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Report of the Permanent Committee on Geographical Information System Infrastructure for Asia and the Pacific

Report Of The Working Group 3: Spatially Enabled Government And Society

Submitted by the Permanent Committee on Geographical Information System Infrastructure for Asia and the Pacific (PCGIAP) Working Group 2: Spatially Enabled Government and Society *

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Toyserkani, Vice-Chairmen

Permanent Committee on GIS Infrastructure for Asia and the Pacific

Working Group 3

Spatially Enabled Government and Society

Status Report 2009-2012

for the

19th UNRCC-AP Conference and 18th PCGIAP Meeting

Bangkok Thailand

29th October – 1st November 2012

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1) Resolutions Adopted at the 18th UNRCC-AP (2009)

1) Data Access (parts of)

The Conference,

Recognizing the benefits of having access to data in time of disaster for assessment and relief, but also the ongoing difficulties of many member states in accessing all forms of spatial data, such as GIS, remote sensing and land administration for disaster management.

2) Data Integration (parts of)

The Conference,

Recognizing the importance of integration of fundamental data with other spatial data including hazard and exposure data sets in support of disaster mitigation and reduction,

Also recognizing the power of spatial tools in integrating various data from many sources and multiple formats,

Noting that the discovery, access, integration, and delivery of geospatial data can become much easier with enhanced interoperability.

3) Spatially enabled government and society

The Conference,

Noting the progress made in the development of national spatial data infrastructures in Asia and the Pacific region,

Also noting the global importance of spatially enabled government and society and the outcome of the forum on this matter, convened by PCGIAP and held in Seoul Korea,

Recognizing that spatially enabled government is an important part of the information and communications technology, e-government and information sharing strategies of counties and is the key activity that fosters innovation,

Recommends that PCGIAP undertake a study to understand, compare and determine the state of spatially enabled government and society, including levels of maturity and governance of spatial data infrastructure, in the region.

Activities

PCGIAP Working Group 2 – Geospatial Data Management and Service is currently compiling a survey to collect this information to understand, compare and determine the state of spatially enabled government and society, including levels of maturity and governance of spatial data infrastructure, in the region.

4) Annual forum on land administration (parts of)

The Conference,

Noting the importance of good land administration systems in supporting sustainable development, poverty alleviation, social justice and economic development,

Also noting the role that land administration and the cadastre plays in providing large scale people-relevant spatial data within spatial data infrastructures,

Mindful of the growing importance to integrate all forms of spatial data, and particularly natural and built environmental spatial data in support of spatially enabled society.

Further noting the importance of the Tehran Declaration on Land Administration to support sustainable land markets and e-government,

Recognizing the needs of nations in Asia and the Pacific region to have an annual land administration forum supported by PCGIAP,

Recommends that PCGIAP formalizes and maintains its annual forum on Land Administration in Asia and the Pacific,

Also recommends that PCGIAP renames the existing WG3 (Spatially enabled government) as “Spatially enabled government and society” being responsible for the two inter-connected components of spatially enabled government and society, and land administration. Under the direction of PCGIAP, WG3 facilitates the annual land administration forum and liaises with the respective agencies in the Asia and the Pacific region in pursuit of this objective.

Activities

Adopting the recommendation made at the 18th UNRCC-AP, PCGIAP Working Group 3 was renamed to "Spatially Enabled Government and Society" by the PCGIAP Executive Board at its first meeting immediately following the UNRCC-AP in Bangkok, 29 October 2009.

2) Actions Taken by the Working Group Since the 18th UNRCC-AP

Much has been achieved in applying geo-information to disaster response, especially in using imagery and fundamental spatial data to "record" what disasters took place and what areas were affected. However, these achievements are variable, reactive, often uncoordinated and not to appropriate standards and/or practices. Further, the ability to apply geo-information technologies to disaster mitigation and reduction (before events happen) has been limited due to a lack of capacity and capability within many member nations.

There are also ongoing and consistent factors that are challenging the establishment and use of geo-information in disaster risk management: the nature and culture of disaster management; and the lack of appreciation/recognition/availability of geo-information tools. Disaster management, especially the crisis response period, presents unique requirements. Decisions have to be made quickly, often under extreme pressure; there is a lot of uncertainty, due to lack of timely information; and decision making is often based on experience and intuition rather than information.

With this in mind, PCGIAP WG3: Spatially Enabled Government and Society is reporting on a number of endorsed case study activities that demonstrate efforts being made by member countries to improve access to data so as to support disaster management in a number of ways, including capturing timely data to support regional hazard assessment, and enable nations to understand and pursue the principles of data integration within the context of spatially enabled society.

These activities contribute to and complement the objectives of WG2: Geospatial Data Management and Service.

1) Case Study 1: Geospatially Enabling the Australia-Indonesia Facility for Disaster Reduction (AIFDR) in Jakarta

In April 2009, the Australian and Indonesian Governments established the Australia-Indonesia Facility for Disaster Reduction (AIFDR) in Jakarta. The AIFDR is a unique partnership through which both countries work together to reduce the risk of natural disasters. It reflects Indonesia and Australia's concern over the growing impact of disasters in the region, including their potential for human suffering and the reversal of hard-won development gains.

The AIFDR supports Indonesia's goal to strengthen national and local capacity in disaster management and to promote a more disaster resilient region. AIFDR supports a range of capacity building and community outreach programs to build Indonesia's disaster management expertise and capacity. AIFDR also supports Indonesian science agencies and Universities to better identify and quantify the natural disaster hazards and risks in Indonesia, and then uses this information to support training and planning exercises for national-level and provincial-level disaster managers.

This end-to-end approach to saving lives was demonstrated through AIFDR's recent work in pioneering the use of realistic natural hazard disaster scenarios as a rigorous foundation for better contingency planning and preparedness. For example, in Jakarta the AIFDR, World Bank and UNOCHA, have worked with the local disaster management agency, university students and representatives from every Jakarta village to map over 6,000 critical facilities, including schools, hospitals and government offices using OpenStreetMap technologies. This was then combined with flood modeling to estimate the likely impact of future floods.

This information is now being used to ensure that the government of Jakarta is better prepared to manage and reduce the impact of future floods. Through building the capacity of science agencies and working closely with disaster managers and communities, the AIFDR is ensuring that better knowledge of disasters is easily understood, believed and, above all, actioned.

The AIFDR is also now working with the Indonesian Geospatial Agency (BIG) and the World Bank to help integrate community mapping approaches into Indonesia's definitive mapping systems through the new Participatory One Map Initiative.

2) Case Study 2: Post-Disaster Data Collection, West Sumatra Earthquake, Indonesia, September 2009

The final report on Case Study 2: Post-Disaster Data Collection, West Sumatra Earthquake, Indonesia, September 2009 has been compiled in a Geoscience Australia record titled *The*

30TH September 2009 West Sumatra Earthquake[1] and is attached.

3) Case Study 3: Strengthening Spatial Data Development and Delivery in the Philippines

In order to accurately analyse the risk from natural hazards, detailed geographic information is required to represent or derive: hazard; exposure; vulnerability; and topography. To assist in developing these fundamental datasets, it was determined that airborne Light Detection and Ranging (LiDAR) would provide the most detailed and versatile solution. In collaboration with the Philippines National Mapping and Resource Information Authority (NAMRIA), Geoscience Australia (GA) and AusAID, Fugro Spatial Solutions was engaged to acquire LiDAR, imagery and derived digital elevation model (DEM) products covering the Greater Metro Manila Area (GMMA) project extent. GA was responsible for project design, management and quality control.

Following acquisition and delivery of the LiDAR and related data, several NAMRIA staff travelled to Australia for training, knowledge transfer and to assist with validation and testing. A preliminary dataset was officially handed over to the Philippine Government in September 2011. At that time, Presidential Advisor on Environmental Protection, Mr. Nereus Acosta, Government of Philippines, provided a very pertinent observation with regard to monitoring and measuring the environment and sustainable development: *"How can you manage that which you cannot measure? This (data) can be used for measuring. Otherwise, how can you monitor effectively that which you cannot map?"*

Following delivery of the preliminary data each of the other components were able to start using the derived digital elevation models for hazard modelling and to assist feature extraction.

Digital Stereo imagery was also acquired to assist validation and improve the LiDAR classification and revising exposure information. Additional hardware and software was

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[1] *The 30TH September 2009 West Sumatra Earthquake,* Sengara, I.W.; Suarjana, M.1; Beetham, D.; Corby, N.; Edwards, M; Griffith, M.; Wehner, M.; Weller, R. – GA Record 2010/44

purchased and installed in NAMRIA to assist in managing, updating and distributing these large volume datasets. Geoscience Australia officers travelled to Manila in March 2012 to provide technical training on the new software for NAMRIA and conducted a LiDAR information seminar for all project partners.

GA will continue to assist NAMRIA to improve the LiDAR and their capacity to extract the most value from it, during the next twelve months.

4) Case Study 4: Enhancing Risk Analysis Capabilities for Flood, Tropical Cyclone, Severe Wind, and Earthquake for Greater Metro Manila Area, Philippines

The Philippines experiences some of the world's worst natural hazards, being exposed to frequent earthquakes, floods, tsunami, landslides, volcanic eruptions, cyclones and annual monsoons. The Greater Metro Manila Area (GMMA), which includes Metro Manila, is particularly vulnerable to the devastating effects of natural disasters, with a population of 21 million residing on land that is cut by active earthquake faults and subject to intense riverine flooding. The GMMA is also frequently affected by typhoons, which can result in severe wind damage, storm surge and intense flooding. Landslides, tsunamis and volcanic eruptions also pose a risk to residents within the GMMA. The risk from these natural hazards is further exacerbated as poverty often results in populations residing in buildings that are not built to withstand these hazards or in areas that are frequently affected by flooding, such as along flood drainages.

The goal of this Activity is to analyse the risk from flood, severe wind and earthquake in the GMMA through the development of fundamental datasets and information on hazard, exposure and vulnerability. The GMMA program of work is divided into six components which are at various stages of completion:

1. **Digital elevation for GMMA -** Base datasets fundamental to natural hazard risk analysis, such as high-resolution digital elevation models have been developed for the GMMA for analysis of natural hazard risk and climate change impacts.

2. **Development of an exposure database for GMMA -** Technical specialists are improving their understanding and capability to produce exposure databases, and exposure information is being developed for the GMMA.

3. **Flood risk modeling in GMMA** - Scientists are building their capacity to better assess

the risk and impacts from flood in the Pasig-Marikina Basin and are gaining an improved understanding of these risks.

4. **Tropical cyclone severe wind risk modelling in GMMA** - Scientists are building their capacity to better assess the risk and impacts of typhoon severe wind are gaining an improved understanding of these risks in the GMMA.

5. **Earthquake risk modeling in GMMA** - Scientists are building their capacity to better assess the risk and impacts of earthquakes and are gaining an improved understanding of these risks in the GMMA.

6. **Establishment of governance arrangements** and other activities, including those related to the broader Metro Manila Rehabilitation and Recovery Program.

This Activity will begin its final year in July 2012 and will be completed 30 June 2013.

5) Activities for: Resolution 5. Spatially Enabled Government and Society; and Resolution 6. Annual Forum on Land Administration

The fourth PCGIAP Land Administration Forum was held in Melbourne, Australia, 5-7 October 2011. Over 110 participants representing 15 countries and 14 organisations attended the forum to consider the focus theme “Beyond Spatial Enablement”. There were four key areas of discussion that addressed the outcomes of the third Land Administration Forum for Asia and the Pacific hosted by the Iranian Government in 2009. As aims and objectives these were:

- To discuss mapping, spatial information, SDI and land administration strategies to facilitate spatially enabled government;
- To share land administration experiences in the Asia and Pacific region with a focus on delivering spatial enablement;
- To share land administration experiences in the Asia and Pacific with a focus on national land administration and 3D cadastre to support e-government; and
- To discuss the role of land administration and mapping agencies in developing a vision for “beyond spatial enablement”.

Worldwide challenges were examined and new UN initiatives being implemented in support of spatially enabled government and society were also considered. It was recognised that regional initiatives and activities undertaken by PCGIAP members in their own jurisdictions in the pursuit of spatial enablement were occurring at different scales from local government to global organisations. The realisation that spatial enablement was impacted by the existence of data silos, making the discovery, access, use and sharing of spatial data still a significant challenge.

The convergence of many economic, social, environmental and national security drivers with location has provided spatial enablement with an increasingly prominent profile on the local and global stage. The emergence or shift in focus towards spatial data underpins a worldwide trend towards growth in the GIS market due to four key areas: location as the fourth driver in decision-making; the role of the cadastre and land administration in spatial enablement; good land governance to facilitate spatially enabled government to build capacity for addressing the global agenda; and the primacy of a spatially enabled government in achieving sustainable development; were considered integral in the spatial enablement of Government and Society.

Emerging trends for future direction were: participation trends especially pertaining to users, the need to differentiate between high accuracy data and other information (including crowd-sourced), evolving standards, growing awareness for open access to data and a focus on service delivery. These emerging trends will provide the basis for the development of new strategies to provide the foundation for future international activities by participants in line with the objectives of the PCGIAP (in particular, WG3), GSDI and FIG, as well as fostering collaborations with global organisations.

The International Symposium on Spatially Enabled Government and Society – "Towards Spatial Maturity" was held in Kuala Lumpur, Malaysia 14–16 February 2012. Over 270 participants representing 19 countries and 108 organisations attended the symposium to consider the focus theme "Spatially Enabled Society" or SES.

Discussions during the symposium centred on the challenge for societies and their governments to become spatially enabled in order to make the right decisions to manage land and water related activities in a sustainable way. SES will be more readily achieved by increasing involvement of and establishing partnerships with the private sector, the public, academia and across all levels of government. The premise for the symposium was that spatial information and data add valuable dimensions to governance decision making processes and supports societies' involvement in the governance process in the pursuit of economic, social, political and environmental objectives.

The symposium addressed 3 key areas: the spatial needs of societies; the role of land administration, management and governance in SES; and the key elements for an SES. It was concluded that there are six fundamental elements required to realise the vision of a spatially enabled society and defined in more detail in FIG Report Number 58 – "Spatially Enabled Society":

- **a legal framework** to provide the institutional structure for data sharing, discovery, and access;
- **a sound data integration concept** to ensure multi-sourced data integration and interoperability;
- **a positioning infrastructure** to enable and benefit from precise positioning possibilities;
- **a spatial data infrastructure** to facilitate data sharing, to reduce duplication and to link data producers, providers and value adders to data users based on a common goal of data sharing;
- **land ownership information**, as the dominant issue in the interactions between government, businesses and citizens relating to land and water resources; and
- **data and information** to respect certain basic principles and to increase the availability and interoperability of free to re-use spatial data from different actors and sectors.

Future activities need to take into account emerging trends in geospatial information and the new opportunities they present for the application of spatial technologies and geographic information. These trends include:

- Location as the fourth element of decision-making;
- Differentiating between information sources - authoritative and volunteered;
- Changing directions in the use of spatial information: underpinning decision making, simple to complex, autonomous to interdependent, spatial ubiquity;

- Growing awareness for openness of data e.g. licensing, and resultant improvements in data quality;
- Recognising spatial information underpins service provision; and
- Recognising the difference between spatial enablement and spatial dependency.

The symposium noted five critical elements that need to be continually addressed, monitored and evaluated in order to achieve spatial maturity:

- Improving the appeal of spatial information beyond traditional users;
- Institutional processes to facilitate spatial enablement, particularly around information policies, access, and risk management;
- Capacity building e.g. research and education, bandwidth;
- Standards and licensing as a means to enable and facilitate partnerships; and
- Creating a seamless platform.

The solutions that underpin the needs of societies are increasingly extending beyond a national scale into the regional and global scale. Spatial data and information, plays a key role in underpinning optimal decision making in relation to complex issues through the analysis of fundamental public good spatial information

Key outputs from the symposium were:

- Kuala Lumpur Declaration on Spatially Enabled Government & Society
- FIG Report number 58 – “Spatially Enabled Society”

Action: PCGIAP to note both documents which are tabled with this Report.

6) Future Workplan

The proposed Workplan for the next 3 years is as follows:

No	Activities/ Steps	Date
1	Presentation of the results of work on Land Administration and Spatially Enabled Government and Society.	2012 - 2015
2	Facilitate and coordination of Land Administration Forum meetings and Seminars in the Asia - Pacific Region	2012 - 2015
3	Report on outcomes of WG3 activities (including analysis of current projects, recommendations, future plan, etc.)	PCGIAP Meetings

Annexed

1. Steudler D & Rajabifard A (2012), Spatially Enabled Society. Joint publication of FIG-Task Force on “Spatially Enabled Society” in cooperation with GSDI Association and with the support of Working Group 3 of the PCGIAP. Retrieved from http://www.fig.net/pub/figpub/pub58/figpub58.pdf

2. Kuala Lumpur Declaration on Spatially Enabled Government & Society. Declaration of the International Symposium on Spatially Enabled Government and Society – “Towards Spatial Maturity”, Kuala Lumpur, Malaysia 2012.

3. Rajabifard A (2011), “Beyond Spatial Enablement”, Proceedings of the 4th Land Administration Forum to Support Spatially Enabled Government, Report on the United Nations Sponsored Permanent Committee on GIS Infrastructure for the Asia Pacific Region Working Group 3 – Spatially Enabled Government and Society, Melbourne Australia 2011

4. Sengara I.W.; Suarjana, M.1; Beetham, D.; Corby, N.; Edwards, M; Griffith, M.; Wehner, M.; Weller, R. 2010. The 30th September 2009 West Sumatra Earthquake, Padang Region Damage Survey. Geoscience Australia Record 2010/44. 201pp.

ANNEX 1

FIG PUBLICATION
NO 58

FIG REPORT

Spatially Enabled Society

Editors
Daniel Steudler and Abbas Rajabifard

Supported by:

GSDI
Global Spatial Data Infrastructure Association

INTERNATIONAL FEDERATION OF SURVEYORS (FIG)

PERMANENT COMMITTEE ON GIS INFRASTRUCTURE FOR ASIA & THE PACIFIC

Spatially Enabled Society

Joint publication of FIG-Task Force on "Spatially Enabled Society"
in cooperation with GSDI Association
and with the support of Working Group 3 of the PCGIAP

Edited by
Daniel Steudler and Abbas Rajabifard

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CONTENTS

LIST OF ABBREVIATIONS

AAA	Accurate, Authoritative and Assured geospatial datasets
CORS	Continuously Operating Reference Station
FIG	Fédération Internationale des Géomètres (International Federation of Surveyors)
GGOS	Global Geodetic Observing System
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSDI	Global Spatial Data Infrastructure
ICT	Information and Communication Technology
IGS	International GNSS Service
IMU	Inertial Measurement Units
ISO	International Organisation of Standardisation
ITRF	International Terrestrial Reference Frame
LBS	Location Based Services
MEP	Member of the European Parliament
NGO	Non-Governmental Organization
NMCA	National Mapping and Cadastral Agencies
NSDI	National Spatial Data Infrastructure
OGC	Open Geospatial Consortium
PI	Positioning Infrastructure
POI	Points of Interest
RRR	Rights, Restrictions, Responsibilities
SDI	Spatial Data Infrastructure
SEG	Spatially Enabled Government
SES	Spatially Enabled Society
UN-ECE	United Nations Economic Commission for Europe
UN-GGIM	United Nations Global Geospatial Information Management

FOREWORD

This publication on "Spatially Enabled Society" is the culmination of a three-year effort by the Task Force that was established by the General Assembly of the Federation in May 2009. The Task Force included representations from the Global Spatial Data Infrastructure Association and Working Group 3 of the United Nations sponsored Permanent Committee on GIS Infrastructure for Asia and the Pacific. This is a collaborative effort led by the FIG Task Force and the publication has been compiled and edited by Dr. Daniel Steudler, Chair of the FIG Task Force on Spatially Enabled Society, and Prof. Dr. Abbas Rajabifard, President of the GSDI Association.

The rapid development and increased demand for spatial information infrastructures in many jurisdictions these past many years have made spatial information an invaluable tool in policy formulation and evidence-based decision making.

Spatial enablement, that is, the ability to add location to almost all existing information, unlocks the wealth of existing knowledge about social, economic and environmental matters, play a vital role in understanding and addressing the many challenges that we face in an increasingly complex and interconnected world. Spatial enablement requires information to be collected, updated, analysed, represented, and communicated, together with information on land ownership and custodianship, in a consistent manner to underpin good governance of land and its natural resources, whole-of-government efficiency, public safety and security towards the well being of societies, the environment and economy.

The main issue societies have to focus on is probably less about spatial data, but much more about "managing all information spatially". This is a new paradigm that still has to be explored, deliberated and understood in the context of a spatially enabled society.

This collaboration between FIG and GSDI is within the aim of the MoU signed in 2010 between these two professional bodies. Together with PCGIAP WG3, this collaboration has allowed for the participation and contribution from contributors and authors with varied expertise, from differing backgrounds and in different regions of the world.

We would like to congratulate the FIG Office, members of the Task Force, all contributors, all co-authors and the two editors for this superb effort. We extend the deep appreciation and gratitude of our Federation and Membership for their invaluable and unselfish contributions.

CheeHai Teo
President

April, 2012

EXECUTIVE SUMMARY

The needs of societies are increasingly of global scale and require spatial data and information about their land, water and other resources – on and under ground – in order to monitor, plan, and manage them in sustainable ways. Spatial data and information, land administration, land management, and land governance play crucial roles in this.

