific non-governmental organization dedicated to the acceleration of earthquake preparedness, mitigation and recovery of large urban areas and serving as a catalyst for the delivery of scientific and technical knowledge to the end-users. EMI focuses its efforts on developing capacity in megacities of the developing world where the effects of earthquakes and other disasters could be devastating to the people, their economy, their culture, and their environment. The EMI Initiative has now been adopted by various national and international organizations such as UNESCO, UNU, ICSU, ICET, IGU, ILP, etc. WSSI continues as one of the main promoters of EMI.

(d) Earthquake Reconnaissance Programs

Two interdisciplinary "learning" teams were sent from developing countries to earthquake disaster regions. One of the teams, consisting of 21 members from 13 countries went to Bhuj with EMI in 2001.

3.3 Is WSSI Successful?

Many of WSSI's actions on "the road to implementation" are expected to result in long-term on the ground changes, and while there is still much to be accomplished, WSSI has reached some major mileposts on this road. These are related to: (a) awareness; (b) training; and (c) implementation:

- Establishment and encouragement of six national earthquake engineering societies in the countries of Malaysia, Myanmar, Nepal, Pakistan, Singapore, Thailand and Uganda. (a) – (c)
- IAEE Guidelines for Earthquake Resistant Non-Engineered Buildings.
  The writing, distribution, and translation into local languages was carried out in conjunction with other organizations (b)
- Many reports from different countries related to (a), (b) and (c) (ICUS 2004-01). One particular success story is given below.

A Nepal Story:

Between 1993 and 1999 the Nepal representative at the WSSI workshop indicated that the earthquake disaster preparedness of Nepal was enhanced greatly, an international project to strengthen school buildings has been carried out successfully, and efforts by the local people attracted the attention of donor countries and international organizations who they supported several projects for earthquake disaster mitigation in Nepal. This success can be seen on the streets where new structures are constructed with sufficient rebar and with proper detailing.

3.4 WSSI in Myanmar

WSSI has been involved with Myanmar since 1996. WSSI has been involved with activities such as high level meetings, deployment of strong motion instrumentation and associated training of staff, and with technical training courses. Many of these have been ably facilitated from the Myanmar side by U Than Myint. WSSI has also supported international workshops on Seismotectonics in Myanmar and Earthquake Risk Management (SMERM).

4. MYANMAR – A CASE STUDY

4.1 Development of Earthquake Risk Mitigation Methods in Myanmar

Myanmar Earthquake Committee (MEC) was formed in 1999 under the Myanmar Engineering Society to study earthquake hazards in Myanmar and to apply earthquake resistant design in buildings and other structures. With the collaboration of geologists in Myanmar, an earthquake zoning map was developed. Myanmar earthquake resistant design guidelines are currently being developed. Earthquake related literature was collected from available sources for engineers and geologists. Seminars and hands-on workshops are held at Myanmar Engineering Society for structural design engineers. Mainly UBC 1997 and ACI 318- 1999 are followed in structural design.

Geologists and structural engineers are working together in the Myanmar Earthquake Committee. With the collaboration of international institutions, research on active faults and other topics related to past earthquakes are being conducted in some areas with active faults and historic seismicity. The existing zoning map is based on a deterministic approach. A probabilistic earthquake hazard map is currently under development. Structural engineers are also studying and applying their knowledge in design of buildings. Earthquake resistant design courses are also given to engineers from public sectors and private sectors. Experts from foreign universities and institutions are also invited to give short courses in Myanmar.

Earthquake hazard awareness programs are also carried out for school teachers, local authorities, officials of government departments and local communities. Position papers on earthquake hazards, and implementation steps are also submitted to concerned authorities for information and consideration. MEC is actively participating in the disaster risk reduction activities of various government departments and other non-government organizations. Educational articles on earthquake hazards are also written by MEC members in local news media for the general public.