Spatial enablement is a concept that adds location to existing information, thereby unlocking the wealth of existing knowledge about land and water, its legal and economical situation, its resources, access, and potential use and hazards. Societies and their governments need to become spatially enabled in order to have the right tools and information at hand to take the right decisions. SES – including its government – is one that makes use and benefits from a wide array of spatial data, information, and services as a means to organize its land and water related activities.

This publication focuses essentially on six fundamental elements, which are required to realize the vision of a SES:

1. a **legal framework** to provide the institutional structure for data sharing, discovery, and access;
2. a sound **data integration concept** to ensure multi-sourced data integration and interoperability;
3. a **positioning infrastructure** to enable and benefit from precise positioning possibilities;
4. a **spatial data infrastructure** to facilitate data sharing, to reduce duplication and to link data producers, providers and value adders to data users based on a common goal of data sharing;
5. **land ownership information**, as the dominant issue in the interactions between government, businesses and citizens relating to land and water resources; and
6. **data and information** to respect certain basic principles and to increase the availability and interoperability of free to re-use spatial data from different actors and sectors.

Land and spatial information professionals play a primary role in translating raw data into useable spatial knowledge resources. These professions should ensure that both the social and technical systems in which spatial enablement will operate within are well understood. Spatial enablement can only be effective when it is designed with the specific needs of the jurisdiction in mind.

The concept of SES is offering new opportunities for government and the wider society, but it needs to move beyond the current tendency for the responsibility to achieve SES to lie solely with governments. SES will be more readily achieved by increasing involvement from the private sector, and in the same vein, if the surveying and spatial industries start to look toward other industries for best practices in service delivery.

Future activities need to take into account emerging trends in spatial information and the new opportunities they present for the application of spatial technologies and geographic information. These trends include among others:

- location as the fourth element of decision-making;
- differentiating between authoritative and volunteered information, yet recognizing the importance and value of both types of information towards spatial enablement and the enrichment of societies;
- growing awareness for openness of data e.g. licensing, and resultant improvements in data quality;
- move towards service provision.

1 INTRODUCTION

Daniel Steudler and Abbas Rajabifard

Our society today is being challenged by issues of global scale: economic development, social conflicts, urban growth, rural development, climate change, global warming, carbon credit management, or disaster management, are just a few issues that need careful assessment and sustainable action. In one way or another, all those issues are linked to location, as "everything happens somewhere", i.e. there is need for effective and efficient geoinformation.

Spatial is no longer special. In fact, spatial is everywhere and our ability to leverage and harness the ubiquity of spatial information will correlate to benefits in terms of wealth creation, social stability and environmental management. Spatial information intrinsically reflects the relationship between people and land by connecting activities to location.

Location is increasingly regarded as the fourth driver in decision-making, in addition to social, economic and environmental drivers. Consequently, land-related information has a key role in spatial enablement where good land governance can facilitate the delivery of a spatially enabled government to respond to the global agenda and achieve sustainable development. Societies and their governments need to become spatially enabled in order to have the right tools and information at hand to take the right decisions.

As surveyors and spatial information specialists, our professions perform a fundamental role in the flow of spatial information through society by translating raw data about land into spatial information. Assisted by new digital technologies, all levels of society are increasingly able to augment current sources of spatial information with their own personal datasets to generate new knowledge resources – the plethora of spatial mashups and crowd-sourced initiatives are testament to increasing levels of spatial utility, or spatial enablement, and contributing to the vision of a spatially enabled society.

We know that spatial enablement is not just about developing and using geographic information system (GIS) technologies. We know that the vast majority of the public are users, either knowingly or unknowingly, of spatial information. We know that a spatially enabled society will demand accurate and timely information about land. For spatial enablement to occur, it needs to be regarded as a concept that permeates all levels of society – government, industry and citizens, and its ability to flow through all levels of society will depend primarily on the spatial data infrastructure (SDI) and land administration system available in the jurisdiction (Williamson et al., 2010a; Williamson et al., 2010b).

Therefore the aim of the "FIG-Task Force on Spatially Enabled Societies" – in cooperation with other global organisations – is to focus on the term "Spatially Enabled Societies" (SES) and the issues linked with it; to come up with a definition of SES; and to support the surveying profession to become aware of those issues in order to provide the appropriate services.

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2 SPATIAL NEEDS OF SOCIETIES

Daniel Steudler and Abbas Rajabifard

When looking at media reports from the last six to 12 months, there are many examples of where sound land information and good land administration and management systems are needed.

In many large cities, the phenomenon of urban sprawl is creating huge problems, as can be seen in the example of Jakarta described by Philip (2010). The Indonesian capital with a population of 9.6 million is facing problems such as pollution, overpopulation, traffic congestions, inefficient transport systems, and urban sprawl without proper planning. In the face of these challenges, the Indonesian authorities are even considering options to move the capital to somewhere else in order to overcome them. The opposition and NGOs, however, are suggesting "to improve the existing city rather than moving into the jungle, and to create incentives to draw the middle classes back into the city centre. Just as elsewhere, high rents have driven many away – and the proliferation of lavish shopping malls has fuelled property speculation. We have to rethink the way we use land, encourage people to move back and stop building tower blocks. Land is crucial and we need the relevant information in order to manage it well". The call for better land information is a strong one, as it is the basis for the analysis and solution to the multiple problems and the well-being of huge populations.

In disaster management, there is also a strong need for sound land information. Mitchell (2010) describes three main threats to landholders in disasters. "First, there are material threats caused by displacement, including the risk of land grabbing and coercion to sell, the need for temporary shelter and resettlement, and the impact of resettlement on those with insecure tenure. A second category of threats is the material threats caused by destruction. These include damage to property, degradation, loss of official records, a reduced capacity of authorities to carry out their duties, and damage to boundary marks. The third type of threat is administrative, post-disaster. These include limited public sector capacity, planning rule changes and inadequate compensation".

A concrete example of these threats is the natural disaster management after the flooding in Brazil in January 2011 and again in March 2011. There were calls that these disasters could have been prevented by the establishment and proper use of hazardous zone definitions, of preventing building houses in those areas, and of flood prediction models. Another example was the 2004 tsunami, which destroyed much of the infrastructure in several countries. Already weak land registration and cadastral systems have become defunct after the disaster, and for financial speculators, it was effortless to manipulate land registration documents and to evict previous landowners. In Aceh, about 80% of the land documents have been destroyed, which posed huge problems for the reconstruction (Abidin et al., 2006). The post-disaster plight in Haiti after the 2010 earthquake revealed similar needs. Commentators were suggesting three building blocks for the reestablishment of a functioning society: nation building, the establishment and enforcement of law and order including land ownership, and the education of people in order to enable them to self-help (Kappeler, 2010).

An example of land grabbing has been described by Bunting (2011). In Mali, an international development company has built a 40km long water irrigation canal mandated by the government. The canal, however, displaced many local people living on the ground for generations. The development company claimed that planning of the canal has been based on maps that show the actual landownership. However, the map did not reflect the actual status on the ground as Mali has almost no private land titles and land is owned ultimately by the state. This has been interpreted with respect for customary land use, though it is not clear how the rights of those living on the land will be protected. Already, more than 150 families have been forced off the land to make way for the canal. Campaigners worry that this is only the beginning: "Even if the land does belong to the government, the people living on it still have rights, and we will do everything to fight against this injustice" (compare Figure 2.1).

Those examples from developing countries show urgent needs for efficient land administration and management systems based on sound spatial land information. In developed countries at the same time, there are important needs to have reliable spatial information as well. Due to the density of the population and the land use, existing cadastral system in such countries are to be extended to also accommodate information that reflects this use. One example is the discussion of 3D Cadastres, i.e., the extension of cadastral systems with the 3rd dimension in order to document the definition of ownership rights in condominiums.

In this same context, the paradigm of landownership rights extending up in the sky and down to the centre of the earth might no longer apply and needs discussion. In urban areas, street or railway tunnels might be built 10–20 m below existing properties and buildings. What is the legal situation when those landowners would like to drill their 100 m bore hole for geothermic heating? Such facts as well as public-law restrictions that potentially impact on the use of the land need to be documented in order to keep the land market transparent. Traditional cadastres documenting private-law rights can be extended in order to accommodate such land related issues.

There are many challenges and needs of our national societies. They are also of global scale and impact on all our lives. The spatial location and land information is in most cases crucial for responding to those needs; and while ownership information is not the sole information, it is more often than not at the core of the solution.

Mali: Whose land is it, anyway?

- Building of new irrigation canal by Government backed international contractors;
- scheme to raise agricultural yields and improve food security (of already intensively used land);
- Mali is a country where 80% of the people depend on subsistence farming for their livelihood;
- fear that this will deprive subsistence farmers of their land and food;
- farmers are promised compensation for their land, and that there will be jobs.

"The compensation they gave was not enough to build a new house," he says. "We are very deeply shocked. I have lived here all my life but I was told my smallholding was not on the map used by Malibya to build the canal. They took me to the tribunal and I was told that I had built on land where building was not allowed – and I lost my home. "This project is good for the government but it is not good for the people."

The Guardian Weekly 21.01.11 **43**

Figure 2.1: *Example of newspaper report on land grabbing.*

In the face of such complex and multi-scale challenges, spatial information and technology can be an effective tool to contribute to dealing with the challenges that society is facing. The notion of spatial enablement, and a spatially enabled society, is a reference to the use of spatial technology across all levels of society – government, industry and citizens, to improve decision-making, transparency and increase efficiency. In this regard, it is essential that land and spatial information practitioners provide the link to ensure that both the social and technical systems in which spatial enablement will operate within are understood: spatial enablement can only be effective if it is designed with the specific needs of the jurisdiction in mind.

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3 THE ROLE OF LAND ADMINISTRATION, LAND MANAGEMENT AND LAND GOVERNANCE IN SPATIALLY ENABLED SOCIETIES

Daniel Steudler and Abbas Rajabifard

Over the last 15–20 years, the topic of cadastre and land registration has been discussed extensively. The FIG-statement on the cadastre (FIG, 1995) established that the "cadastre assists in the management of land and land use, and enables sustainable development and environmental protection". In the 1990s the UN-ECE (1996) coined the term "land administration" in order to express the broader need and use of land information for managing the land as an asset. The Bathurst Declaration concluded in 1999 that sustainable development is the key driver influencing the humankind to land relationship and that it needs sound land administration (UN-FIG, 1999).

3.1 *Land Administration and Land Management in Context*

Land administration and management are serving the particular needs of societies as discussed in chapter 2. A spatially enabled society certainly needs well organized and efficient land administration and land management systems. The context of administration and management and their respective tools and methods are illustrated in Figure 3.1.

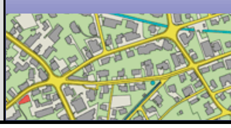
Tasks	Land related activities	Tools / Methods
Strategy • visions and objectives	**Land policy**	• political activities
Management • measures and projects for the implementation of the policy	**Land management** 	• land-use planning • land consolidation • land reallocation • melioration • landscape develop-ment • land recycling
Administration / Documentation • handling of spatial information, data analysis, data visualization • cadastral operations, data modelling, data acquisition, data maintenance, data distribution	**Land administration and cadastre** 	• monitoring • navigation • geoinformation • land registration • cartography • surveying • geodesy

Figure 3.1: *The broader context of land documentation, land administration and land management (adapted from Kaufmann, 2008).*

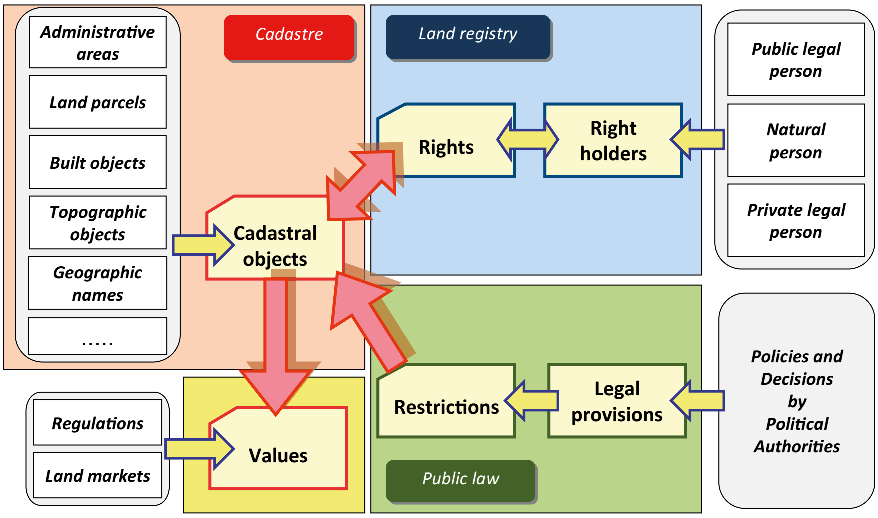


Figure 3.2: *Elements of a land administration system (from Horisberger, 2010).*

3.2 Elements of a Land Administration System

A land administration system has originally been defined by the UN-ECE as the "processes of determining, recording and disseminating information about the tenure, value and use of land when implementing land management policies". The land administration system is a basic foundation for the spatial enablement of a society and is considered to include land registration, cadastral surveying and mapping, fiscal, legal and multi-purpose cadastres and land information systems (UN-ECE, 1996).

Horisberger (2010) proposes a set of basic elements that a land administration system consists of. Those basic elements are (compare Figure 3.2):

- **cadastre** with the basic entity "cadastral object", i.e. land parcels, built objects, topographic objects, or administrative areas;
- **land registry** with the basic entities of ownership rights and rights holders;
- **land valuation** with the basic entities of land market value and regulations, based on land parcels;
- **public-law issues** with the basic entities of restrictions (with spatial extend) and legal and political provisions.

It is of course possible that a land administration system has more elements than those four basic ones. A society through its adopted land policy would have to define these other elements depending on the need. What is important is that all these elements have a link to the geographic location as they are documenting legal and administrative issues happening at a specific geographic location.

3.3 Land Administration and Spatial Data Infrastructure (SDI)

Due to sustainable development drivers and the need to manage an increasingly complex array of land rights, restrictions and responsibilities (RRRs), land administrations systems are starting to support more sophisticated land markets which include complex commodities (Williamson et al., 2005).

However, the realisation of sustainable development objectives necessarily requires the integration of cadastral data (built environment) with topographic data (natural environment) (Williamson et al., 2005). The SDI concept, which facilitates the sharing, access and utilisation of spatial data across different communities to better achieve their objectives, provides a mechanism to facilitate this integration of cadastral and topographic data to facilitate decision-making. Indeed, the importance of this relationship was underscored in the Bogor Declaration on Cadastral Reform in 1996 which stated that the spatial cadastral framework – usually a cadastral map – should be a fundamental layer within a national SDI (FIG, 1996). Land administration typically generates information about places while SDIs organize spatial information. Together, they can provide information about unique places people create and use.

3.4 Towards Land Governance

'Land administration' and 'land management' are concepts that have been widely discussed and used within FIG for many years. More recently, the term 'land governance' has been introduced, conceptualized as an elaboration of the broad notion of 'good governance' particularly with relevance to land management issues.

The term 'land governance' has become a widely accepted concept globally, and generally refers to the "the policies, processes and institutions by which land, property and natural resources are managed" (Enemark, 2009, p. 4). This includes access to land, land rights, land use and land development: essentially, land governance is about determining and implementing sustainable land policies and inherent to this, is the legal and institutional framework for the land sector (FIG, 2010).

Therefore, land administration systems provide the basis for conceptualising rights, restrictions and responsibilities; land administration functions form the operational component of land management; land governance enables the determination of land policies that direct land administration systems and land management practices so that these can be effectively implemented to ensure sustainability.

By bringing together the various strands – land administration, land management and land governance, we can create a strong framework by which land and natural resources can be effectively managed to fulfil political, economic and social objectives, that is, to help realize sustainable development objectives.

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4 KEY ELEMENTS FOR A SPATIALLY ENABLED SOCIETY

Daniel Steudler and Abbas Rajabifard

SES and its role in government and society

Spatial enablement is a concept that adds location to existing information and thereby unlocks the wealth of existing knowledge about the land, its legal and economical status, its resources, potential use and hazards. Spatial enablement uses the concept of place and location to organize information and processes and is now a ubiquitous part of e-Government and broader government ICT strategies (compare Figure 4.1). Information on landownership is thereby a basic and crucial component to allow for correct decision-making. Such data and information must be available in a free, efficient, and comprehensive way in order to support the sustainable development of society. It therefore needs to be organized in such a way that it can easily be shared, integrated, and analysed to provide the basis for value-added services.

However, SES, and inherent to this, the concept of Spatially Enabled Government (SEG), has gained momentum internationally as jurisdictions begin to recognize the benefits it delivers. This can be seen in the number of conferences, symposiums, and numerous activities that have been organized around the theme of spatial enablement. SEG is now part of the objectives of governments in many countries, highlighting the importance of spatial information and strategies in policy development and decision-making in the public sector. SEG increasingly operates in a virtual world, but SEG initiatives need to be coupled with real world institutional and structural reforms in the use of spatial information and spatial data infrastructures as an enabling platform.

Therefore, a society can be regarded as spatially enabled when location and spatial information are commonly available to citizens and businesses to encourage creativity

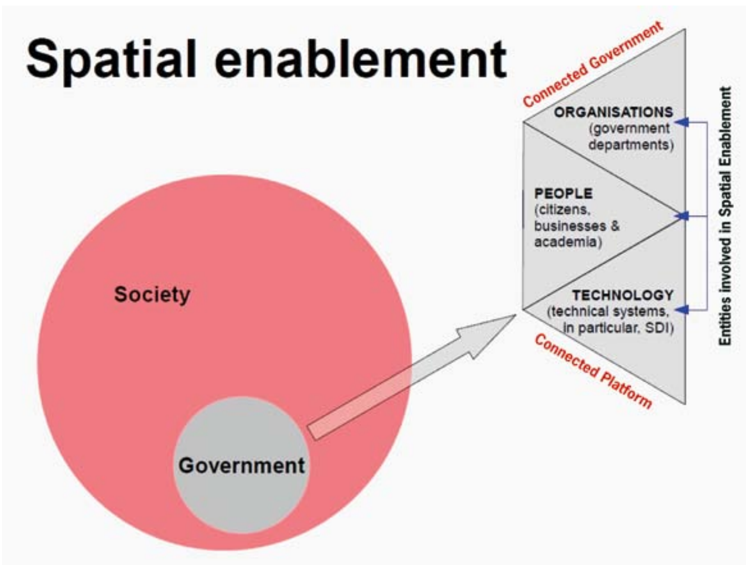

Figure 4.1: *Concept of spatial enablement and how it relates to social and technical systems within a society (adapted from Holland et al., 2009).*

and product development (Wallace et al., 2006), and it is also defined as an innovator and enabler across society and a promoter of e-Democracy.

Spatial enablement, and therefore SES, should be regarded as an evolving definition. Similar to other emerging concepts, there are different views on spatial enablement but essentially it requires data, and in particular, services, to be accessible and accurate, well-maintained and sufficiently reliable for use by the majority of society which is not spatially aware.

Definition

The Task Force agreed on the following definition for the term "Spatially Enabled Society", which not only focuses on land, but also includes water:

> A spatially enabled society – including its government – is one that makes use and benefits from a wide array of spatial data, information, and services as a means to organize its land and water related activities. Spatial enablement is a concept that adds location to existing information and thereby unlocks the wealth of existing knowledge about land and water, its legal and economical status, its resources, potential use and hazards. Information on the ownership of land and water is thereby a basic and crucial component to allow for correct decision-making. Such data and information must be available in a free, efficient, and comprehensive way in order to support the sustainable development of society. It therefore needs to be organized in such a way that it can easily be shared, integrated, and analysed to provide the basis for value-added services.

Six key elements

In order to support this concept, the Task Force identified six elements, which are critical to its implementation. Without those six elements, the spatial enablement of a society or government would seriously be held back in its progress. They are:

– **Legal framework:** to provide a stable basis for the acquisition, management, and distribution of spatial data and information;

– **Common data integration concept:** to facilitate that existing spatial data – from government as well as other sources – respect the common standards in order to ensure interoperability for the benefit of all;

– **Positioning infrastructure:** to provide a common geodetic reference framework in order to enable the integration of spatial data and information;

– **Spatial data infrastructure:** to provide the physical and technical infrastructure for spatial data and information to be shared and distributed;

– **Landownership information:** to provide the updated and correct documentation on the ownership and tenure of the land, fisheries, and forests, without which spatial planning, monitoring, and sound land development and management cannot take place;

– **Data and information concepts:** to respect and accommodate the different developments in the acquisition and use of spatial data and information.

In terms of keeping a society spatially enabled, there are probably further issues that need to be considered, namely the educational framework, the technical and institutional development of spatial data management, the development of awareness on all levels of society – such as citizens, institutions, and decision-makers – and the development and applicability of land management tools in order to make best use of spatial data. These elements, however, are not further discussed in this report.

The following sections now look at the six key elements listed above and highlight their relevance and their roles in a spatially enabled society. Six renowned authors from around the world have been invited to share their views.

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4.1 Legal Framework

Abbas Rajabifard, Serene Ho and Jude Wallace

Introduction

This chapter focuses on the legal framework pertaining to land and spatial information and the role it plays in supporting the vision of Spatially Enabled Societies (SES). This is in line with the relationship between people and land, which is often governed and protected by law in the form of land title and land rights, restrictions and responsibilities (RRRs). Moreover, in some cultures, this relationship may alternatively be recognized within informal – yet no less legitimate – customary norms and practices.

The concept of SES depends on the effective use and delivery of spatial data and services. This effectiveness is a consequence of legislation that mandates its use, and implicitly deals with issues of data quality and liability (Onsrud, 2010). A jurisdiction's legal framework sets up the rules and regulations that mandate how information can, or should be, shared. This is often the crucial precursor to technical interoperability. Additionally, the social aspects of land and spatial information operations are important, as is a move towards applying standards of good governance to land administration and its various functions.

Jurisdictional framework

The legal framework is a key element in achieving SES as it constitutes an integral component of a jurisdiction's institutional structures. The framework depends on the set of laws and regulations that govern behaviour and create institutional arrangements within a jurisdiction. These usually appear in an hierarchical structure flowing from the national constitution to local laws. These highly formal laws and regulations are augmented by many subordinate, sometimes highly sophisticated, protocols, standards, conventions, and rules that operate in professional, business and technical areas. These structures are what facilitate the use, sharing, access and management of spatial information and technologies within and between different levels of society. Consequently, these also underpin the mechanisms of a jurisdiction's spatial data infrastructure (SDI) as an enabling platform.

As SES is dependent on the effective use and delivery of spatial data and services, the types of legislation that need to be considered are primarily those addressing the availability of spatial data (either by facilitation or limitation). Inherent to this is legislation that authorizes the government (or its contractors) to collect information about land, in all its social and economic complexity, as this underpins the reliability, legal effect and authenticity of information. Once data has been collected, secondary legislation will affect its availability: access, re-use and sharing. Finally, there will likely be broader legislation within the jurisdictional framework that deals with issues such as privacy, liability and intellectual property: these will provide a constraining factor in the use (and re-use) of spatial data (Janssen and Dumortier, 2007). Therefore, the combination, coherence and currency of such categories of legislation that exists within a jurisdiction will undoubtedly shape the strategic challenges in realising SES.

In addition to its particular local content, the framework needs to deal with issues that will inevitably arise. These include use of information in formal situations (especially in courts as evidence); proofs and verifications of information, commercial-in-confidence limitations, privacy and personal protection, protection of people in special circumstances (such as politicians or people under threat of violence), licence arrangements, embellishment for innovative or secondary purposes, reuse (especially on a commercial basis), social access, intellectual property, storage and archiving, liability for error, responsibility for maintenance, forms in which the information is kept, and more. One further constraint is overarching: the nature of a legal framework ensures that it will always run behind the technological frontier.

Legal interoperability and challenges

As part of the jurisdictional framework, legal interoperability is a very important aspect. The ability to enable spatial data sharing and interoperability by reconciling often competing legislative policies has always posed a significant challenge to governments (Onsrud et al., 2004). However, recent technological developments and adoption of open access information policies have contributed to increased online availability of spatial data and tools to facilitate easy creation and distribution of new customized spatial resources (using existing spatial datasets). This has given rise to the issue of legal interoperability. The datasets used to create new resources could potentially have conflicting licensing, or legal use, requirements and in this context, legal interoperability has been defined as (Onsrud, 2010):

… "a functional environment in which:

- differing use conditions imposed on datasets drawn from multiple disparate sources are readily determinable, typically through automated means, with confidence;
- use conditions imposed on datasets do not disallow creation of derivative products that incorporate data carrying different use conditions; and

- users may legally access and use the data of others without seeking permission on a case-by-case basis."

The users and their purposes of using or accessing spatial data will be governed by a variety of information and legal policies (Janssen and Dumortier, 2007; Onsrud et al., 2004). The use of data that is not legally interoperable may expose the user to legal liabilities including copyright, or other intellectual property law, infringements. This issue is of particular significance for spatially enabled datasets as they often have multiple uses that were not anticipated in the original licensing conditions or in its creation, which could increase the risk of litigation should injury result from the inappropriate use of the data (Pomfret and Ramage, 2010).

Sharing data is therefore a complex issue, of which intellectual property is but one facet. Onsrud and Rushton (1995, in Onsrud, 2010: 7) defined the complexities in GIS sharing as needing to deal with "both the technical and institutional aspects of collecting, structuring, analysing, presenting, disseminating, integrating and maintaining spatial data". More recent trends in spatial data use have further compounded the already complex privacy and intellectual property challenges. These trends include ubiquitous location-based devices and services and the collection and use of personal information; the call for more open access to data and the variety of licensing regimes; and the crowdsourcing movement borne of Web 2.0 (Pomfret and Ramage, 2010). While SDIs provide a platform that facilitates the resolution of some of these issues, they nonetheless still pose significant challenges.

Governance and SES

One of the ways in which an SDI, as an enabling platform, can support the legal framework is to provide an avenue for governance. According to Rajabifard and Box (2009), the notion of governance is an old one, derived from ancient Greek and meaning to steer or pilot a ship. Today, it is a key concept in a number of disciplines, but has different, and often contested, definitions. This has contributed to the lack of a common approach in addressing governance challenges, which means that each jurisdiction must independently solve governance challenges. This duplication of effort leads to incompatible approaches to governance which ultimately diminishes both the prospects for reuse of data as well as the ability to foster dependencies between SDIs. Ultimately, these constraints will have a negative impact on the realisation of SES objectives.

In considering the role of governance as applied to SDIs, Rajabifard and Box (2009) highlighted the importance of considering the nature of SDIs to arrive at a more appropriate conceptualisation of governance. They noted that governance is traditionally considered a 'steering' function because it provides leadership and an enabling framework for collective decision-making; however, as applied to SDI, governance has become shorthand for the institutional arrangements that enable an SDI, and therefore includes functions such as co-ordination and management. These 'rowing' functions extend the scope of governance to include decision implementation.

Governance plays a central role in SDI, and therefore SES, by enabling the creation of agreements that bind together the people and geospatial resources (data and technology) involved. A range of other functions are however necessary to channel collective efforts towards common goals. A broader view of SDI governance is that of a framework enabling stakeholders to make and implement decisions and evaluate commu-

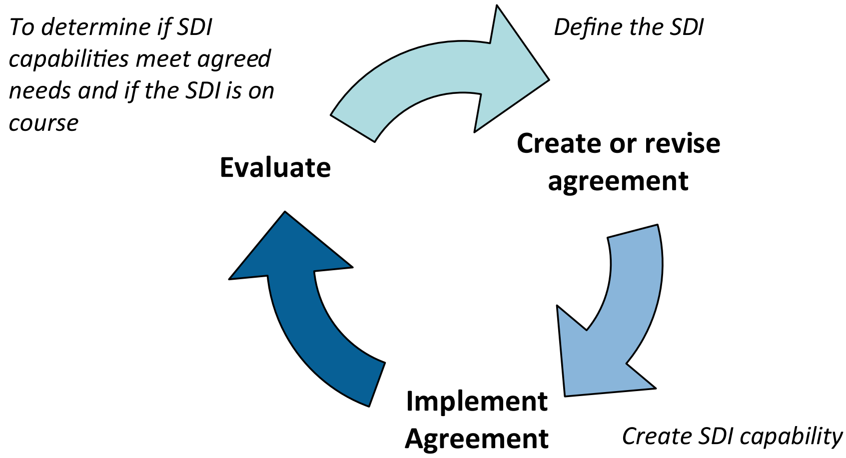

Figure 4.2: *SDI governance as a cyclical process (Box and Rajabifard, 2009).*

nity efforts towards the realisation of agreed common goals, thus keeping the initiative on track. This view of SDI governance as a cyclical process is shown in Figure 4.2 above.

The creation of agreements and their periodic review, ensuring that they continue to achieve desired outcomes, is the first step in the process. The governance of technical agreements, such as standards, specifications and application schema, is one of the major challenges of SDI and therefore will be a challenge in SES governance. Technical agreements are used to define how SDI capabilities (primarily data delivered via technology-supported services) are configured. Capabilities are developed, owned and operated by individual organisations, in accordance with agreements, to meet agreed community needs.

SDI governance can be likened to steering a flotilla of ships representing institutionally independent but functionally interdependent capabilities. To keep both individual vessels and the entire flotilla on course it is necessary to provide an unambiguous definition of the collective and individual responsibilities for decision-making, implementation and evaluation, together with the mechanisms that enable these.

Conclusions

Spatial data has traditionally been used by public organisations, businesses and academia. However, in line with spatial enablement objectives, spatial data is also increasingly being used by ordinary citizens. The users and their purposes of using or accessing spatial data will be governed by a variety of information and legal policies. The ability to enable land and spatial data sharing and interoperability by reconciling often competing legislative policies has always posed a significant challenge to governments. However, with the rapid development of practices such as crowd-sourcing and open access to information, there are acknowledged gaps in the current legal framework that are not yet able to provide effective regulation or even basic guidance.

These challenges were acknowledged at the first United Nations Global Geospatial Information Management (UNGGIM) High Level Forum held in Seoul, South Korea, in October 2011. Consequently, one of the declarations that emerged highlights the importance for governments around the world to share their experiences in "policy-making, supporting legislation, and funding strategies to encourage and develop best practices in the management (i.e. collection, storage, maintenance and dissemination) with respect to global geospatial information management, and to facilitate and to promote the sharing of knowledge and expertise, especially with developing countries".

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4.2 Common Data Integration Concept

Jürg Kaufmann and Daniel Steudler

Context

In every society – spatially enabled or not – data in digital format is collected by different authorities, offices, private and public sector bodies and persons. They all need the data to either run a business or to enforce laws and regulations; and they all began to automate their work processes and to transform their data into digital format. The content of the data sets responds to the needs of the respective data owners. Due to the fact that businesses as well as laws and regulations concern affairs taking place somewhere in the living space, the majority of the data is related to a position, i.e. has a spatial relation. In order to establish this spatial relation, all data owners use the technique best known to him, be it a verbal description, a street address, or a coordinate.

Ultimately, a spatially enabled society (SES) needs to establish a digital data model of the reality. The better and more complete this model is, the better the decisions can be prepared and implemented and the impacts forecasted in that model.

In a SES all the data representing the model finally shall be made available to other parties and institutions not being owners of the individual data sets. This process is called "Data Integration" and was defined by Lenzerini (2002) as: ***Data integration*** *involves combining data residing in different sources and providing users with a unified view of these data*.

A common data integration concept therefore is to be considered as a key element of a SES. Indeed a SES can only be operational when a common data integration concept is agreed upon.

Role of the common data integration concept

SES means that all stakeholders within a society can depend on reliable information about their living space to investigate the state of affairs, to elaborate projects for the development of the society and its environment, to evaluate the projects in view of sustainability and to implement them when the decision process is completed.

Reliable information can only be produced when objective and correct data is available and when the society can understand the content and the meaning of the data available. The data integration concept must ensure that no misinterpretation falsifies investigation, project preparation and evaluation, and implementation.

Information must be as complete as possible. This means that data gaps must be avoided, because information compiled with incomplete data sets will not be correct.

The data integration concept must also serve to avoid loss of data. Data acquisition is in most cases expensive. This means that already captured data represents a significant value. This value should be protected from loss. This can best be achieved by a sound data integration concept.

Three pre-conditions for a common data integration concept

The three pre-conditions for successful data integration are: i) an integration-friendly data structure; ii) a standardized data modelling concept; and iii) a common geodetic reference framework. FIG has already discussed these issues (Kaufmann and Steudler, 1998).

Integration-friendly data structure

Successful data integration is made possible by an integration-friendly data structure based on the existing legal framework. The legislation normally defines the given and lived realities of the different societies regulating the behaviour expected from the citizens and the political and economic institutions and fixes the responsibilities of the authorities charged with the enforcement of the laws. The legal prescriptions concerning the living space define what shall happen where and fix the impacted areas. These legal frameworks are similar in structure and content because existing laws of other countries are often used to draft proposed legislation. However, certain differences exist in the handling of the different issues as well as in the enforcement. The legislation provides a stable framework for the arrangement of the spatial data and for the creation of consistent data models.

A first condition to design an integration-friendly structure is fulfilled when the **geo-data representing spatial objects subject to the same law and underlying a unique adjudication procedure are arranged in separate data layers**.

This type of arranging the data layers is called the principle of "legal/institutional independence". This principle allows the design of a model corresponding to the allocation of the responsibilities as defined by the legal framework.

The legal framework assigns the responsibility for the data layers to a particular authority. Those authorities are the data owners and are responsible for the collection, updating and management of certain spatial data layers. Data ownership is not altered by the introduction of a model with legal/institutional independence. They are therefore not divested of their initial responsibilities and keep the full control of the data layers for which they are declared to be responsible (compare Figure 4.3).

With this arrangement the allocation of the responsibilities corresponds to the laws and regulations. In addition each data owner has access to the data layers of the other stakeholders. All the users of this model can use the information for their work and decision-making. There is no need to deliver information to other stakeholders or to receive copies of data of other data owners.

Common geodetic reference framework

The second condition to achieve integration friendliness **is the localisation of all spatial objects in the same geographic reference framework.**

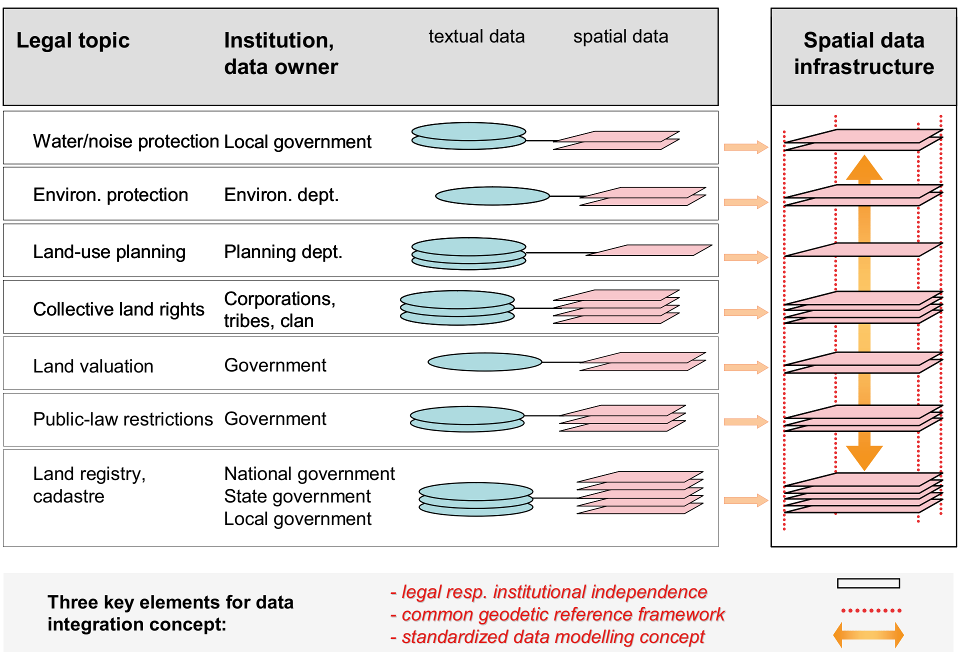

Figure 4.3: *Legal/institutional independence, where the different stakeholders can manage their data sets independently from outside interference.*

With the location of the spatial objects in a common reference framework, the model of reality becomes coherent and sufficiently correct. This arrangement makes it possible to derive the relation between objects through their location in space with the help of algorithms at any moment when needed. This means that there is no need to take explicit care of the logic relation between objects by storing and maintaining it. The use of localisation algorithms – drilling through the spatial data layers – instead of logic relations makes the model absolutely flexible and efficient.

A system where the logic relations between spatial objects are to be stored and maintained will contain (n*(n–1))/2 links. This is 1 link for 2 objects, 45 links for 10, 4,950 for 100, and 499,500 links for 1,000 objects. All these links must be verified and adapted to a new state of affairs, whenever there is a change to one of the objects. This means that there is more work and a higher risk of inconsistency in the data sets.

In the data model based on a common reference framework, the data layers will change as the dynamic state makes it necessary. The relation between objects is established only when required. There is no unnecessary work to be done.

When new spatial data layers are to be introduced, they are simply added without any need to re-arrange or adapt already existing data and layers. If data layers are no longer needed, for example because a law becomes obsolete, the respective data layer can be removed, without any effect to other data and links in the system. Such a concept allows full flexibility and interoperability in the set-up of spatial data infrastructure.

Standardized data modelling concept

The aspect of data modelling is crucial for the concept of a SES. For a long time, the map was the traditional model of spatial reality. If the data was represented according to the drafting rules for map production a model represented on paper emerged. The map was at the same time data storage and representation medium in one. In a data-centred solution, maps or drawings will serve simply to represent information derived from data stored in data bases. The storage media is no longer the map, but the data bases.

This means that the two functions of the paper map are now divided into two parts. The data base must be modelled according to the logic of data processing. The representation of the data by means of drawings makes it easier to understand the content of the data bases and to interpret an existing or planned situation. The representation is modelled with a representation model according to the needs of the viewers.

Data and representation description are to be IT-friendly. Data and their structure are described with something akin to a programming language. The best solution is an interpretable data description language readable by a computer. Thus data bases can be designed by intelligent software and data can be checked automatically. Representation models shall be IT-friendly as well. They serve to compile machine-aided representations.

Unless a society is able to change from a map to a model paradigm, it cannot be considered to be spatially enabled.

With the help of standardized data description languages such as, for example, INTERLIS or future ISO Standards, it is possible to integrate data sets and make them available for interested partners with a high level of reliability, correctness, and completeness.

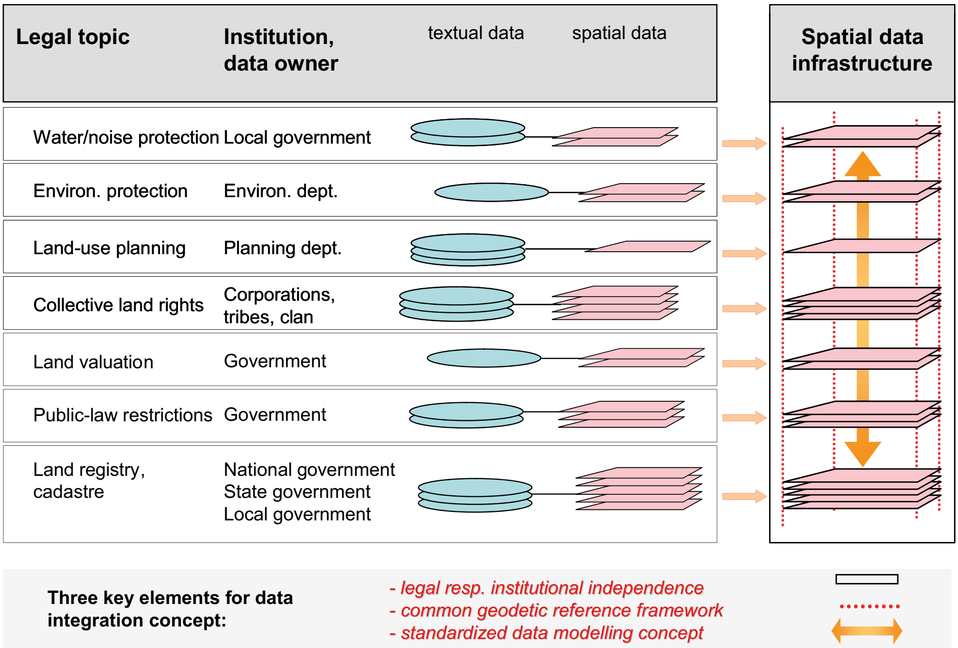

Figure 4.4: *Three key elements for the data integration concept: legal/institutional independence, common geodetic reference system, and standardized data modelling concept.*

Summary

The common data integration concept is based on three pillars: legal/institutional independence, common geodetic reference system, and standardized data modelling concept as shown in Figure 4.4.

Difficulty in implementing a common data integration concept

The way to implement a common data integration concept is, according to experience, a stony and steep path and a great number of obstacles are to be overcome. Several reasons can be identified, which make the implementation of a data integration concept difficult.

Low acceptance for standards and rules

The fact that the existing data collections emerged from an individual need makes the owners feel threatened and suspicious if another stakeholder wishes to use the data and to impose a certain regulation. A proposal to apply another technique to define the data or to change the way of the description of the location generally provokes dismissive reactions. This effect is somehow understandable because such attempts are understood as an outside interference similar to a trespass on a property.

Fear to lose the lead and to suffer from disadvantages

The owners of data collections have acted according to their individual skills and needs. They had to find and introduce appropriate solutions for their purposes without reference to other users. Any attempt to introduce standards creates fear of losing control over the established solutions and the proven advantages.

Many stakeholders

SES means that many stakeholders with different tasks and interests and acting on different political and administrative levels are involved. It is difficult to win the confidence and to persuade the many stakeholders that cooperation and standardisation is needed to achieve the goal of a spatially enabled society. It proves to be necessary to carefully call for the stakeholders and to open the way into a new integrated environment in an individual way. The legal/institutional independence can help to overcome the fears because the stakeholders retain the responsibility for their data.

Possible approaches for successful implementation

Common data integration concepts do not emerge automatically. There is a need to promote their implementation. A basic need is an effective and open communication between the stakeholders.