Myanmar Engineering Society, Myanmar Geosciences Society and Myanmar Earthquake Committee are doing their best for mitigation of earthquake risk in Myanmar. One major step gained is the formation of the Committee for Quality Control of High-rise building Projects (CQHP) by the government to look after the design of buildings with nine or more storeys, especially considering earthquake concerns. Due to the formation of this committee, most structural engineers, developers, authorities and building owners are aware of earthquake resistant design. Inspection of construction is also conducted by CQHP.

Paleoseismic studies to evaluate the faults, likely rupture on these faults, and the seismic hazard are going on in Myanmar with the collaboration of Prof. Kerry Sieh, currently at Nanyang Technical University and his students, Prof. K. Stake, currently at Tokyo University, Prof. Tsutsumi of Kyoto University. Myanmar Geologists and post graduate students are also involved in these studies and they themselves also conduct independent research on the active faults of Myanmar.

While there is now significant awareness of earthquake hazards, a lot more needs to be accomplished at every level to make Myanmar an earthquake proof country. Myanmar Earthquake Committee has initiated steps to mitigate losses and earthquake proof the country in order that future Myanmar generations will be protected.

4.2 Historical Changes in Building Design and Construction

According to Dr. Nyan Myint Kyaw (2009), before 1988, most major structures were designed by the government and seismic resistance was optional.

Between 1988 and 2002, the private sector became dominant, and structures 8 stories and more were built in Yangon based on the regulations of Yangon City Development Committee (YCDC).

After 1992, buildings taller than 3-stories required structural analysis and design by a licensed structural engineer, British Standards (BS) and American Concrete Institute (ACI) codes were commonly used. Most buildings were designed for gravity loads only but some were also designed for wind load. Soil investigations were optional until 1999.

After 2003, for structures less than or equal to 2 stories in height, structural analysis and design are optional, for 3 storey structures structural analysis and design is required, but soil investigations were optional. For structures from 4 to 8 stories, both structural analysis and design, as well as soil investigations are required. Structures nine storeys and higher are required to possess seismic resistance. The structural analysis and design process was controlled by CQHP (Committee for Quality Control of Highrise Building Projects). Site inspection during construction is also conducted by CQHP. To date there are less than 50 of these taller structures in Myanmar. Currently the national code is still under development, and several foreign codes can be used for seismic design including BS, ACI, ASCE, UBC, Japanese codes and others. There are currently sufficient facilities for soil investigations for bearing capacity and there is ongoing work to develop facilities and techniques relating to possible settlement and deformation. Analysis and design is conducted using 3-D structural analysis and design software such as ETABS, STAAD Pro and SAP. The recently developed seismic zone map (based on UBC-97 zones) shown in Figure 5 can be used for static analysis but not for response spectrum or time history analysis. Soil maps, and geological formation maps, are being developed. Reinforced concrete is commonly used for most construction. Steel structures are used for a few high rise structures. Formwork is commonly made of timber and plywood. Scaffolding is generally from bamboo and timber. Both of these are generally designed by the contractor. The construction process uses skilled workmen for installing the formwork, bending and fixing the bars, and for masonry work. Ready-mix concrete is available in Yangon. Foundations may be mat, or pile (driven, pushed or bored). Moment frame and dual frame systems are common with brick masonry for walling. While the number of skilled and experienced seismic structural engineers, quality control personnel, and skilled workmen is low, the numbers are increasing especially as a result of government efforts to train people in all aspects of construction particularly through MES and the universities.

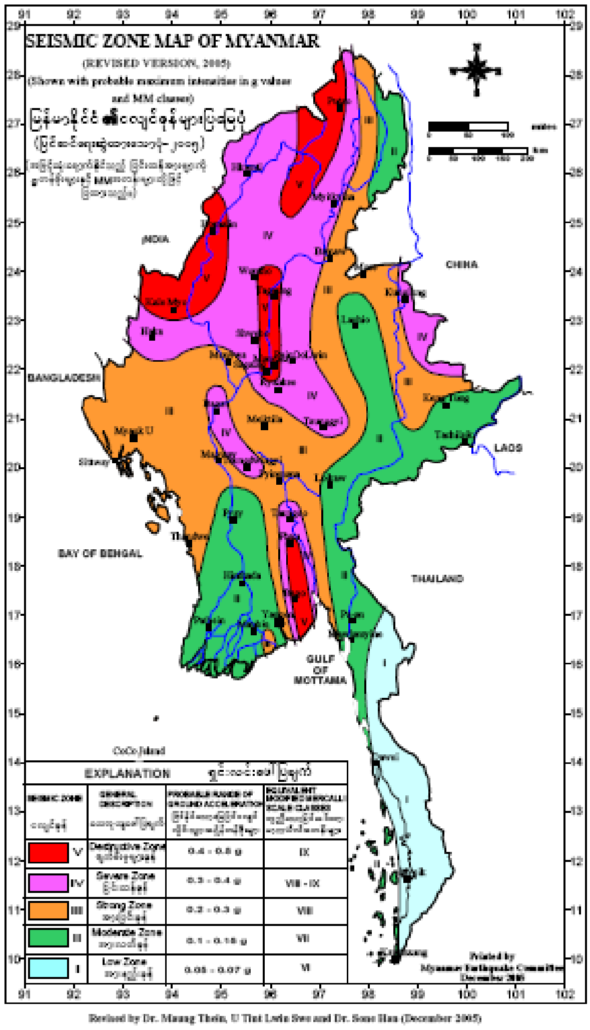

Figure 5. First Generation Seismic Hazard Map based on Historic Seismicity (Dr. Thein, 2009)

4.3 Summary of Recent Activities in Myanmar

To date only a few structures in Myanmar have been designed explicitly to resist strong earthquakes, and there is still some work required to make a robust system. Major steps have been undertaken by the people and government of Myanmar to put in place an infrastructure, such as that shown in Figure 3, so that in the near future there is the possibility of designing almost all of the structures with earthquake resistance. These include:

Developing political commitment. This has been achieved by bringing representatives from many groups, including geologists, engineers and policy makers in the same room, on the same committees and to the same workshops. The Myanmar Engineering Society (MES), supported by the government, was established a few years ago. One of its roles is to address the engineering aspects of earthquake risk. MES has been very active in raising awareness, communicating risk to the public and authorities, organizing local meetings, obtaining the best in overseas knowledge, approving code documents for design, and evaluating at the quality of the design. Under the Myanmar Engineering Society, with its current president U Han Zaw, a number of committees have been established which enable planning to be made for not only natural disasters, but for all engineering related activities. The new headquarters built in Yangon with well-wishers support provide state-of-the-art facilities and a meeting place for many groups wanting to improve engineering. Through MES, the formation of the Committee for High Rise Structures (which evaluates and approves all designs of high rise structures in Myanmar), the Myanmar Earthquake Committee (which encourages geological investigations, response and recovery activities, etc.) and many other committees. Recent international workshops have contributed to this. For example, from 29-30 April 2009, the Myanmar Engineering Society (MES) held its 2nd International Workshop on Seismotectonics in Myanmar and Earthquake Risk Management (SMERM 2009) at the MES building in Yangon in commemoration of the life of Mr Satoru Ohya, a WSSI board member who was deeply committed to Myanmar before he passed away in 2007. The workshop, shown in Figure 6, brought together geologists, seismologists, geotechnical engineers, structural engineers, planners and officials from within Myanmar as well as a number of international speakers. They were in the same room for 2 days and there were talks about a range of topics relevant to Myanmar.

Figure 6. Some Participants at the 2nd International Workshop on Seismotectonics in Myanmar and Earthquake Risk Management (SMERM-09), 29-30 April 2009

The political will to mitigate earthquake loss has increased after Cyclone Nagis, in the same way that disaster preparedness became more a priority in the US after Hurricane Katrina.