The application of the principle of legal/institutional independence leaves the responsibility for the data layers to the institution declared as data owner by law. Taking away that responsibility engenders fear that a task cannot be fulfilled any more.

Also important is the awareness that the agreement on a concept always needs a certain period of time and that the implementation on a voluntary base will be slow. The time consumption can be influenced by additional imposed measures such as the obligation to use certain standards. Unfortunately, development of a concept is also an agreement process.

The best method is to fix the requirements for data structure, data modelling and data definition in a law. This makes many discussions superfluous and forces the stakeholders to reach agreement.

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4.3 *Positioning Infrastructure*

Matt Higgins

What is positioning infrastructure?

In recent years, the concept of a Positioning Infrastructure (PI) has developed based on the widespread availability of receivers of Global Navigation Satellite Systems for geodesy, surveying and for geo-spatial data capture. The concept of a PI as used in this section is shown in Figure 4.5 and has two main components:

1. The first and most essential components of a PI are the satellite navigation systems themselves;
2. The second component further augments the satellite systems through additional ground infrastructure in the form of Continuously Operating Reference Stations (CORS) to improve accuracy and/or reliability for users.

Looking at the first component, most current users of satellite positioning employ the USA's Global Positioning System (GPS) but the future will be dominated by the overarching concept of Global Navigation Satellite Systems (GNSS) as a system-of-systems, which includes GPS but extends to other global systems such as Russia's recently completed GLONASS and systems currently under development such as Europe's Galileo and China's Beidou. India and Japan are also developing their own regional systems. For a recent description of GNSS developments and their impact on PI see Rizos et al. (2010)Each of these individual GNSS systems has a number of sub-components including the space segment, which are the satellites themselves, and the ground segment. The ground segment typically includes a sparse network of tracking stations across the globe, which enables tracking the position and condition of each satellite to be broadcast to the user's receiver.

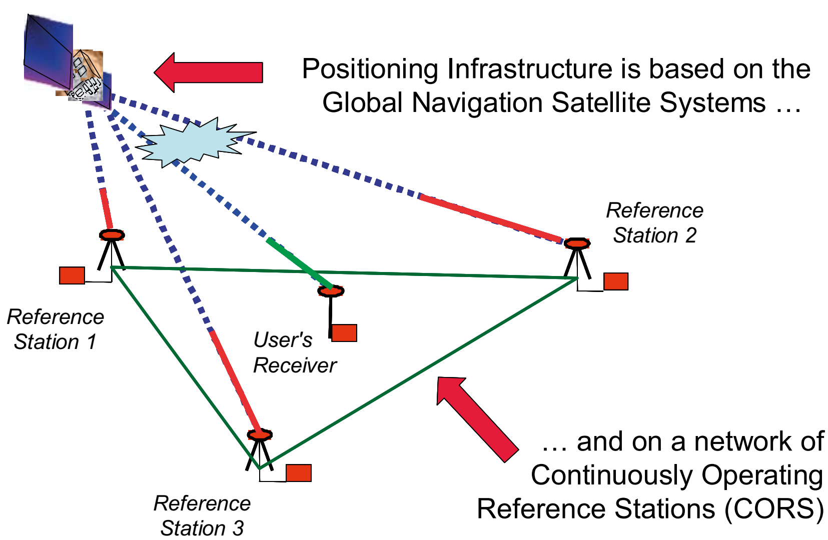

Figure 4.5: *Components of a Positioning Infrastructure.*

Most currently available mass-marketed receivers use only GPS and allow a typical accuracy of a few metres to tens of metres when used in single point position mode. Many users require improved accuracy and/or improved reliability and therefore need to position themselves relative to nearby reference stations. A reference station uses a high quality GNSS receiver at a known location to calculate corrections for factors such as the satellite orbits, the ionosphere and troposphere. Those corrections can then be applied to the user's receiver which can then be more accurately positioned relative to the reference station.

Why is positioning infrastructure important?

While PI based on CORS has its root in surveying and the activities traditionally associated with a geodetic datum, the concept now extends to much broader roles on the global stage. Therefore, the roles of a modern PI can be grouped into three main categories:

1. Geodesy – Continuation of the traditional role of a geodetic datum as the fundamental layer of a Spatial Data Infrastructure by underpinning surveying and mapping activities;
2. Monitoring – Providing a stable geodetic reference frame for precise measurement and modelling of global processes such as sea level rise and plate tectonics; and
3. Services – Extension to the concept of a true infrastructure that underpins the explosion in industrial and mass market use of positioning technology.

Geodesy – Continuation of the Traditional Role of a Geodetic Datum

The Geodetic Datum is widely recognized as the most fundamental layer of any Spatial Data Infrastructure (SDI). Traditionally, the geodetic datum has been realized through the placement of permanent survey marks and carrying out surveys to generate accurate latitudes, longitudes and heights for those marks. A global trend during the last decade has been a trend away from reliance on survey marks and episodic measurement campaigns to the establishment of Continuously Operating Reference Stations (CORS) with GNSS receivers. CORS networks enable a highly accurate and continuously monitored realization of the reference frame and are therefore complementing and/or replacing permanent survey marks as a means of realizing and delivering the geodetic datum (Figure 4.6).

The GNSS data from CORS networks in any country can now be processed with data from the global CORS network run by the International GNSS Service (IGS, see Dow et

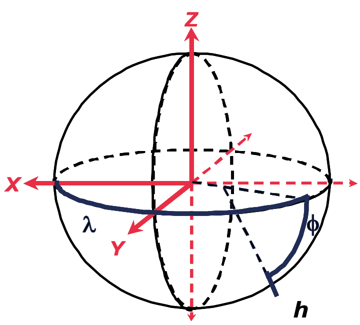

Figure 4.6: *Mathematical model for a geodetic datum.*

al., 2008). The connection to IGS enables the local geodetic datum to achieve excellent internal and external accuracy, as well as global compatibility through links to the International Terrestrial Reference Frame (ITRF). Therefore, the concepts behind PI and geodetic datum are becoming increasingly intertwined.

Monitoring – Measurement and modelling of global processes and changes over time

Enemark (2008) summarizes the key challenges of the new millennium as climate change, food shortage, energy scarcity, urban growth, environmental degradation, and natural disasters. Against that background, the second role of PI considered here is the enhancement of our ability to measure and model global processes and to monitor any changes over time.

A simple example of this second role for the PI is that it is difficult to be confident of millimetre quality measurements of sea level rise using a tide gauge, when the wharf on which the tide gauge is mounted could be subsiding. Therefore, the state of the art approach to monitoring sea level rise is to mount a CORS on the tide gauge to monitor its height relative to a reference frame that is highly stable over time through connection to the national and global CORS network, as portrayed in Figure 4.7.

Thinking more broadly, the role of understanding global processes is typified by the concept of the Global Geodetic Observing System (GGOS, see Rummel et al., 2005). GGOS is being developed under the auspices of the International Association of Geodesy (a sister organization of FIG) and is enabling greatly improved measurement capabilities and monitoring of global processes, such as:

- changes in sea level due to global warming;
- changes in various layers of the atmosphere over the short and long term;
- changes in the planet's overall water storage, either as liquid, vapour or ice;

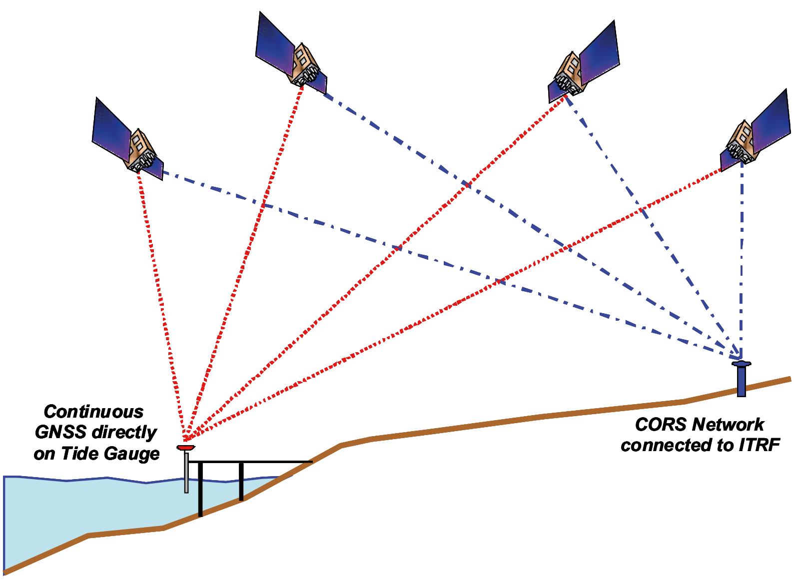

Figure 4.7: *GNSS and CORS for monitoring sea level rise.*

– changes in ground cover through desertification or deforestation;

– changes in the earth's crust as motion, uplift or deformation and including plate tectonics;

– applying some or all of the above change detection capabilities to disaster monitoring and management, including earthquakes, tsunamis, floods, cyclones and hurricanes.

In a world influenced by global change, surveyors will be involved in many land policy decisions that will need to be based on high quality measurements at a given instant and on the ability to regularly repeat such measurements over long time scales into the future. Therefore, those measurements will need to be based on a highly accurate and stable geodetic reference frame, which is best realized through a PI that is strongly connected to the International Terrestrial Reference Frame.

Extension to the concept of a true infrastructure that underpins industrial and mass market positioning

The third and most recent role comes from the growing trend to think of positioning capability in a more systematic way and in terms of a true infrastructure. In coming years PI will come to be seen as the fifth infrastructure after water, transport, energy, and telecommunications. Similar to those others, the PI will be seen as a critical infrastructure for society's triple bottom line.

The first two roles of a PI can often be satisfied by post-processing of a user's GNSS data relative to the CORS network but the other important characteristic of this third role is that it extends to the ability to deliver services in real-time. The state of the art is the real-time network approach, where a central computer uses the CORS to model errors across the network coverage area due to the satellite orbits, the ionosphere and the troposphere. The current state of the art requires CORS spaced at intervals of no more than 70km to deliver centimetre accuracy in real-time. It is likely that less dense networks may be required in the future as more satellite signals and new processing algorithms become available.

While real-time precise positioning has its roots in surveying, the most important recent influence has been the rapidly growing market outside surveying with the current emphasis being on precise guidance of heavy machinery. In an Australian example, the Allen Consulting Group (2008), has found that in agriculture, construction and mining alone, productivity gains from machine guidance have the potential to generate a cumulative benefit to the Australian economy of between $73 billion and $134 billion over the next 20 years (Australian Dollars or AUD). The study also found that a coordinated roll-out of a national network of CORS across Australia (as opposed to depending solely on market forces) would increase the total uptake and the rate of uptake, providing additional cumulative benefits of between $32 billion and $58 billion (AUD) gross to 2030.

Significant environmental benefits are also enabled by a PI because many of the efficiency gains from machine guidance arise from fuel efficiency. For example, in controlled track farming of wheat, fuel efficiencies have been estimated to reduce the carbon footprint by 89 kg of CO_2 equivalent gases per hectare. Other significant contributions to carbon footprint come from the manufacture of fertilizers and pesticides. Therefore, reducing their usage along with less soil disturbance and then adding to the fuel savings means that controlled track farming could reduce overall emissions of CO_2 equivalent by as much as 300 kg/ha (Tullberg, 2008). As well as the carbon footprint, there are also significant additional environmental benefits through minimization of fertilizer and pesticide use.

Positioning infrastructure's role in SES

As described earlier, the first key components of a PI are the GNSS satellites themselves. It is interesting to note that unlike other infrastructures such as water, transport, energy or telecommunications, the same basic level of GNSS service is available globally to users in every country, rich or poor. As such, GNSS could be considered as perhaps the most truly global infrastructure available today.

That global ubiquity along with the availability of low cost receivers has made GNSS one of the key technological developments underpinning the broad spatial enabling of society. The widespread availability of GPS in mobile phones and cars means that hundreds of millions of people are now able to locate themselves with an accuracy that would have been envied by trained navigators and surveyors just 30 years ago. However, the ubiquity of that spatial enablement is also addictive and GNSS is no different from other technologies in that users soon find applications that require constantly improving performance. With GNSS, such improved performance is often required in terms of accuracy or reliability and often in terms of both.

The hunger for ever improving performance is being addressed in part by new GNSS systems providing more satellite signals to increase the availability of positioning in areas where GPS alone might not work effectively; areas such as urban canyons or forests. It is of interest that this need to increase availability is felt even in mass market spatial enablement, as can be seen in the latest Apple iPhone (the 4S at the time of writing) being able to track both the USA's GPS and Russia's GLONASS satellites.

However, there are limits to the advantages that come from simply adding more and more satellite signals so there is still a need for the second component of a PI in the form of ground based CORS to deliver significant improvements to both accuracy and reliability.

As mentioned earlier, the overall PI, for example, is enabling new applications for precise positioning through machine guidance. That is taking spatial enablement to new levels in industrial applications, which are further enhanced by the data communications moving spatial enablement into the real-time domain and taking advantage of data exchange in both directions. Such data exchange can now be tailored not only to the user's application, but also to their location. In heavy construction machinery, for example, if a bulldozer's performance begins to drop when it is operating on steeply sloping land, it might signal a looming maintenance problem. In such a case, it is possible to trigger an alert for an off-site mechanic to undertake diagnostic checks in real-time and make decisions about whether or not the machine should come in for maintenance.

In the next decade, we can expect to see spatial enablement based on precise positioning further evolve from industrial applications and into the mass market. A key application area to watch in this regard will be the so-called Cooperative Intelligent Transport Systems (C-ITS). That development will see vehicle navigation systems go beyond their current function of basic navigation and leverage real-time communications to develop warning functions, such as informing a driver about an accident on the road ahead. That evolution will continue to an even higher level where it may eventually be possible for the vehicle's guidance system to take control of the vehicle to help avoid an impending collision.

All of the above increased requirements of the PI will also put parallel high demands on the spatial data infrastructure (SDI). Continuing with the road safety example, high-end collision avoidance systems are likely to require mapping of all major roads in a given area at a level of accuracy that enables a vehicle to not only avoid colliding with another vehicle, but also to include the location of road side obstacles, such as guard rails or trees. So for fully automatic vehicle safety systems to work on all roads and between all vehicles, the ultimate accuracy requirement of both the PI and SDI is likely to be better than 10 cm and at very high confidence levels. For example, the 95% confidence levels typically used to express positional uncertainty in spatial data sets leaves open the possibility of a 5% failure rate which may not be acceptable in a vehicle safety system.

Overall, it can be seen that we are only at the beginning of an era of accelerating and broadening spatial enablement based on PI. However, while the possibilities are exciting, it is not all good news. As the PI serves more and more high performance applications, with high economic and environmental value (such as in mining operations) or with high societal value (such as in road safety), it will be necessary to ensure that such high levels of performance can be guaranteed and that users are warned of any threats. An example of a threat to PI that has already occurred is interference to the GNSS signals, either through accidental interference by other radio sources or by intentional jamming. This adds another dimension to the need to think of PI as a true infrastructure and to ensure that the technical and institutional arrangements are in line with those expected of a robust and resilient critical infrastructure.

How can positioning infrastructure best be implemented?

In many countries, PI implementation is often hierarchical, which Rizos (2008) has characterized into several Tiers. How those Tiers can serve the three roles for a PI outlined above is depicted in Table 4.1.

In designing a PI it can also be useful to consider the accompanying policy considerations. Higgins (2008) suggested some key principles that might underpin PI policymaking, which were further developed in Rizos et al. (2010) and can be stated in generic terms as follows:

- *Public Good:* Meeting public good needs such as strengthening rather than fragmenting the geospatial reference frame and supporting improved management of natural disasters and climate change;
- *Open Standards:* Conforming to well defined and open standards in relation to issues such as interoperability for equipment and data transmissions and for connection to the geospatial reference frame;
- *Multi-purpose:* Enabling multiple applications where possible, including science;
- *Beneficial:* Allowing full realization (by users and operators) of the economic, environmental and societal benefits;
- *Optimal:* Avoiding unnecessary duplication of stations and associated infrastructure to minimize the costs of establishment and maintenance to the economy as a whole;
- *Collaborative:* Encouraging the appropriate level of participation across the public, private and research sectors;

CORS Tier	Description	Role 1 – Geodesy	Role 2 – Monitoring	Role 3 – Services
1	IGS-class CORS for the Nation	International link to ITRF.	Essential reference frame + can also act like Tier 2.	Essential reference frame + can be real-time enabled to act like Tier 3.
2	IGS Quality but Higher Density	Fleshes out national reference frame.	Essential for detailed models of natural processes and long term change analysis.	Additional Framework + can be real-time enabled to act like Tier 3.
3	Real-Time Network	Delivers reference frame directly to users in real-time.	Value for monitoring depends on physical stability of the Tier 3 CORS.	Essential for real-time centimetre services.

Table 4.1: *Tiers versus roles for Positioning Infrastructure.*

- *Sustainable:* Allowing for revenue streams for station owners to recover operating and replacement costs either directly or through partnerships with commercial service providers;
- *Extensible:* Recognizing that availability of resources to build the PI may vary in time, location and across sectors. Therefore, extensibility is desirable to take advantage of funding injections when available.

A particularly pragmatic aspect to be considered when designing a PI is that as with many other types of infrastructure, the quality and coverage that can be justified is often based on population densities. Fully developed PIs delivering real-time centimetre level positioning services – e.g. based on CORS at a maximum spacing of 70km – are most viable where there are a large number of users in a relatively small area. Such areas also tend to be where the necessary mobile communications infrastructure is also readily available. In such cases, it may be possible to justify the establishment of a PI based on the benefits for the surveying and spatial sector alone.

However, justifications based solely on the surveying and spatial sector can often be more challenging when there is a desire to extend the PI coverage into rural and remote areas of a given country or region. In such cases, it may be necessary to broaden the business case, beyond surveying and spatial data, to include machine guidance for agriculture, construction and mining and to use their economic, environmental and safety benefits to help bolster the business case.

As well as those broader benefits, any organization contemplating the establishment of PI should also consider whether or not they are best placed to undertake all aspects of the PI. Looking at currently established PIs in various countries, we see a mix of government and private sector involvement, such as a government deploying the reference stations and the private sector delivering value added services to users. Higgins (2008) outlines a generic model as shown in Figure 4.8 that can be used for understanding and agreeing the roles of various organizations; from specifying and operating the PI through to delivering the services to users.

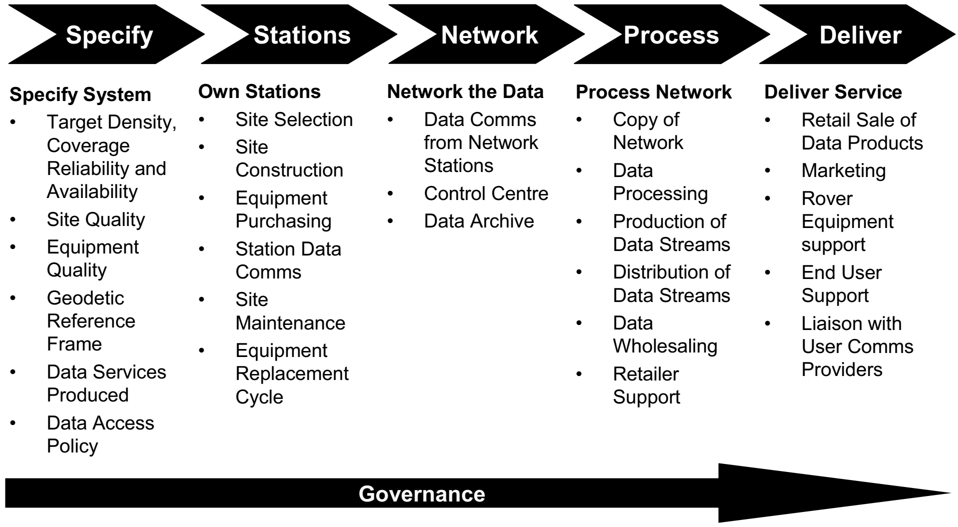

Figure 4.8: *A model for organisational roles within a Positioning Infrastructure.*

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4.4 Spatial Data Infrastructure

Abbas Rajabifard

Introduction

The notion of a spatially enabled society has generally been used to refer to the concept where location, place and other spatial information and services are ubiquitously available to governments, citizens and businesses as a means of organising their activities and information transparently. This concept has become widely embraced as people have increasingly realized that ready and timely access to spatial information – knowing where people and assets are – is essential and a critical tool for making any informed decisions on key economic, environmental and social issues (Rajabifard, 2009).

The effective management, networking and sharing of spatial information and services across agency, state and even national boundaries will result in information being used more efficiently and effectively, and lead to the creation of new services. In facilitating this and to improve access, sharing and integration of spatial data and services, spatial data infrastructures (SDIs) have emerged as a key network infrastructure, and more recently, has evolved to become conceptualized as an enabling platform.

This section will discuss the components of an SDI and outline the various elements that need to be considered – both technical and non-technical – for successful implementation so as to support the dynamic, hierarchic, multi-levelled and multi-disciplinary use of SDI as an enabling platform in a spatially enabled society.

SDI as an enabling platform

SDIs were initially developed as a mechanism to facilitate access and sharing of spatial data for use within a GIS environment, using spatial information to provide a unifying medium linking solutions to location (see Figure 4.9).

The conceptualisation of SDIs have evolved over time, resulting in three different approaches. The hierarchical approach conceptualized SDIs as a link across different levels (local to global) (Rajabifard et al., 2000). The network approach, which is perhaps the concept most relevant to this chapter, is less concerned with linking through the levels,

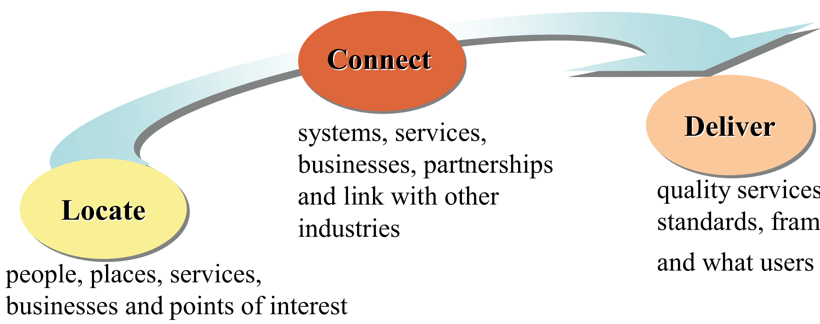

Figure 4.9: *A network to locate, connect and deliver spatial information and services.*

and more concerned with linking across different organisations (see Vandenbroucke et al., 2009; Crompvoets et al., 2010). More recently, with the increasing role of private industry in providing spatial information, the SDI has taken on the dimension of a market place, facilitating transactions in spatial information in all sectors of industry and society (for example, see ANZLIC, 2011).

However, the role that SDI initiatives are playing within society is now changing. Users now require the ability to gain access to precise spatial information and services in real time about real world objects, in order to support more effective cross-jurisdictional and inter-agency decision, making it a priority in areas such as emergency management, disaster relief, natural resource management and water rights. The ability to gain access to information and services has moved well beyond the domain of single organisations, and SDIs now require an enabling platform to support the networking of services across participating organisations.

This has led to an evolution of the concept of an SDI, where it is now increasingly viewed as an enabling platform linking data producers, providers and value adders to data users based on a common goal of data sharing (see Figure 4.10) (Rajabifard et al., 2006). Therefore, SDIs as a platform have come to be regarded as an integrated, multi-level hierarchy of interconnected SDIs based on partnerships at corporate, local, state/provincial, national, multi-national (regional) and global levels. This enables users to save resources, time and effort when seeking to acquire new datasets by avoiding duplication of expenses associated with the generation and maintenance of data and their integration with other datasets, and can lead to the creation of new services.

The development of an SDI as an enabling platform for a country or a jurisdiction will assist in the realisation of a spatially enabled society by enhancing the capability of government, the private sector and the general community to engage in systems-based, integrated and holistic decision-making about the future of that jurisdiction. Such a platform would lower barriers to access and use of spatial data and services, to both government and the wider community within any jurisdiction, and particularly to the spatial information industry. This in turn would enable organisations to pursue their core business objectives with greater efficiency and effectiveness. In particular, industry would be able to reduce their costs, which would encourage investment in capacity for generating and delivering a wider range of spatial information products and services to a wider market, thereby helping to realize a spatially enabled society.

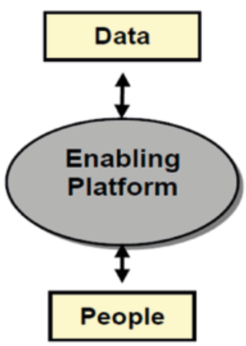

Figure 4.10: *SDI as an enabling platform connecting people to data.*

In order to develop a successful and functioning platform, a set of concepts and principles are required to ensure the design of such a platform facilitates interoperability and inter-working of functional entities within a heterogeneous environment. The following section outlines the key elements of an SDI.

Elements of an SDI

The aim of an SDI is to facilitate the ability of stakeholders to share, access and discover spatial information, and therefore, needs to evolve with its users. As an enabling platform, it also needs to constantly evolve in line with the development of available network technologies. With this in mind, at the heart of the SDI lies five core, but dynamic, components – people, access network, policy, standards and data (see Figure 4.11).

Social and technical components

SDIs are fundamentally about facilitation and coordination of the exchange and sharing of spatial data. However, much of the potential for the use of data and services lies in the ways by which knowledge may be shared. This depends heavily upon the culture of a society. All communities and societies have a culture – a system of shared meaning (Langdon and Marshall, 1998). Similarly, any initiative or function, including the sharing of information, also has a specific culture which needs to be promoted to prepare the environment for developing/pursuing the specific activity. Whether that culture is weak or strong is important to both a coordinating agency and individual parties. Therefore, sharing knowledge and information requires a specific culture – a culture for sharing. The people component can therefore be viewed as the social aspect of an SDI, which includes an organisation's policies and remits, its financial and human resources as well as the culture of sharing.

The technical component can be viewed as the networking and delivery mechanisms such as access network, policies and standards, as well as spatial data itself. In developing SDI as an enabling platform, practitioners will typically find that much of the necessary technological foundation already exists; however, the successful development of an SDI is as much dependent on the institutional and cultural willingness to share outside of one's immediate work group, as on its technical components. This creates the need for jurisdictional governance and inter-agency collaborative arrangements to bring together both information and users to promote interoperability and to facilitate the realisation of an SDI as an enabling platform.

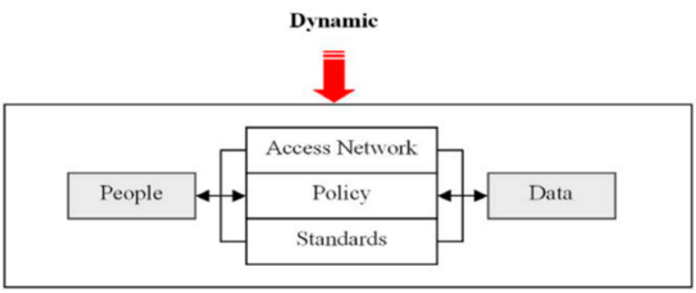

Figure 4.11: *Components of an SDI (Rajabifard, 2008).*

Interoperability

The social and technical components are necessary to ensure that those working at the appropriate (global, regional, national, local) scale are not impeded in meeting their objectives. This in turn supports decision-making at different scales for multiple purposes, and enables users to save both time and money in accessing and acquiring new datasets by avoiding duplication of expenses and effort associated with the generation and maintenance of spatial data. However, this is reliant on an SDI being interoperable with other systems and information. Interoperability can be described as the ability to transfer and use data and information in a uniform and efficient manner across multiple organizations and information systems.

The SDI shares reliance on interoperability with other information platforms. In this context, and in the context of data integration as part of an SDI platform, reflecting its social and technical components, there are various technical and non-technical issues such as legal, policy, institutional, and social factors that affect interoperability (see Figure 4.12). For example, technical interoperability is maintained by continued involvement in the development of standard communications, construction of data exchanges, modelling, and storage as well as access portals, as well as creating interoperable web services equipped with user-friendly interfaces.

The importance of interoperability cannot be understated: efforts to establish an SDI as an enabling platform will fail unless a coordinated approach is used to address all the issues and inconsistencies associated with multisource data integration as outlined by Williamson et al. (2010) (see Table 4.2).

SDI implementation

The steps to develop an SDI model vary depending on the background and needs of each country. It is therefore important that countries develop and follow a roadmap for implementing an SDI. Aspects identified in developing an SDI roadmap include the vision, the improvements required in terms of national capacity, the integration of different spatial datasets, the establishment of partnerships as well as the financial support for an SDI. A vision within the SDI initiative is essential for sectors involved within the project as well as for the general public. The SDI vision helps people to understand the government's objectives and to work towards achieving these objectives.

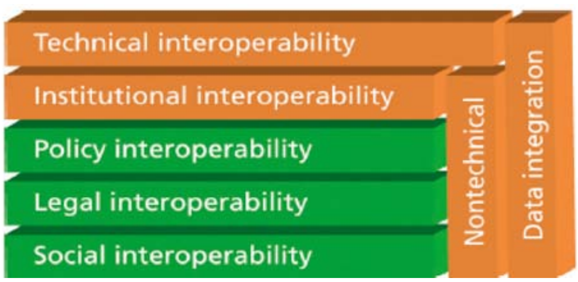

Figure 4.12: *Interoperability components (Mohammadi et al., 2010).*

TECHNICAL ISSUES	NONTECHNICAL ISSUES		
Institutional issues	Policy issues	Legal issues	Social issues
– Computational heterogeneity (standards and interoperability) – Maintenance of vertical topology – Semantic heterogeneity – Reference system and scale consistency – Data quality consistency – Existence and quality of metadata – Format consistency – Consistency in data models – Attribution heterogeneity – Utilization of consistent collaboration models – Funding model differences – Awareness of data integration	– Existence of supporting legislation – Consistency in policy drivers and priorities (sustainable development) – Pricing	– Definition of rights, restrictions, and responsibilities – Consistency in copyright and intellectual property rights approaches – Different data access and privacy policies	– Cultural issues – Weakness of capacity-building activities – Different backgrounds of stakeholders

Table 4.2: *Integration issues that need to be resolved for SDI to function as an enabling platform.*

In support of this vision, there will be a need to identify those components that support an environment where information that is generated and held by governments and systems delivering services will be valued, worked and managed as part of national strategic assets. There is also a need to develop a framework to provide the principles that underpin sound information management and establish the concepts, practices and tools that will drive the successful sharing of information and services across organisational, jurisdictional and national boundaries.

Essentially, an SDI is about facilitation and coordination of the exchange and sharing of spatial data and services. It is often described as the underlying network infrastructure – policies, standards and access networks that allows data to be shared between and within organisations, states or countries. The success of these systems depends on collaboration between all parties and their design to support efficient access, retrieval and delivery of spatial information. It is therefore essential that SDI practitioners understand the significance of human and community issues as much as technical issues, as these determine and contribute to the success of SDI initiatives. SDIs therefore, cannot be regarded primarily as just a technical matter: developing a successful SDI initiative depends at least as much upon issues such as political support within the community, clarifying the business objectives which the SDI is expected to achieve, sustaining a culture of sharing, maintaining reliable financial support and enlisting the cooperation of all members of the community, as upon technical issues relating to spatial data access, networking, and standards. Therefore, developing a successful SDI within a jurisdictional level must be seen as a socio-technical, rather than a purely technical, exercise; the communities concerned are expecting to reap benefits from their investment in SDI in terms of improved corporate performances and cooperation.

Looking to the future

The role that SDI initiatives are playing within society has changed from being organisation-based to becoming an enabling platform for SDIs of different scales and hierarchies. This reflects a growing trend that is demanding access to timely and precise spatial information in real time about real world objects to support more effective cross-jurisdictional and inter-agency decision-making in priority areas such as emergency management, disaster relief and natural resource management, and in meeting sustainable development objectives which are complex and involve temporal processes with multiple stakeholders. As such, SDIs have become a key infrastructure in realising a spatially enabled society.

However, the realisation of spatial enablement is still being impacted by the existence and perpetuation of data silos both within, and between, organisations. This makes the discovery, access, use and sharing of spatial data and services still a significant challenge. More recently, the convergence of many economic, social and environmental drivers with location has provided spatial enablement with an increasingly prominent profile both on local and global stages. In light of the emerging importance of location as the fourth driver in decision-making, alongside the role of the cadastre and land administration in spatial enablement, there is also a continued need for good land governance to facilitate spatially enabled governments, so as to build capacity for addressing the global agenda as well contributing to the primacy of spatially enabled governments in achieving sustainable development and a spatially enabled society.

Conclusion

We are living in an increasingly complex and rapidly changing world. Our relationships with our physical world and the ways we use our social networks are changing as we deploy technology to create new ways of interacting with and understanding each other. Spatial information and technologies assist this transformation because they allow us to understand relationships according to place. These new tools facilitate the realisation of a spatially enabled society, where location, place and other spatial information are ubiquitously available to governments, citizens and businesses as a means of organising their activities and information transparently.

With this in mind, SDIs have emerged as both a fundamental network infrastructure, as well as an enabling platform to help achieve the vision of a spatially enabled society as it aims to connect people to data to facilitate decision-making. An SDI comprises both social and technical components and as such, the successful development and implementation of an SDI depends on practitioners understanding the significance of human and community issues, as much as technical issues, that impact on the exchange and sharing of spatial data and services; that is, its interoperability with other systems and information. A failure to support both social and technical interoperability will inevitably lead to the creation and perpetuation of data silos, impeding the discovery, access, use and sharing of spatial data and services and ultimately, spatial enablement.

More recently, the trend towards a convergence of economic, social and environmental drivers with location has led to the emerging realisation of the importance of location as the fourth driver in decision-making. SDIs will play an important role in providing location-based information and services, and when connected with the cadastre and land administration activities, as well as good land governance, can be a powerful tool for building capacity for addressing the global agenda, achieving sustainable development goals and realising the vision of a spatially enabled society.

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4.5 Land Ownership Information

Paul van der Molen

What is 'land ownership' data, and why is it part of a spatially enabled society?

Although a precise definition of "Spatially Enabled Society" (SES) is still developing (Williamson et al., 2011), the existing body of literature indicates its crux is that governments, the private sector and citizens can better function when data related to location is a common good for everyone (Wallace et al., 2006; Williamson et al., 2010a; Williamson et al., 2010b; Williamson et al., 2011).

In general, we talk about a huge amount of data. Although not exactly proven, it is estimated that 80% of all government data is related to location (Lawrence, 2002; Probert et al., 2009; Steudler and Rajabifard, 2010; Tonchovska and Adlington, 2011). However, location or 'place' is not an easy concept and by consequence many attempts to embed 'place' into location-based technologies and spatial data infrastructures have failed, resulting in consumer frustration with for example web mapping tools and car navigation systems (Winter et al., 2010).

Looking at the overall goal of spatial enablement – enhancing the capability of governments, businesses and citizens in decision-making about their society's future with regard to sustainable development and Millennium Development Goals – the rationale for understanding, what data should be 'common good' for all is found in the decisions that will determine that future. There is ample evidence that a substantial amount of such decisions have to do with how a society manages its land and water resources, or broader: its physical environment (e.g. GTZ, 1998; Deininger, 2003; EU, 2004; CLEP & UNDP, 2008; Habitat, 2008; FAO, 2010; Williamson et al., 2010b).

Also, when we look at the functions a government has to deliver and at the related interactions between government, businesses and citizens, this becomes clear. First, governments safeguard institutions such as laws and regulations regarding human rights and social equity, property rights and socially desirable land use, economic development and market interventions. Second, governments set policies, for example to achieve sustainable housing and agriculture, poverty reduction, generation of revenues, protection of the environment, transparent markets, and sustainable use of energy. Third, the operational instruments to implement those policies, thus operational rules for access to land and land related benefits, access to land by vulnerable groups and women, protection of ownership and possession of land, for land and credit markets, managing land use, land taxation, and management of state and public land.

To deliver these services, businesses and citizens are faced with many bodies of government. The subsidiarity principle (originally a central principle of EU policy making by the Treaty of Maastricht in 1992, it has meanwhile been adopted by the global community as a general principle) saying that political decisions must always be taken at the lowest possible administrative and political level, and as close to the citizens as possible, leads to a division of roles between local, district provincial, national and federal government bodies. Consequently, in the domain of land management, a prominent role is assigned to local governments, irrespective whether mandates are assigned to state or customary administrations.

Here we find the justification that – for a 'spatially enabled society' – land ownership data comes on the screen.

This has something to do with the concept of 'public goods', formulated by Samuelson (1954) in his article *The pure theory of public expenditure*, in which he argues that some goods in contrast with private goods are to be available for everyone (non-excludability) and without competition (non-rivalry). This concept is later developed into the theory of public goods. As private persons cannot be hold responsible for providing public goods – although they sometimes do, however often on a voluntary basis – it is the State that should guarantee public goods.

The above mentioned government functions reflect this: the government has to safeguard these functions in those instances where it normally does not have the power to dispose over land in private hands. An excellent example is the goal of a society to achieve socially desirable land use through land use planning and control. Regarding land use planning (and related to that, the power of the government to 'take' private land) the public goods theory justifies the intervention of the government in private property rights. It is a political matter however, to what extent the government is allowed to interfere, and with what means. There is for example a discussion whether a municipality can use lease-conditions (private law) to achieve public goals, instead of applying public law. It should be noted that 'general interest' is not always synonymous with the interest of the municipality or the central government. The many court cases against government interventions (e.g. in the case of expropriation and zoning) provide evidence for that (see Kelo vs. Connecticut USA, 2005). It is clear that these government interventions should be legitimate supported by the law (see Figure 4.13).

The interventions of the government often take the form of restrictions based on public law. Within the law, private law rules the relation between natural and legal persons, public law rule the relationship between State and citizen. The nature of these public law measures is often prohibitive: a zoning regulation prohibits certain uses; it does not force the landholder to realize the allowed land use. If the government wishes landholders to do something (a 'positive' act), it has to encourage them with a subsidy, or – if the landholder still refuses – buy the property to realize the land use by itself. The number of restrictions imposed by the government is often impressive (Bennett, 2007).

In sum, in many interactions between government, businesses and citizens, data about land ownership is of a dominant presence. This is in line with Steudler and Rajabifard (2010), who say that a prerequisite to achieve spatial enablement is the modelling of the real world: a crucial element in dealing with global problems is the spatial information regarding landownership, as a cadastre is crucial for establishing the link of people to land.

Figure 4.13: *Private property is to be respected, although the Government as guardian of the public interest has the right to intervene.*

Examples of interactions between government, businesses and citizens in the domain of landownership concern land tenure and land tenure security, and market, mortgage market, land taxation, urban and rural land use planning, managing and upgrading informal settlements, management of state owned land, resolution of land conflicts, large scale investments in agriculture, land "grabbing", adaptation to and mitigation of climate change, gender equity when assessing land ownership, protection of indigenous land rights, land ownership and land use in disaster prone areas (for the latter see Mitchell, 2010).

Because the history and culture of countries is different, it is necessary to define how we should understand 'land ownership' data. Referring to the definition of land administration by the UN (1996), which is "the processes of determining, recording and disseminating information about the ownership, value and use of land when implementing land management policies", it encompasses information about ownership, value and use of land. Broadening this to a global relevance, 'ownership' includes any relationship between people and land whether statutory or non-statutory (customary, social, informal), 'value' includes value for any purpose (market, taxation, credit, expropriation, carbon credit etc) and 'use' might include use for any purpose (land cover, given land use). Defining "ownership, value and use of land" in this broad sense, we seek assurance that this FIG report encompasses all countries in the world. This broadening also sheds light on the use of the word 'cadastre' as being "central to the concept of spatial enablement" (Williamson and Wallace, 2006; Williamson et al., 2010a). This might be true when 'cadastres' are available in a country, other countries might also derive 'landownership' information from other sources, such as social tenure information systems, other land information systems, in sum any collection of relevant data that can be useful (see also Uitermark et al., 2010).

How to connect 'land ownership data' with the concept of spatially enabled society

The tool to connect land ownership information to the concept of spatially enabled society is the spatial data infrastructure (SDI). This is backed by much literature: (UNRCC-AP, 2009a and 2009b; Wallace et al., 2010; Williamson et al., 2010a; Williamson et al., 2011; Tonchovska and Adlington, 2011; Bennett et al., 2012).

The process of land administration, as defined by UN (1996), results in land administration systems, in whatever form: datasets may vary from a manual register of cards to a very modern database. The body of literature reveals that spatial enablement through SDIs is a matter of creating a digital environment of spatial data and capitalizing on investments in land information within the land administration and related systems (Williamson et al., 2010a).

In line with what stated above, land administration systems are more than 'cadastres'. Although land surveyors easily speak of the central role in SDIs of 'cadastres' or of 'digital cadastral databases' (Williamson and Wallace, 2006), or the "central role of cadastres to the concept of spatial enablement" (Williamson et al., 2010a), the 'how' question still remains. The FIG adopted the standardized "Land Administration Domain Model" as an extensible basis for establishing cadastres, which facilitates them to be the cornerstone of SDIs (van Oosterom et al., 2009; Uitermark et al., 2010; Wallace et al., 2010; Bennett et al., 2012). The advantage is that all types of tenure relationships and spatial objects can be accommodated, which excludes no country to create a spatially enabled society.

Land ownership is connected with 'place', as it concerns ownership, value and use of a defined lot of land. This lot of land can have various spatial dimensions, from a single point value (for example the centroïd of the specific lot) to an accurate representation of the whole lot (through a land survey of its boundaries). Whatever spatial representation is chosen in a country, the average and normal case is representation of the whole lot through the 'cadastral parcel', although the concept of 'parcel' in Cadastre 2014 is broadened by 'cadastral object', extending private law parcels to private and public law 'objects', in response to the increasing number of land rights, which are based on public law (such as restrictions, zoning areas, natural resource areas) because of increasing government interventions in private law rights.

As the nature of cadastral parcels is that they are uniquely defined, making them suitable to serve as the place or location data element in an SDI independent from the technical advance of the spatial reference (from the single point to accurate boundaries).

An example at European level is the implementation of the EU Directive 2007/2/EC establishing an infrastructure for spatial information in the European Community called Inspire (Tonchovska and Adlington, 2011). The cadastral parcel finds itself defined as a core element of Inspire, for which the specifications were developed by a technical working group of the distinguished national organisations responsible for cadastre and land registration grouped in EuroGeographics and the Permanent Committee on the Cadastre PCC (Martin-Varés and Salzmann, 2009). The data specifications are now assigned as official guideline (Inspire document D2.8.1.6).