Myanmar has legislation processes which are effective in achieving governmental objectives. Earthquake design is mandated for all structures over 8 stories in height and requires seismic design codes to be followed. While Myanmar currently uses many codes, efforts to write a Myanmar building code have initiated.

Efforts are being made to enlarge the skill base of designers and builders. This is being done through the universities, short courses, training programs, etc. The MES is acting as a facilitator for this. With its library, a large amount of information is available. Figure 7a shows some participants at the April 2009 Short Course on the Seismic Design of Structures. The participants in this short course were given pre-course training to ensure that the students would understand what the lecturers in the short course would teach. Lecturers in the short course on structural seismic engineering were Professors Durgesh Rai from IIT Kanpur, Sudhir Jain who is the director of IIT Gandhinagar, and Gregory MacRae from the University of Canterbury. The agenda of the course is given in Appendix 2. The course was simple, without a lot of mathematics, in order to give a good foundation of basic concepts. Field trips, such as that shown in Figure 7b are used to emphasize the connection between theory and practice. Figure 7c shows a prop for training engineers and builders at the MES. The annual MES conference and the development of a MES bulletin provide an opportunity for engineers and researchers to share the latest information. The recent development of the first generation seismic zone map shown in Figure 5 is helpful for design. MES is continuing to plan further courses, such as a short course in geotechnical seismic engineering.

(a) Participants at the Short Course

(b) Site Field Trip as Part of Short Course

(c) A mock-up joint at MES

Figure 7. The 2009 Short Course on Structural Earthquake Engineering at MES

Efforts to monitor the quality and ensure standards are met are being advocated by the MES committees involved with high rise construction.

The public, and the owners of the structures, are continually being made aware of the earthquake risk especially by activities of the Myanmar Earthquake Committee. One of the participants on this committee, a retired geologist and university lecturer, is involved in taking earthquake related articles from the worldwide web, translating them, and publishing them in Burmese. This means that any earthquake damage which occurs anywhere around the world becomes something that individual citizens can see and understand. In addition, television interviews of visiting professionals are used to maintain a high public awareness of earthquake risk.

Costs to provide an infrastructure for compliance with building standards are being met through the MES, governmental agencies and universities. Further funding is needed to continue the good work that has been started by continuing to train designers, builders, and quality controllers. While the additional costs of providing earthquake resistance to a new structure are normally only a small percentage of the total cost, there are more significant costs in retrofitting existing structures and in developing the infrastructure to ensure quality design and construction.

5. FUTURE DIRECTIONS

It was shown above that earthquake proofing a country involves doing more than is currently done in most earthquake resistant zones in the world. In most countries design is carried out to prevent life loss by making sure that structures do not collapse. While the structures may be safe, and may not collapse, structural damage is expected. This damage can occur to non-structural elements (such as internal partitions, ceilings, computers, and so forth) as well as to the structural elements. As a result even well designed structures may need to be replaced, or there may be significant downtime (or business interruption) while the building structures and their non-structural components are fixed. Therefore, structures designed using the current worldwide code methods are not resilient! Really, resilient structures, which will be usable and functional immediately after a major earthquake, are required to earthquake-proof a country. Significant studies have been conducted on these structural types and a number have been constructed around the world. Countries, like Myanmar, which are over the next few years likely to have a massive increase in their building stock, with proper coordination, may be able to avoid the mistakes of many countries and immediately develop resilient structures which will enable them to weather the storms of future earthquakes.

6. CONCLUSIONS

In this paper it was shown that scientists, engineers and policy makers must work together to establish the robust systems to ensure earthquake-proof structures. Such structures are a prerequisite for an earthquake proof country. The aims of the World Seismic Safety Initiative, which is interested in developing earthquake proof societies, were described. Then, a case study is conducted of Myanmar. It is shown that while there is still much to do, Myanmar has made great progress over a short time by setting up an infrastructure to design buildings that will not collapse in earthquakes. Also, a number of structures have been successfully designed.