An example at national level is the role and status of land ownership data as a base register. Implementing an SDI quickly brings the issue of specifications of data sets on the screen: what do they represent, how accurate are they, can they be trusted? In many countries, such as Finland, USA, UK, Lithuania, Germany, and the Netherlands, we observe that governments develop so-called base registers (van der Molen, 2005). In the Netherlands, as an example, after an in-depth government investigation in 2000, it became evident that the underperformance of the government had much to do with how it organized its information infrastructure: non-interoperable data, unknown quality data, conflicting data, inaccessible data, multiple collection of data, non-sharing of data, etc. The proposed solution was the identification or creations of single authentic registers in key administrative areas, which all government and non-government sectors should use. At the core of the system of authentic registers are six key authentic registers: census database, legal entities (businesses), addresses, buildings, cadastral parcels, and registers, topography 1:10,000 (van der Molen, 2005; van der Molen and Wubbe, 2007): an exemplary real life illustration of the use of 'land ownership data' as a core of spatial enablement (compare Figure 4.14).

How can land surveyors contribute?

For countries, which already maintain a country-wide cadastre, it is easier to establish SDIs that include land ownership information than those other countries without a country-wide cadastre. However, land surveyors in those fortunate positions should look beyond their traditional scope. The inclusion of land ownership information requires a comprehensive overview of how government information is organized and a broad understanding of the technical requirements to realize SDIs. Political sensitivity is a must: governments should be persuaded that investment in base-registers, in the development of legal frameworks for single collection, storage and multiple use

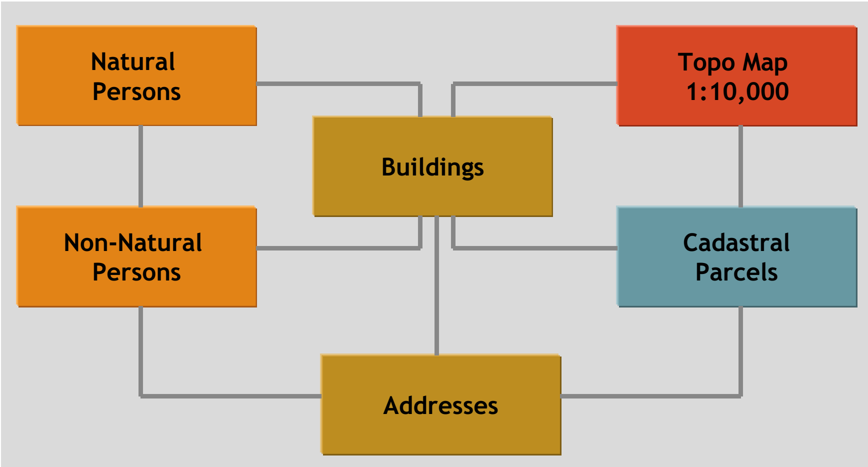

Figure 4.14: *The six key authentic registers in the Netherlands.*

of data, in the application of technology of interoperability, standards, quality indicators, access portals, shall create a desirable return in favour of the performance to the government, at all levels. The arguments for government decisions should come from land surveyors; otherwise other professionals will render land surveyors as irrelevant. Land surveyors in countries, which do not yet have country wide cadastres, should create viable solutions, such as establishing land information systems based on satellite imagery with lower accurate cadastral boundary identification (even single point georeferences), and must try to convince the government in dedicating funds for later upgrading. Adoption of the concept of general boundaries is an option. In sum, land surveyors should take the lead in creating spatial enablement through delivery of solutions, rather than creating problems or erecting obstacles.

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4.6 Data and Information

Robin McLaren

The location revolution

Until recently our interest in geography and locations was probably limited to paper maps. This has changed dramatically as electronic versions of mapping pervade our TVs, games, local government websites and our smart phones. A new generation of Internet products, such as Google Earth and Bing Maps, for example, are stimulating a greater interest and use of geography in society. We are much more location aware and Location Based Services (LBS) are reshaping how we plan trips, meet friends and find good local restaurants. Web 2.0 social media has turned location-based and has moved social media from cyberspace to real place (Sui and Goodchild, 2011). Most location-based social media allow users to know and see on a map where their friends are physically located at a particular time, primarily based on GNSS-enabled mobile phones.

The global market for LBS is projected to reach over US$21 billion in annual revenue by 2015, registering around 1.24 billion subscribers (PRWeb, 2012). The market is being driven by the proliferation of GNSS-enabled smart phones, growing popularity of mobile commerce, and increasing usage of location based social network services, location based shopping applications, location enabled search, and location based mobile advertising. Additionally, increasing demand for personal navigation and LBS that provide users with Points of Interest (POI) information augurs well for the future of this market and the associated geospatial data market.

This location revolution in our personal lives is being mirrored in our professional lives. Geospatial information is increasingly being used to ensure emergency services arrive at incidents in time, to support the formulation of policies to mitigate the impact of climate change, to ensure that services are better targeted to citizens needs and to empower citizens and communities to manage their localities more effectively.

The delivery of the benefits associated with this location revolution is dependent on the availability of geospatial data that is readily accessible for re-use, has minimal restrictions, is affordable, has an appropriate quality and can be easily integrated and linked into collaborative environments using standards from the Open Geospatial Consortium (OGC) and the International Organisation of Standardisation (ISO) and techniques such as linked data (http://linkeddata.org) – used for exposing, sharing, and connecting pieces of data, information and knowledge on the semantic web. A recent McKinsey report (McKinsey, 2011) estimates that in 2020 the worldwide personal geospatial data market will generate over US$100B in revenues for the service providers and generate US$700B of value to end users by 2020; data is the new currency.

Sources of geospatial data to support the location revolution

Public sector response

Many governments are responding to this geospatial data demand by formulating National Spatial Data Infrastructure (NSDI) strategies and implementing policies that produce geospatial data that are (Place Matters, 2009):

- fit for purpose;
- collected once to universally accepted standards;
- appropriately maintained and used many times by the public and private sectors and civil society;
- referenced to a definitive information framework supporting seamless combinations;
- better able to support cross organisational business processes;
- easy to discover, and with clear terms for use;
- simple to access and easy to share and integrate;
- understood sufficiently to maximize its application; and
- aligned with wider regional or global SDI requirements.

In Europe the adoption of NSDI strategies and policies has been broadened to include all member states of the European Union (EU). The EU INSPIRE Directive is currently being incrementally implemented and is about improving access to and the interoperability of location information across Europe to better inform environmental policy and the public, e.g. monitoring the effects of climate change across national boundaries

Improved access to public sector geospatial information is also being enhanced by the increasing adoption of Open Government policies across the world. The USA and the UK were the first and launched their open data initiatives in 2009. These Open Government initiatives normally have three main strands:

- **Open Data:** offering government data in a more useful format to enable citizens, the private sector and non-government organisations to leverage it in innovative and value-added ways (see Figure 4.15);
- **Open Information:** proactively releasing information, including information on government activities, e.g. civil servant salaries and budgets, to citizens on an ongoing basis to increase transparency; and
- **Open Dialogue:** giving citizens a stronger say in Government policies and priorities, and expanding engagement through Web 2.0 technologies. For example,

FixMyTransport (www.mysociety.org/fixmytransport) is a website that aims to use the power of the crowds using British public transport to notify operators of problems with rail, bus, tube and even ferry services. It provides citizens with tools to report their public transport problems to the correct operator or authority and to post them online so that other people can see where problems are. The site also aims to become a rallying point for people who have persistent problems by allowing them to create a campaign page. It offers a powerful toolbox to help them spread the word and lobby for change.

The key elements in working out which operators are responsible for each part of a journey has come via the UK government's open data project www.data.gov.uk, launched in January 2010. The data for FixMyTransport comes from the National Public Transport Data Repository (NPTDR) and National Public Transport Access Nodes (NaPTAN) data sets, released through the open data initiative, which provide route names, stops and operators. More than 400,000 bus, train, tube and tram stops are represented on individual pages.

The project is the latest brainchild of www.MySociety.org, a non-profit organisation which has tried to make UK public data and information more accessible to the wider public.

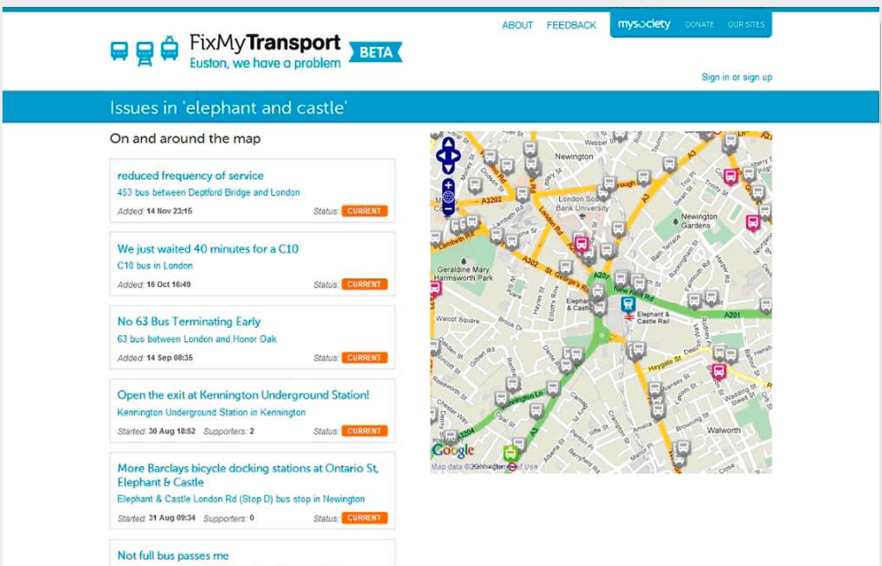

Figure 4.15: *Crowd-sourcing to solve travel problems (Arthur, 2011).*

> “It’s Your Parliament” (www.itsyourparliament.eu) gives citizens a unique overview of the votes cast in the European Parliament. Citizens can find and compare voting records of members of the European Parliament (MEPs) and political groups, make their own comments and cast their own “votes”.

The opening up of governmental data, free for re-use, has been justified on economic grounds (Vickery, 2011; ACIL, 2008) since access to this data will have major benefits for citizens, businesses, and society and for the governments themselves. This public sector sourced data can include geospatial data, statistics, meteorological data, data from publicly funded research projects, and digitized books from libraries. Some of the benefits include:

- **New businesses can be built on the back of this data**: Data is an essential raw material and can be integrated into a wide range of new information products and services, which build on new possibilities to analyse and visualize data from different sources. Opportunities for re-use have multiplied in recent years as technological developments have spurred advances in data production as well as data analysis, processing and exploitation. Facilitating re-use of this raw data will create jobs and thus stimulate growth;
- **Greater Transparency**: Open data is a powerful instrument to increase transparency in public administration, improving the visibility of previously inaccessible information, informing citizens and business about policies, public spending and outcomes; and
- **Evidence-based policy making and administrative efficiency**: the availability of robust public data will lead to better evidence-based policy making at all levels of government, resulting in better public services.

Governments have so far tended to make free for reuse their medium to small scale geospatial datasets through Open Data initiatives. Their more valuable and costly to create and maintain Accurate, Authoritative and Assured (AAA) geospatial datasets (Williamson, 2011), such as cadastral boundaries, administrative boundaries, addresses and large scale topographic datasets, are still sold under license; restricting their wider use across the Spatially Enabled Society.

Private sector response

New technology, such as high resolution satellite imagery, LiDAR and passive crowd-sourced data from mobile phones, has significantly reduced the cost of capturing and maintaining geospatial data. A number of global reach companies involved with navigation and routing, e.g. Tele Atlas now owned by TomTom and Navteq now owned by Nokia, have created or locally sourced road information and points of interest. These data are used world-wide to support commercial and consumer navigation and logistical applications.

The global search engine companies of Google and Microsoft have significantly changed the geospatial data landscape over the past five years. Their business models, based on advertising revenues for example, have allowed them to provide free, on-line access to the global coverage of their geospatial data that includes satellite imagery, street view video and topographic map data. This is being driven by the needs of location based shopping applications, location enabled search, and location based mobile advertising.

These great digital powers, along with Apple, Facebook and Amazon, are now building Digital Civilisations, rather than a series of mere products, individual platforms or even ecosystems around a platform (Fogg, 2011). They are pursuing strategies that reach far beyond the confines of existing markets. They are causing widespread market collisions as they push industries to overlap, merge or cease to exist. They are outflanking and disrupting companies that follow less ambitious corporate strategies, including the geospatial data sector. These new Digital Civilisations use identity to tie numerous disparate products, many devices, multiple platforms and product portfolios together into their long term strategy. Each Digital Civilisation has hundreds of millions of active users – often with credit cards attached – far more than even the largest telecom operators or media companies; Amazon has over 121 million active buyers (November 2010), Apple has over 225 million accounts with credit cards attached (June 2011) and there are over 800 million active Facebook users (November 2011). These Digital Civilisations are increasingly using geospatial data and associated services to entice users to become and stay members.

The ESRI Community Maps Program (www.esri.com/software/arcgis/community-maps-program) is creating a world-wide mapping resource by publishing and hosting contributions from geospatial data providers interested in making their data content broadly available. Authoritative contributions are preferred as the program attempts to differentiate itself from the comparable Google and Microsoft web mapping resources.

We are also witnessing the emergence of new business models for geospatial data. For example the 'freemium' model understands that "attention" is the currency of data and entices users into initially using free information services, then migrating them to paid information services and value added services. A powerful example is the ESRI Community Maps Program.

The gaming industry is having a major influence on how we expect to use and view geospatial data. Increasingly users are expecting 3D and immersive virtual real worlds, for example Google Earth and C3 Technologies' approach for rendering photo-realistic 3D maps.

Citizen response

Traditionally governments have had their own formal channels for collecting public sector geospatial information through National Mapping and Cadastral Agencies, for example. Originally internal resources were used, but increasingly over the past 30 years the private sector has been involved in the collection and maintenance of data through outsourcing and partnership agreements. However, a dramatic shift in how geospatial data are sourced is unfolding through the direct involvement of citizens in crowd-sourcing. Its roots lie in the increasing convergence of three phenomena: the widespread use of Global Navigation Satellite Systems (GNSS) and image-based mapping technologies by professionals and expert amateurs; the emerging role of Web 2.0, which allows more user involvement and interaction; and the growth of social networking tools, practices, and culture. This crowd-sourcing approach is also known as "Citizen Cyberscience", "Volunteered Geographic Information" and "neogeography" (McLaren, 2011).

The highest profile mapping based crowd-sourcing initiative is OpenStreetMap (www.OpenStreetMap.org) which in 2004 spearheaded the democratisation of mapping. In August 2011 this world-wide initiative involved over 400,000 citizens and 2,480,072,760

GPS points had been uploaded in mapping covering most countries of the world (OSM, 2011). It is perfectly adequate for many applications and is completely free to reuse under the Open Database Licence (ODbL) and has certainly influenced both public and private sector data suppliers. For example, Google Map Maker now provides citizens in 188 jurisdictions with the ability to help populate and update Google Maps' graphical and attribute data (Google, 2011). The licensing regime and the 'fitness for purpose' have set an example to which many public sector suppliers now aspire.

State governments in Victoria, Australia and North-Rhine Westphalia, Germany use a 'private' crowd and employ volunteers to input to their mapping programs (Coleman et al., 2010). In the commercial domain, firms such as NAVTEQ and TomTom use web-based customer input to locate and qualify mapping errors and/or feature updates required in their road network databases.

Not all capture of crowd-sourced information is active. We are increasingly carrying devices that can sense and can be sensed. Ubiquitous sensing has entered the back pocket and handbag. In the case of mobile phones, a significant amount of information is captured passively (usually with the authority of the user). Mobile phones are progressively being spatially enabled through integration with GNSS technology, cell phone triangulation or Wi-Fi positioning. The location of mobile phones can therefore be regularly sampled to determine traffic flows (Cheng, 2008) and to measure signal strengths (www.OpenSignalStrength.org) to create coverage maps, for example. The mobile phone is generating a move to distributed citizen / participatory sensing and supporting Mobile (M)-government as an extension or supplement to e-government and providing information and services through mobile devices (Trimi and Sheng, 2008).

The phenomenal growth of social media, such as Facebook and Twitter, and the more recent development of location based social networking have raised awareness of location issues across society. Location based social media allows users to know where their friends are at any particular time and can see them on a map – for example the Foursquare (www.foursquare.com) social check-in site. These citizen sensors in social media are providing new sources of real-time and dynamic geospatial information that can be used in time-critical or real-time monitoring and decision-making. These will require new spatial analysis tools to understand human behaviour, societal transformations and environmental processes, for example (Sui and Goodchild, 2011).

As well as geospatial information supporting outdoor navigation, the integration of Inertial Measurement Units (IMUs) into future generations of mobile phones will provide geospatial data on the layout of buildings through passive crowd-sourcing to provide more effective support of indoor navigation.

Crowd-sourced data are people centric and have strengths in local knowledge, higher currency, a wider range of geospatial data, greater attribution and good vernacular. However, crowd-sourced data are not normally managed in a systematic manner with moderation and therefore tend to have inconsistent coverage with variable and unknown quality and authenticity. Despite these weaknesses, crowd-sourced geospatial data are being used in an increasing number of professional and social applications where AAA geospatial data are not required. It is delivering significant benefits to developing countries where up-to-date mapping is sparse.

The future of geospatial data

The increasing availability of free to re-use geospatial data from crowd-sourcing, the powerful private technology companies and public sector open data initiatives is putting pressure on National Mapping and Cadastral Agencies (NMCAs) to remain viable in delivering their authoritative geospatial data in challenging economic times. Many NMCAs are developing strategies to incorporate crowd-sourced data into their production processes. These proposed strategies range from: using open crowd-sourced data to just derive change intelligence; through using crowd-sourced data from more trusted targeted sources, e.g. professional map users such as mountain guides; to the NMCA acting as a moderator of semi-structured crowd-sourced inputs similar to the Wikipedia approach. Most NMCAs are cautious about this change as combining crowd-sourced with authoritative data is perceived to devalue the NMCA authoritative products and potentially increase their exposure to litigation.

The global technology companies have understood the power of location and just how effective the use of geospatial data is in generating significant revenues through location based shopping applications, location enabled search and location based mobile advertising. Where these companies cannot source existing geospatial data then they are creating their own sources with increasing levels of detail and quality. These data will be augmented by crowd-sourcing, increasingly sourced through location-based social media and passive crowd-sourcing. This will place further pressure on the survival of NMCAs who will retreat to the diminishing market for authoritative geospatial data.

Geospatial data used to be definitive and expensive and there were no alternatives. The fusion of sources of geospatial information from the public sector, commercial companies, the citizen as a 'prosumer' and the expanding sensors in the 'Internet of Things' is transforming the geospatial information landscape. Society now has access to an ever increasing rich set of geospatial information and associated location based information services that are embedded and pervasive in our professional and personal lifestyles. The delivery of these innovative location based services using the six billion mobile phones across the world will ensure that we have a fully inclusive spatially enabled global society.

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5 DISCUSSION

Daniel Steudler and Abbas Rajabifard

The previous chapters illustrate the challenges that our societies are confronted with on a global scale. They offer solutions and debate how land administration, land management, and land governance are critical in tackling those challenges. Data and information about land and water resources play a crucial role in this. Land administration systems provide the basis for conceptualising rights, restrictions and responsibilities, and form the operational component of land management. Strong frameworks are required by which land and natural resources can be effectively managed to fulfil political, economic and social objectives, that is, to help realize sustainable development objectives. Spatial enablement, and Spatially Enabled Societies (SES), are concepts which have evolved to reflect the trend in using land and spatial information to augment current information resources, to help achieve these objectives by linking information to location.

The Task Force has identified six key elements, without which a society cannot become spatially enabled. The contributions of the six authors in chapter 4 focused on those key elements and together, they provide a holistic view of what spatially enabled means and how it can be achieved. The take-away messages of these six contributions are:

- SES needs to be based on a **legal framework**, which takes a whole-of-government approach to spatial data and information, and which enables and supports the broad use of geoinformation;
- it is crucial for SES to have a **common data integration concept**, which ensures interoperability of data and information and which respects the institutional independence of the different actors;
- the concept of SES is built upon a set of several infrastructures: the development of those needs to be based on **business cases**, demonstrating their – mostly long-term – benefits and contributions to the overall goal of sustainable development;
- SES needs a **spatial data infrastructure** that provides the platform to make interoperability happen;
- SES needs complete **information about ownership** of land and water resources in order to guarantee their sustainable management and development;
- **crowd-sourced data** carry a high potential for impact, which public sector institutions need to learn how to deal with.

These issues may not be new, but collectively, they provide a sound basis for spatially enabling public and private data and information, or in other words to reach a maturity level to ″manage data spatially".

The development of a society towards spatial enablement can be thought of as a continuum over several steps, which may happen for each key element at different speed. When a society has attained full spatial enablement, decision-making procedures may become feasible, which were not possible before. The following two examples illustrate what this might be (compare Figures 5.1 and 5.2).