ACKNOWLEDGEMENTS

Gregory MacRae is grateful to the people of Myanmar, to Myanmar Engineering Society and its president U Han Zaw for the invitation to go to Myanmar after a gap of 6 years to participate as a director of the World Seismic Safety Initiative in the SMERM-09 conference at the end of April 2009 and in the Short Course on Structural Design at the beginning of May 2009. He is also grateful to U Than Myint and people with him, for working with WSSI and other groups over many years to increase the earthquake resistance of Myanmar.

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APPENDIX 1. Summary of Historical and Recent Earthquakes in Myanmar (mostly along the Sagaing fault) (Soe Thura Tun et al. 2009)

Date		Location	Magnitude and/or Brief Description
	1429	Innwa	Fire stopping enclosure walls fell
	1467	Innwa	Pagodas, solid and hollow, and brick monastries destroyed
24 July	1485	Sagaing	3 well known pagodas fell
	1501	Innwa	Pagodas, etc. fell
13 September	1564	Bago	Pagodas including Shwemawdaw and Mahazedi fell
	1567	Bago	Kyaikko Pagoda fell
	1582	Bago	Umbrella of Mahazedi Pagoda fell
9 February	1588	Bago	Pagodas, and other buildings, fell
30 March	1591	Bago	The Great Incumbebt Buddha destroyed
23 June	1620	Innwa	Ground surface broken, river fish were killed after earthquake
18 August	1637	Innwa	River water flush
10 September	1646	Innwa	
11 June	1648	Innwa	
1 September	1660	Innwa	
11 June	1690	Innwa	
15 September	1696	Innwa	4 well known pagodas destroyed
8 August	1714	Innwa	Pagodas, etc. fell. River water gushed into the city
4 June	1757	Bago	Shwemawdaw Pagoda damaged
2 April	1762	Sittway	M=7 destructive shaking felt over Bengal, Rakhine and up to Calcutta
27 December	1768	Bago	Ponnyayadana Pagoda fell
15 July	1771	Innwa	
9 June	1776	Innwa	A well known pagoda fell
26 April	1830	Bago	Some pagodas in the Bago area (Mahazedi and Desunpa) fell
21 March	1839	Innwa	Old palace and many buildings demolished
23 March	1839	Innwa	Pagodas and city walls fell. Ground surface ruptured and river flow revversed for some time. Mingun pagoda shattered. About 300-400 deaths.
6 February	1843	Kyaukpyu	Eruption of mud at the Rambye (Ramree) island
3 January	1848	Kyaukpyu	The civil line and other buildings were damaged
24 August	1858	Pyay	Collapsed houses and tops of pagodas at Pyay, Henzada, and Thayetmyo. Some damage in Innwa, Sittway, Kyaukpyu and Yangon
8 October	1888	Bago	Mahazedi pagoda collapsed
6 March	1913	Bago	Shwemawdaw Pagoda lost its finial
5 July	1917	Bago	Shwemawdaw Pagoda fell
10 September	1927	Yangon	
17 December	1927	Yangon	M=7; extended to Dedaye
8 August	1929	Near Taungoo	Bent railway tracks. Bridges and culverts collapsed. Loaded trucks overturned. (Swa earthquake)
5 May	1930	Near Khayan	M=7.3, MMI = IX. Rupture zone extended north-south for 37km south of Bago. About 50 people in Bago died.
3 December	1930	Nyaunglebin	M= 7.3. Railway tracks twisted. About 30 deaths (Pyu earthquake)
27 January	1931	East of Indawgyi	M = 7.6, MMI = IX. Numerous fissures and cracks. (Myitkyina earthquake)
10 August	1931	Pyinmana	
27 March	1931	Yangon	
16 May	1931	Yangon	
21 May	1931	Yangon	
12 September	1946	Tagaung	M=7.5
12 September	1946	Tagaung	M=7.75
16 July	1956	Sagaing	M=7.0. Several pagodas severely damaged. 40-50 people died.
8 July	1976	Bagan	M=6.8. Several pagodas in Bagan City severely damaged. 1 death.
22 September	2003	Taungdwingyi	M=6.8. Severe damage to rural houses and religious buildings. 7 deaths.