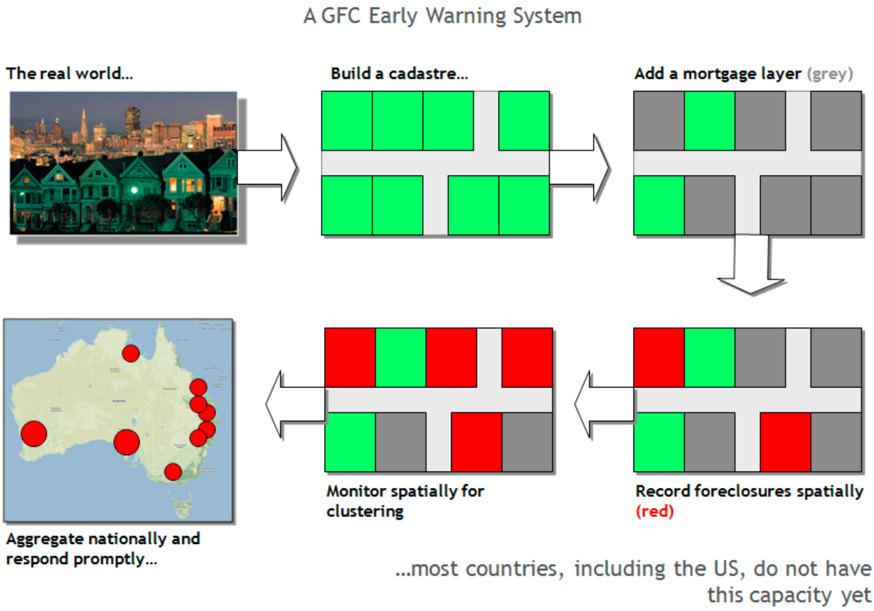

Figure 5.1: *Spatial enablement in action (from Bennett et al., 2012).*

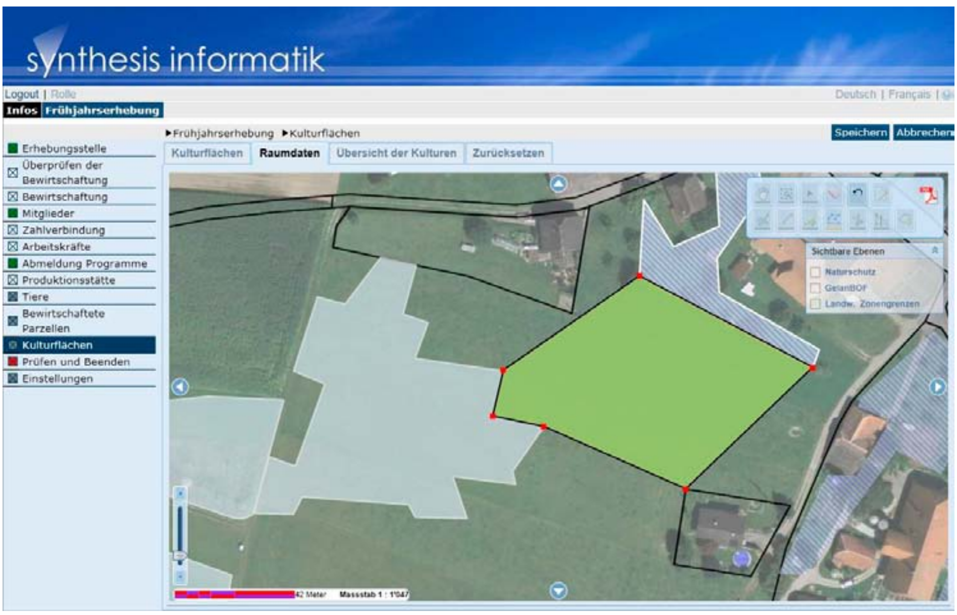

Figure 5.2: *Prototype of web-based tool for farmers indicating their cultivation areas for annual subsidies. © Synthesis Informatik, Gümligen, Switzerland, www.syn.ch.*

A first example is taken from Bennett et al. (2010), where the cadastral landownership layer is complemented with mortgage and foreclosure information. Such information can then be aggregated at a state or national level, which allows detecting patterns or clustering phenomena. The spatial representation of such phenomena can serve important political decision-making processes (see Figure 5.1).

Another example is a project in Switzerland, where a web-based portal is being developed for farmers to declare their annual cultivation areas online. Farmers are receiving subsidies on the basis of the crops and areas that they are cultivating. Based on the cadastral landownership and an orthophoto layer, the portal offers tools such as easy-to-use snapping functions and standard forms to be filled out (see Figure 5.2). This will allow a much more direct and efficient notification process for farmers to provide their data and receive their subsidies. Such a solution would not be possible without a complete documentation of landownership and the interoperability of the information, both of which are in place in Switzerland.

With the technological developments and the web-based possibilities, there will be more such examples and better solutions coming up. These solutions can be pushed by the public sector or in cooperation with the private sector. What is crucial is that the six key elements for a SES are in place and operational. Without them, a society will struggle in its spatial enablement.

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6 CONCLUSION AND FUTURE DIRECTIONS

Abbas Rajabifard and Daniel Steudler

Summary

The objective of this publication is to provide professional surveyors including land and spatial information professionals and the wider society with an overview of the definition, concepts and elements pertaining to the notion of a Spatially Enabled Society (SES).

Spatial enablement is a concept that adds location to existing information, thereby unlocking the wealth of existing knowledge about land and water, its legal and economical situation, its resources, potential use and hazards. Societies and their governments need to become spatially enabled in order to have the right tools and information at hand to take the right decisions. SES – including its government – is one that makes use and benefits from a wide array of spatial data, information, and services as a means to organize its land and water related activities.

With the myriad challenges facing society today at multiple scales, location has emerged as a key facilitator in decision-making, so much so that it is now commonly regarded as the fourth driver in the decision-making process, complementing the more traditional triple bottom line approach (social, economic and environmental drivers). Consequently, land-related information has a key role in spatial enablement where good land governance can facilitate the delivery of a spatially enabled government to respond to the global agenda and achieve sustainable development.

In parallel, recent technological developments, such as Web 2.0 and ubiquitous location based services, have made it easier for ordinary citizens and businesses to become spatially enabled, but just as importantly, these developments have provided them with tools to contribute to the flow of spatial information through all levels of society. Such inclusive participation is essential for achieving spatial enablement, as it should be regarded as a concept that permeates all levels of society – government, industry and citizens. SES, and its ability to flow through all levels of society, will depend primarily on the spatial data infrastructure (SDI) and land administration system available in the jurisdiction. Inherent to this, there are essentially six key elements required to help realize the vision of SES:

1. **legal framework**, which provides an important institutional structure to enable data sharing and access, but also to regulate relevant issues such as privacy and liability;
2. a sound **data integration concept** based on legal/institutional independence, common geodetic reference system and standardized modelling concept to ensure data integrity and the ability to harmonize data from multiple sources;
3. **positioning infrastructure** and its role in enabling new levels of spatial enablement by precise positioning through machine guidance;
4. **spatial data infrastructure** (SDI) to reduce duplication and resource waste by providing an enabling platform linking data producers, providers and value adders to data users based on a common goal of data sharing;

5. **land ownership information**, as it is the dominant issue in interactions between government, businesses and citizens, and the key to connecting such information to the concept of SES is the SDI; and
6. **data and information**: increasing availability of free to re-use geospatial data from different sectors of society and public sector open data initiatives is transforming the geospatial information landscape and will help ensure a fully inclusive SES.

In considering the six key elements, it is clear that land and spatial information professionals play a primary role in translating raw data into useable spatial knowledge resources. However, in addition, these professions should provide the link to ensure that both the social and technical systems in which spatial enablement will operate within are understood as spatial enablement can only be effective if it is designed with the specific needs of the jurisdiction in mind.

Future directions

The future of spatial enablement, and therefore the realisation of a spatially enabled society, lies in it being a holistic endeavour where spatial (and land data) and non-spatial data are integrated according to evolving standards and with the SDI providing the enabling platform.

The concept of SES is offering new opportunities for government and wider society in the use and development of spatial information, but it needs to move beyond the current tendency for the responsibility to achieve SES to lie solely with governments. SES will be more readily achieved by increasing involvement from the private sector, and in the same vein, if the surveying and spatial industries start to look toward other industries for best practices in service delivery.

Future activities need to take into account emerging trends in geospatial information and the new opportunities they present for the application of spatial technologies and geographic information. These trends include (but are not limited to):

- location as the fourth element of decision-making;
- differentiating between authoritative and volunteered (including crowd-sourced) information, yet recognising the importance and value of both types of information towards spatial enablement and the enrichment of societies;
- changing directions: simple to complex, autonomous to interdependent, spatial ubiquity;
- growing awareness for openness of data e.g. licensing, and resultant improvements in data quality;
- move towards service provision; and
- recognizing the difference between spatial enablement and spatial dependency.

In light of these trends, future activities will essentially need to be fit-for-purpose, ubiquitous, transparent and seamless to the user. Additionally, there is also a need to consider the developing challenges that are arising from having differing levels of maturity in use and management of geospatial information, and perhaps a need to increase the focus on critical areas that are proving to be challenging. These include:

- improving the appeal of spatial information to attract a broader audience;
- institutional processes to facilitate spatial enablement particularly around information policies, access, and risk management;
- capacity building e.g. research and education, bandwidth;
- standards and licensing as a means to enable and facilitate partnerships; and
- creating a seamless platform.

Even as we begin to think about what the future of SES may look like, at its heart, the realisation of SES will always be predicated on the key elements listed in this publication: legal framework, data integration abilities, positioning and network infrastructures, and the various data and information principles. These key elements need to be embraced by the established professional communities or face the threat of being taken over by those that better understand the messages of change. As surveyors, land and spatial information specialists, it is imperative that we understand the technological changes, developments and possibilities, so that we can convey these messages and requirements to our partners, to political decision-makers, and to society at large.

KL Declaration on Spatially Enabled Government and Society

The following "Declaration on Spatially Enabled Government and Society" is the result of an Expert Group Meeting and an International Symposium on Spatially Enabled Government and Society – "Towards Spatial Maturity" – held on 14–16 February 2012 in Kuala Lumpur, Malaysia. The events were organized by the Department of Survey and Mapping, Ministry of Natural Resources and Environment, Malaysia; kindly hosted by the Malaysian Government; and supported by the Permanent Committee on GIS Infrastructure for Asia & The Pacific (PCGIAP), the International Federation of Surveyors (FIG), the Global Spatial Data Infrastructure Association (GSDI), the International Cartographic Association (ICA), and the International Society for Photogrammetry and Remote Sensing (ISPRS). The resulting KL Declaration is in response to the aims of the UN Initiative on Global Geospatial Information Management (UN-GGIM).

Kuala Lumpur Declaration
on
Spatially Enabled Government & Society

We, the participants of the United Nations sponsored Permanent Committee on GIS Infrastructure for Asia and the Pacific International Symposium on Spatially Enabled Government and Society, with the theme "Towards Spatial Maturity" held at the Kuala Lumpur Convention Centre, Kuala Lumpur, Malaysia on February 15th and 16th, 2012, having met in the context of building trust to promote understanding and to enhance collaboration in the field of geospatial information and spatial enablement that addresses current national, regional and global challenges, hereby issue this **Kuala Lumpur Declaration on Spatially Enabled Government and Society.**

Recalling Resolution 16 at the 13th United Nations Regional Cartographic Conference for Asia and the Pacific in 1994 that established the Permanent Committee on GIS Infrastructure for Asia and the Pacific (PCGIAP),

Noting Resolution 1 at the 16th United Nations Regional Cartographic Conference for Asia and the Pacific in 2003 on the importance of spatial data infrastructures in supporting sustainable development at national, regional and global levels,

Further noting Resolution 5 at the 18th United Nations Regional Cartographic Conference for Asia and the Pacific in 2009 to understand, compare and determine the state of spatially enabled government and society including levels of maturity and governance of spatial data infrastructure in the region,

Bearing in mind that the rapid development and increased demand for spatial information infrastructures in all countries in past years has made geospatial information an invaluable tool in policy planning and evidence-based decision making,

Mindful that spatial enablement, that is, the ability to add location to almost all existing information, unlocks the wealth of existing knowledge about social, economic and environmental matters, and can play a vital role in understanding and addressing the many challenges that we face in an increasingly complex and interconnected world,

Acknowledging that spatial enablement, by definition, requires information to be collected, updated, analyzed, represented, and communicated, together with information on ownership and custodianship, in a consistent manner to underpin effective delivery systems, good governance, public safety and security towards the well being of societies, the environment and economy,

Recognizing that geospatial information includes 'fundamental data' that is essential and therefore must have authority, currency, resilience and sustainability, be comprehensive, freely available, accessible and usable for informed decision-making, which immediately leads to better policies and sustainable actions, and more open, accountable, responsive and efficient governments,

Agree that spatially enabled societies and governments, recognizing that all activities and events have a geographical and temporal context, make decisions and organize their affairs through the effective and efficient use of spatial data, information and services,

Resolve to fully support the initiative of the United Nations to implement global mechanisms to foster geospatial information management among the Member States, international organizations, and the private sector, and in this regard to make every effort to:

- enhance national efforts including investments towards the managing of all information spatially and the realizing of spatially enabled governments and societies with a focus on citizens and users;
- confirm the importance of governance and legislative frameworks and the need for legislative interoperability;
- confirm the importance of authoritative and assured data and information, encourage the incorporation of volunteered information, develop enabling platforms by locating, connecting and delivering information from different scales, purposes and origins;
- confirm the importance of common geodetic reference frameworks, positioning and network infrastructures;
- avail resources to invest, manage and sustain the capture, collection and collation of fundamental data and information and to reduce duplication in these efforts;
- build and use common standards and frameworks to ensure interoperability;
- enhance institutional arrangements and stakeholder collaborations; and
- improve returns on investment through better coordination, use and reuse of data, information and systems and to enhance innovation and productivity.

Kuala Lumpur
16th February 2012

ABOUT THE EDITORS

Daniel Steudler is a scientific associate with the Swiss Federal Office of Topography swisstopo, working for the Federal Directorate for Cadastral Surveying. He is active in FIG-Commission 7 for many years and is now chair of the FIG-Task Force on "Spatially Enabled Society". He published widely in the cadastral field and consulted internationally in land administration and cadastral issues.

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ACKNOWLEDGEMENTS

The work of the FIG-Task Force on "Spatially Enabled Society" (SES) and the publication of this report would not have been possible without the support of many.

First of all, we would like to thank Prof. Stig Enemark, immediate past president of FIG, who initiated the idea of a Task Force around this topic. It was his enthusiasm about the high relevance of SES and the potential of professional surveyors' contribution in current global agendas that triggered this project. This was in line with the dialogue between both presidents of FIG and GSDI Association for collaboration around SES and also the MOU that has been signed between both institutes. We also would like to

thank CheeHai Teo, the current FIG President, who has taken the issue of SES as one of the main topics in his FIG agenda, and carried over the Task Force into his presidency. He made possible a Symposium and Expert Group Meeting in Malaysia in February 2012 to foster the issue. While this publication may have originated with surveyors in mind, we acknowledge the equally important contributions of our colleagues in other spatial professions in addressing societal challenges and hope this booklet may be of interest to them as well.

For the actual work, we would especially like to thank Jürg Kaufmann, who gave the courage and much appreciated support in undertaking this task. He provided ideas, supplied the motivation for the task, and served as a patient sounding board. We also like to thank Serene Ho for her continued assistance in the preparation of this publication. We would also like to thank the different contributing authors – Jürg Kaufmann, Matt Higgins, Paul van der Molen, Robin McLaren, Serene Ho and Jude Wallace – for their very valuable contributions and insights into the six key elements.

Lastly, layout and printing was made possible by the sponsorship of FIG. We would like to thank Markku Villikka for his special effort, who made it all happen in the end. We would like to thank our employers, the Swiss Federal Office of Topography swisstopo, and the University of Melbourne, to have allowed us to work on this project.

To all of these kind supporters, we give our most cordial thanks.

Dr. Daniel Steudler
Chair of FIG-Task Force on "Spatially Enabled Society"

Prof. Abbas Rajabifard
President GSDI

FIG-TASK FORCE ON "SPATIALLY ENABLED SOCIETY"

The Task Force was established by the General Assembly of FIG in May 2009 in Eilat and has met in Sydney in May 2010, in Melbourne in October 2011 and in Kuala Lumpur in February 2012. It included representations from the Global Spatial Data Infrastructure Association and Working Group 3 of the United Nations sponsored Permanent Committee on GIS Infrastructure for Asia and the Pacific, who were in person Abbas Rajabifard, Ian Williamson, Stig Enemark, CheeHai Teo, Greg Scott, and myself.

It was crucial that CheeHai TEO, the current FIG President, has taken the issue of SES as one of the main topics in his FIG agenda, and sustained the Task Force into his tenure. He worked with the United Nations sponsored Permanent Committee on GIS Infrastructure for Asia and the Pacific (PCGIAP) and the Department of Survey and Mapping Malaysia (JUPEM) and convened an Expert Group Meeting and an International Symposium in Malaysia in February 2012 to foster this issue. I would like to thank Prof Ian Williamson, the immediate past director of the Centre for SDI and Land Administration (CSDILA) at the University of Melbourne, Mr Greg Scott and Mr. Ahmad Fauzi Nordin of PCGIAP Working Group 3 for their insights, contribution and encouragement.

Dr. Daniel Steudler
Chair of FIG-Task Force on "Spatially Enabled Society"

FIG PUBLICATIONS

The FIG publications are divided into four categories. This should assist members and other users to identify the profile and purpose of the various publications.

FIG Policy Statements

FIG Policy Statements include political declarations and recommendations endorsed by the FIG General Assembly. They are prepared to explain FIG policies on important topics to politicians, government agencies and other decision makers, as well as surveyors and other professionals.

FIG Guides

FIG Guides are technical or managerial guidelines endorsed by the Council and recorded by the General Assembly. They are prepared to deal with topical professional issues and provide guidance for the surveying profession and relevant partners.

FIG Reports

FIG Reports are technical reports representing the outcomes from scientific meetings and Commission working groups. The reports are approved by the Council and include valuable information on specific topics of relevance to the profession, members and individual surveyors.

FIG Regulations

FIG Regulations include statutes, internal rules and work plans adopted by the FIG organisation.

List of FIG publications

For an up-to-date list of publications, please visit
www.fig.net/pub/figpub

FIG PUBLICATION 58

This publication on "Spatially Enabled Society" is the culmination of a three-year effort by the FIG Task Force that was established by the General Assembly of the Federation in May 2009. The Task Force included representations from the Global Spatial Data Infrastructure Association and Working Group 3 of the United Nations sponsored Permanent Committee on GIS Infrastructure for Asia and the Pacific. This is a collaborative effort led by the FIG Task Force and the publication has been compiled and edited by Dr. Daniel Steudler, Chair of the FIG Task Force on Spatially Enabled Society, and Prof. Dr. Abbas Rajabifard, President of the GSDI Association.

The rapid development and increased demand for spatial information infrastructures in many jurisdictions these past many years have made spatial information an invaluable tool in policy formulation and evidence-based decision making.

Spatial enablement, that is, the ability to add location to almost all existing information, unlocks the wealth of existing knowledge about social, economic and environmental matters, play a vital role in understanding and addressing the many challenges that we face in an increasingly complex and interconnected world. Spatial enablement requires information to be collected, updated, analysed, represented, and communicated, together with information on land ownership and custodianship, in a consistent manner to underpin good governance of land and its natural resources, whole-of-government efficiency, public safety and security towards the well being of societies, the environment and economy.

The main issue societies have to focus on is probably less about spatial data, but much more about "managing all information spatially". This is a new paradigm that still has to be explored, deliberated and understood in the context of a spatially enabled society.

Prepared by

FIG	International Federation of Surveyors (FIG), Copenhagen, Denmark
GSDI Global Spatial Data Infrastructure Association	Global Spatial Data Infrastructure Association

Supported by

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Permanent Committee on GIS Infrastructure for Asia & the Pacific	Permanent Committee on GIS Infrastructure for Asia & The Pacific

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ANNEX 2

The following “Declaration on Spatially Enabled Government and Society” is the result of an Expert Group Meeting and an International Symposium on Spatially Enabled Government and Society – “Towards Spatial Maturity” – held on 14–16 February 2012 in Kuala Lumpur, Malaysia. The events were organized by the Department of Survey and Mapping, Ministry of Natural Resources and Environment, Malaysia; kindly hosted by the Malaysian Government; and supported by the Permanent Committee on GIS Infrastructure for Asia & The Pacific (PCGIAP), the International Federation of Surveyors (FIG), the Global Spatial Data Infrastructure Association (GSDI), the International Cartographic Association (ICA), and the International Society for Photogrammetry and Remote Sensing (ISPRS). The resulting KL Declaration is in response to the aims of the UN Initiative on Global Geospatial Information Management (UN-GGIM).