APPENDIX 2. Programme for the 2009 Myanmar Short Course on Structural Seismic Design

Monday, May 4, 2009

9:00 - 9:30 Registration
9:30 - 10:15 Inauguration
10:15 - 11:00 Group Photograph and Tea
11:00 - 11:30 Introduction of Participants and the Course
11:30 - 12:30 Introduction to Engineering Seismology (DCR)
12:30 - 1:30 Lunch
1:30 - 2:30 Myanmar Seismicity and Past Earthquakes (U Than Myint)
2:30 - 3:30 Vibration of Single Degree of Freedom System (GAM)
3:30 - 4:00 Tea
4:00 - 5:00 Concept of Response Spectrum (SKJ)
5:00 - 5:30 General Discussions / Questions (GAM/SKJ/DCR)

Tuesday, May 5, 2009

9:00 - 10:00 Lateral Load Resisting Systems in Buildings (SKJ)
10:00 - 11:00 Lateral Load Distribution in Building Systems (SKJ)
11:00 - 11:30 Tea
11:30 - 12:30 Vibration of Multi Degree of Freedom Systems (GAM)
12:30 - 1:30 Lunch
1:30 - 2:30 Behaviour of Buildings in Past Earthquakes (DCR)
2:30 - 3:30 Concepts of Earthquake Resistant Design (DCR)
3:30 -4:00 Tea
4:00 - 5:00 Some Important Issues in Seismic Design (GAM)
5:00 -5:30 General Discussions / Questions (GAM/SKJ/DCR)

Wednesday, May 6, 2009

9:00 - 10:00 Seismic Code (e.g., UBC) Provisions on Buildings I (GAM)
10:00 - 11:00 Seismic Code (e.g., UBC) Provisions on Buildings II (GAM)
11:00 - 11:30 Tea
11:30 - 12:30 Seismic Design and Detailing of R.C. Frames I (SKJ)
12:30 - 1:30 Lunch
1:30 - 2:30 Seismic Design and Detailing of R.C. Frames II (SKJ)
2:30 - 3:30 Demonstration of Computer Analysis (DCR)
3:30 - 4:00 Tea
4:00 - 6:00 Trip to Construction Site (U Than Myint)

Thursday, May 7, 2009

9:00 - 10:00 Seismic Behaviour, Design, and Detailing of Shear Walls (SKJ)
10:00 - 11:00 Seismic Design of Steel Structures (GAM)
11:00 - 11:30 Tea
11:30 - 12:30 Aseismic Structural Configurations (DCR)
12:30 - 1:30 Lunch
1:30 - 2:30 Seismic Design of Masonry Buildings (DCR)
2:30 - 3:30 Advanced Elastic Analysis Methods (GAM)
3:30 - 4:00 Tea
4:00 - 5:00 Use of Inelastic Analysis (GAM)
5:00- 5:30 General Discussions / Questions (GAM/SKJ/DCR)

Friday, May 8, 2009

9:00 - 10:00 Some Modelling Issues for Computer Analysis of Building Systems (DCR)
10:00 - 11:00 Novel Structural Systems (GAM)
11:00 - 11:30 Tea
11:30 - 12:30 Topics on request (GAM/SKJ/DCR)
12:30 - 1:30 Lunch
1:30 - 2:30 Course feedback, Questions and answers.
2:30 – 3:30 Valediction
3:30 – 4:00 Tea

DCR = Prof. Durgesh Rai (from IIT Kanpur, India)
GAM = Gregory MacRae (from University of Canterbury, New Zealand)
SKJ = Prof. Sudhir Jain (from IIT Kanpur, India)