Kuala Lumpur Declaration
on
Spatially Enabled Government & Society

We, the participants of the United Nations sponsored Permanent Committee on GIS Infrastructure for Asia and the Pacific International Symposium on Spatially Enabled Government and Society, with the theme “Towards Spatial Maturity” held at the Kuala Lumpur Convention Centre, Kuala Lumpur, Malaysia on February 15th and 16th, 2012, having met in the context of building trust to promote understanding and to enhance collaboration in the field of geospatial information and spatial enablement that addresses current national, regional and global challenges, hereby issue this **Kuala Lumpur Declaration on Spatially Enabled Government and Society.**

Recalling Resolution 16 at the 13th United Nations Regional Cartographic Conference for Asia and the Pacific in 1994 that established the Permanent Committee on GIS Infrastructure for Asia and the Pacific (PCGIAP),

Noting Resolution 1 at the 16th United Nations Regional Cartographic Conference for Asia and the Pacific in 2003 on the importance of spatial data infrastructures in supporting sustainable development at national, regional and global levels,

Further noting Resolution 5 at the 18th United Nations Regional Cartographic Conference for Asia and the Pacific in 2009 to understand, compare and determine the state of spatially enabled government and society including levels of maturity and governance of spatial data infrastructure in the region,

Bearing in mind that the rapid development and increased demand for spatial information infrastructures in all countries in past years has made geospatial information an invaluable tool in policy planning and evidence-based decision making,

Mindful that spatial enablement, that is, the ability to add location to almost all existing information, unlocks the wealth of existing knowledge about social, economic and environmental matters, and can play a vital role in understanding and addressing the many challenges that we face in an increasingly complex and interconnected world,

Acknowledging that spatial enablement, by definition, requires information to be collected, updated, analyzed, represented, and communicated, together with information on ownership and custodianship, in a consistent manner to underpin effective delivery systems, good governance, public safety and security towards the well being of societies, the environment and economy, 65

Recognizing that geospatial information includes ‘fundamental data’ that is essential and therefore must have authority, currency, resilience and sustainability, be comprehensive, freely available, accessible and usable for informed decision-making, which immediately leads to better policies and sustainable actions, and more open, accountable, responsive and efficient governments,

Agree that spatially enabled societies and governments, recognizing that all activities and events have a geographical and temporal context, make decisions and organize their affairs through the effective and efficient use of spatial data, information and services,

Resolve to fully support the initiative of the United Nations to implement global mechanisms to foster geospatial information management among the Member States, international organizations, and the private sector, and in this regard to make every effort to:

- enhance national efforts including investments towards the managing of all information spatially and the realizing of spatially enabled governments and societies with a focus on citizens and users;
- confirm the importance of governance and legislative frameworks and the need for legislative interoperability;
- confirm the importance of authoritative and assured data and information, encourage the incorporation of volunteered information, develop enabling platforms by locating, connecting and delivering information from different scales, purposes and origins;
- confirm the importance of common geodetic reference frameworks, positioning and network infrastructures;
- avail resources to invest, manage and sustain the capture, collection and collation of fundamental data and information and to reduce duplication in these efforts;
- build and use common standards and frameworks to ensure interoperability;
- enhance institutional arrangements and stakeholder collaborations; and
- improve returns on investment through better coordination, use and reuse of data, information and systems and to enhance innovation and productivity.

Kuala Lumpur
16th February 2012

ANNEX 3

Report on

4th Land Administration Forum

Beyond Spatial Enablement

PCGIAP-Working Group 3 (Spatially Enabled Government)

5-7 October 2011
The University of Melbourne
Melbourne, Australia

EXECUTIVE SUMMARY

This report is part of a consultancy project between Geoscience Australia and the Centre for SDIs and Land Administration (CSDILA), The University of Melbourne, in designing and conducting the fourth Land Administration forum of Permanent Committee on GIS Infrastructure for the Asia Pacific Region (PCGIAP) Working Group Three (WG3) to contribute to the '*Spatially Enabled Government and Society*' strategic plan and activities of WG3.

The forum was organised as a joint collaborative effort between Geoscience Australia and CSDILA.In response to the forum theme, the keynote addresses emphasized four key areas: the emergence of location as the fourth driver in decision-making; the role of the cadastre and land administration in spatial enablement; good land governance to facilitate spatially enabled government to build capacity for addressing the global agenda; and the primacy of a spatially enabled government in achieving sustainable development.

The forum presenters reported on current initiatives and activities occurring within their own jurisdictions in the pursuit of spatial enablement. These views represented activities occurring at different scales – from local government organisations to global institutions like the World Bank. The worldwide challenges were examined and new initiatives that the UN and its member countries are currently implementing in support of spatially enabled government and society were also considered.

It was observed that the realisation of spatial enablement was still being impacted by the existence and perpetuation of data silos both within and between organisations. This made the discovery, access, use and sharing of spatial data still a significant challenge. However, it was acknowledged that the convergence of many economic, social and environmental drivers with location has provided spatial enablement with an increasingly prominent profile both on the local and global stage: a commonly used example was the Millenium Development Goals and how appropriate initiatives for addressing these goals utilise location-specific information. This shift in focus towards spatial data underpins a worldwide trend towards growth in the GIS market.

In considering emerging trends for future direction, many different aspects were discussed. Key to these were participation trends especially pertaining to users, location as the fourth element of decision-making, the need to differentiate between high accuracy data (the new concept of 'AAA' information) and other information (including crowd-sourced), evolving standards, growing awareness for open access to data, a focus on service delivery and finally, a caution that the move to achieve spatial enablement could result in spatial dependency. These emerging trends will provide the basis for the development of new strategies to provide the foundation for future international activities by participants in line with the objectives of the PCGIAP (in particular, WG3), GSDI, FIG and the Memorandum of Understanding arrangements that currently exist with these organisations, as well as fostering collaborations with global organisations like the International Cartographic Association (ICA) and the International Society for Photogrammetry and Remote Sensing (ISPRS).

The forum was preceded by a day of collaborative workshops by CSDILA in the areas of national land infrastructure, spatial metadata automation and 3D property management. For further information about these projects, please visit www.csdila.unimelb.edu.au. The forum concluded with the ten-year anniversary celebration of CSDILA.

ATTACHMENT 1: FORUM PROGRAM

Day 1 (Workshop Day)- Wednesday 5 October 2011	
08:30	Welcome and Registration
09:00	**Workshop 1- NATIONAL INFRASTRUCTURE FOR MANAGING LAND ADMINISTRATION**
	This expert group meeting will use an inter-disciplinary approach to analysis of drivers, issues and practical approaches for achieving an effective national infrastructure for managing land information. National initiatives on land information and issues will be explored. These include identification of the features of owner, parcel, interest and transaction information which are AAA standard, engagement of national government in land information activities, growth of water and carbon administration systems, and the lifecycles of land information. Potential applications for the national infrastructure will be presented. This will be followed by a discussion on collaborative frameworks needed in in a federation of states where land information created by activities of states and territories is essential for local and national governments.
10:20	Morning Tea
10:40	**Workshop 1- NATIONAL INFRASTRUCTURE FOR MANAGING LAND ADMINISTRATION**
12:00	Lunch
13:00	**Workshop 2- SPATIAL METADATA AUTOMATION**
	This workshop aims to discuss the latest developments in the ARC research project on Spatial Metadata Automation. The research team will be presenting the progress to date, as well as a live demonstration of a prototype system and technologies which have been developed to automate spatial metadata creation, updating and enrichment. This includes the integration of Web 2.0, Geography Mark-up Language (GML), Web Feature Service (WFS), and Catalogue Service for the Web (CSW) technologies to facilitate the spatial metadata automation process. This will be followed by a discussion on possible improvements to the prototype system and future directions.
14:40	Afternoon Tea
15:00	**Workshop 3- 3D CADASTRE AND PROPERTY MANAGEMENT**
	This workshop aims to launch the ARC research project on “land and property information in 3D”. In this workshop, the aims and objectives of the project will be introduced. The latest national and international developments in this area will be discussed to help reflect on the original aims and objectives defined, and to determine the project direction for the next three years. Drivers for and aspects of the land and property information in 3D will be presented, followed by a 3D prototype system demonstration.
17:00	Close

Day 2 (Forum) - Wednesday 5 October 2011	
08:30	Registration
09:00	**OPENING AND WELCOME- (Greg Scott- Abbas Rajabifard and Hiroshi Murakami)** *Moderator: Greg Scott- Abbas Rajabifard*
09:20	**Keynote presentations**
	Spatial Enablement in Australian Government *Dr. Chris Pigram, Chief Executive Officer Geoscience Australia*
	Spatial Enablement in Europe- The Role of Cadastre and Land Administration (*Abstract*), *Ms. Dorine Burmanje, Chair Executive Board Dutch Kadaster. President Eurogeographics*
	Land Administration: Facilitating Spatially Enabled Government and Supporting the Global Agenda (*Abstract*) *Prof. Stig Enemark, Department of Development and Planning Aalborg University*
10:30	Morning Tea

11:00	**SESSION 1: SPATIAL ENABLEMENT IN ACTION** *Moderator: Ian Williamson*
	Disaster Management – Japan Tsunami Case study *Dr. Hiroshi Murakami, Japan National Mapping Agency*
	From Strategy to Benefits: Spatially Enabling New Zealand *Mr. Kevin Sweeney, Geospatial Custodian, New Zealand Geospatial Office (NZGO)*
	Spatial Enablement in Malaysia *Prof. Abdul Kadir Bin Taib, Survey General Malaysia*
	World Bank Initiatives in Spatial Enablement *Dr. Keith Bell, World Bank, USA*
12:30	Lunch
13:30	**SESSION 2: THE ROLE OF LAND ADMINISTRATION IN SPATIAL ENABLEMENT** *Moderator: Paul Harcombe*
	Cadastre in Victoria and its Role in Spatial Enablement *Mr. Chris McRae, Executive Director Land Victoria*
	The Role of Surveyors in support of Spatial Enablement *Mr. Teo CheeHai, FIG President*
	The Role of Private Sector in Spatial Enablement-PSMA Experience *Mr. Dan Paull, CEO PSMA Australia*
	Swiss Cadastre and Spatial Enablement *Dr. Daniel Steudler, SwissTopo*
	Spatially Enabled MDBA *Dr. Alan Forghani, Director Natural Resources Information, MDBA, Australia*
15:00	Afternoon Tea
15:30	**SESSION 3: THE ROLE OF GOVERNMENT AND THE PRIVATE SECTOR** *Moderator: Stig Enemark*
	The Role of Government and Private Sector in delivering Spatial Enablement *The Hon. Gary Nairn, Former Minister, Australia*
	Spatial Enablement in Victorian Government *Mr. Bruce Thompson, CIO Department of Sustainability and Environment, Victoria*
	ICSM Activities and Spatial Enablement *Mr. Paul Harcombe, Chief Surveyor/Director CS2i*
	The Role of National Industry Association in Spatial Enablement *Ms. Liz Marchant, Executive Director ANZLIC, Australia*
	Spatial Enablement in Europe- the status of initiatives and the role of land administration *Prof. Bas Kok, Delft University, The Netherlands*
17:00	Close
Day 3 (Forum) - Friday 7 October 2011	
08:30	**SESSION 4: CHALLENGES AND OPPORUNITIES TO ACHEIVE SPATIAL ENABLEMENT** *Moderator: Teo Chee Hai*
	Opportunities in Spatial Enablement *Prof. Ian Williamson, The University of Melbourne*
	Spatial Enabled Policy and Strategy-Victorian Experience *Mr. Olaf Hedberg, Chair, Victorian Spatial Council*
	Challenges Ahead for Spatial Enablement

	Ms. Jude Wallace, Senior Research Fellow, the University of Melbourne
	International Society of Digital Earth and Spatial Enablement *Dr. Richard Simpson, Executive Committee member, International Society of Digital Earth (ISDE)*
10:00	Morning Tea
10:20	**SESSION 5: DISCUSSIONS** **THE WAY FORWARD TO BEYOND SPATIAL ENABLEMENT** *Moderator: Greg Scott, Abbas Rajabifard (facilitated by: Ian Williamson)*
12:15	**OFFICIAL LUNCH** **CSDILA 10 YEAR ANNIVERSARY CELEBRATION**
14:30	Close

ATTACHMENT 2: FORUM SPEAKERS

Mr. Greg Scott
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Group Leader, National Geographic Information Group
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A/Prof. Abbas Rajabifard
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ANNEX 4

Australian Government
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AusAID

The 30TH September 2009 West Sumatra Earthquake

Padang Region Damage Survey

Sengara, I.W.; Suarjana, M.; Beetham, D.; Corby, N.; Edwards, M.; Griffith, M.; Wehner, M.; Weller, R.

Record
2010/44
GeoCat # 70863

AUSTRALIA-INDONESIA FACILITY FOR DISASTER REDUCTION

The 30th September 2009 West Sumatra Earthquake
Padang Region Damage Survey

GEOSCIENCE AUSTRALIA
RECORD 2010/44

by

Sengara, I.W.[1], Suarjana, M.[1], Beetham, D.[2], Corby, N.[3] Edwards, M.[3], Griffith, M.[4], Wehner, M.[3], Weller, R.[5]

Australian Government
Geoscience Australia

AUSTRALIA-INDONESIA FACILITY FOR DISASTER REDUCTION

1. Institut Teknologi Bandung
2. GNS New Zealand
3. Geoscience Australia
4. University of Adelaide
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Contents

Executive Summary

BACKGROUND

Natural hazard risk is high in some developing nations as a result of the nature of their building stock coupled with large populations and high natural hazard. This risk is manifested in severe events which inflict considerable damage, loss of life and place acute demands on emergency services. Ultimately, these devastating consequences can only be addressed with effective and targeted disaster risk reduction strategies. Understanding hazard, vulnerability and exposure can enable the identification of key factors contributing to community risk and assist in developing appropriate strategies for risk reduction.

The establishment of the Australia-Indonesia Facility for Disaster Reduction (AIFDR) was jointly announced by Australia and Indonesia on 22 November 2008. AIFDR aims to work with Indonesian counterparts to quantify the prevailing natural disaster hazards and risks in Indonesia and then use this information to support activities, training and planning exercises for national-level and provincial-level disaster managers. The outcomes of these two activities are also shared with the region through partnerships with APEC, ASEAN and the United Nations. In this way, AIFDR will build Indonesian and regional capacity to self-manage disasters. AIFDR is a tangible response to the growing challenges posed by natural disasters to Indonesia and the Asia region. The Facility reflects Indonesia's and Australia's concern over the growing impact of disasters in the region, including their potential for human suffering and the reversal of hard-won development gains.

THE EARTHQUAKE

On 30 September 2009 a magnitude 7.6 earthquake struck West Sumatra. The exposed region is heavily populated and the earthquake significantly impacted the large coastal city of Padang. Widespread damage to buildings resulted and an estimated 1,117 lives in the Padang and Padang Pariaman Districts were lost. Thankfully the event occurred during daylight and after office hours when people were mobile and many were out of doors. The event prompted a large Indonesian relief effort which was assisted by an international response at the invitation of the Indonesian government.

Significantly this was not the major plate boundary earthquake anticipated for the region, but rather an intra-plate event within the subducting tectonic plate off the Sumatran coast. The characteristics of the rupture were a high stress drop, high frequency content bedrock motions, very few aftershocks and no accompanying tsunami.

THE SURVEY ACTIVITY

Under its mandate the AIFDR responded to the earthquake event in pursuit of the primary objective of understanding of the factors that had contributed to the result of the earthquake. It supported a team of Indonesian and international engineers and scientists who collected and analysed damage information that could subsequently be used for future disaster risk reduction in West Sumatra and Indonesia more broadly. The activity was jointly led by the Centre for Disaster Mitigation at the Institut Teknologi Bandung (ITB) and Geoscience Australia. The teams convened in Jakarta on 22 October for a briefing by AusAID and arrived in Padang to commence work on 23 October 2009. The survey activity was undertaken from 24 October to 10 November with logistical support provided by the AIFDR.

The survey work had two primary aims. The first was to examine buildings to ascertain their performance when exposed to ground shaking and identify the structural characteristics that may have contributed to their damage state. The initial focus of this activity was on schools and medical facilities but this broadened to include other building uses and structural types. This work was undertaken by two teams of expert engineers and scientists. The second, and larger, activity was directed at systematically surveying complete populations of structures at a lower level of detail in targeted locations which were understood to cover a range of shaking intensities. This population-based survey was undertaken by eight further teams comprised of engineers and local engineering students. The work was directed at the capture of statistically useful information on building performance. Information on residential habitability, occupant injuries and utility service disruption was also captured. The activities of the combined survey group were supported by a logistical support team who provided food, accommodation, field equipment support and survey data processing.

THE SURVEY OBSERVATIONS

In total 3,896 buildings were surveyed in the Padang and Pariaman region. This comprised a range of types which included medical centres (108), educational buildings (460), commercial buildings (479) and residential structures (2,268). The survey work also entailed 1,700 interviews with local residents. The survey indicated widespread liquefaction and foundation related failures. Buildings of all age categories were damaged and nominally engineered structures also suffered significant damage. Often unreinforced masonry, that was not part of the structural system *per se*, was required to provide the needed resistance to seismic actions. Observations revealed poor structural configurations, poor detailing of reinforcement and the use of low quality construction materials.

POST-SURVEY ACTIVITY

It had been hoped that there would be a large variability in the hazard severity experienced across the region. Initial felt intensities were taken from individual building surveys but were found to be biased by the actual level of damage which varied from building to building. Reference to surficial geological mapping, the spatial extent of liquefaction and landslide locations resulted in Modified Mercalli Intensities (MMI) which ranged from MMI 7 to 8 (consistent with the USGS Pager assessment). This assessment was further refined by the use of the MASW survey derived peak ground accelerations (PGA) predicted by ITB. While the predicted PGA values varied across the city, conversion of these to MMI values indicated that they all fell within the MMI 8 range. Accordingly a MMI value of 8 was used as the typical ground motion intensity for the vulnerability assessment work reported herein.

The field survey data collected were transcribed into digital form by the support team and linked to associated imagery (e.g. photos). In Australia this information was subjected to a record by record quality checking and editing process. In total some 70 different field staff had been involved in the information gathering and, as a result, the completeness and consistency of the field data required validation.

The attributed earthquake intensity and damage data was subsequently used as validated data that could be used to develop vulnerability models. The physical damage was associated with the cost of repair using quantity surveying information sourced by ITB. Finally, for building types for which there was a useful sample size of damage observations, statistical analyses were undertaken to characterise the likelihood of each building type experiencing a specific level of damage (damage state) for the ground motion experienced in Padang.

The survey activity and the combined outcomes of the work were reviewed at a workshop convened at Geoscience Australia on 28 and 29 April 2010. Learnings on effective field survey processes were made, benchmark vulnerability models were derived for nine structure types, the categorisation schema for Indonesian building types was refined and a process was agreed upon for extrapolating the benchmark models to the full schema. Most importantly, the key outcomes of the survey pursuant to the original aims of the activity were distilled.

OUTCOMES

The survey work, post-survey analysis and workshop engagement have provided an illuminating picture of the evolution of building regulations in Indonesia and tangible evidence of the effectiveness of their implementation in local design and construction. While the current regulations align with best-practice in other earthquake prone countries they are not fully benefiting Indonesian communities in the Padang region due to shortfalls in their uptake. The survey activity was able to identify a number of factors contributing to this outcome which include poor structural configuration, poor detailing of reinforcement, the use of very poor construction materials and a lack of site investigation and specific foundation design for large buildings on soft soils.

The survey has also highlighted some more recently adopted construction practices that have significantly reduced the likelihood of building damage and casualties. Confined masonry construction in particular suffered lower damage levels than the unreinforced masonry equivalent. Promotion of cost-effective construction practices which reduce vulnerability and the development of other structural systems with these attributes are central to reducing earthquake risk.

The activity has also resulted in a broad categorisation of the Indonesian building stock and the commencement of a process that will furnish a full national suite of models defining the vulnerability of these structure types to earthquake ground motion. Padang damage data was directly applied in the workshop process to develop nine benchmark models that define both economic loss and the likelihood of physical damage. In addition, consensus was reached on a process for ranking other building types in the schema against these benchmarks and the utilisation of other Padang data. The process for delivering a national suite of earthquake vulnerability curves for Indonesia is presently underway.

Finally, processes for capturing post-disaster information have been reviewed on the basis of the Padang reconnaissance and recommendations made for more effective capture of damage information in future surveys. The benefits of reaching a regional consensus on methodologies, survey templates and tools to cover a range of severe hazards have been highlighted and recommendations made for how these protocols could be transferred to Indonesian professionals and academics.

RECOMMENDATIONS

The earthquake was not the anticipated mega-thrust subduction earthquake for the section of the Sunda Arc in the Padang region. The section of the subduction zone in proximity to Padang last ruptured in the Great Sumatran earthquake of 25 November 1833 (M_w 8.8 to 9.2). More recently, other sections of the plate boundary have sequentially ruptured with transferral of stress to this region. As a consequence the subduction interface is considered to have a high likelihood of failure in the next 30 years. When this section does fail the mega-thrust earthquake it will generate is expected to produce ground motions possibly 30% stronger than those that occurred during the September 30 earthquake and be followed some 30 minutes later by a tsunami with maximum wave heights of 5 to 10 m. Within this risk context the West Sumatran Earthquake of 30 September 2009 gives urgency and impetus to "building back better" in Padang and addressing legacy issues with current substandard construction.

The following specific recommendations are made:-

1) Buildings damaged in the 30 September earthquake should be repaired and strengthened to a high standard to be capable of withstanding the future megathrust earthquakes and any accompanying tsunami.

2) New buildings intended to provide vertical evacuation from a tsunami should be designed and built to a standard where they will be essentially undamaged after a worst-case future earthquake.

3) Other new buildings should be designed and constructed in accordance with current standards with particular attention required to ensure the use of appropriate foundation systems and quality construction materials. Enforcement mechanisms may require review to ensure compliance.

4) New residential construction should utilise cost-effective systems that were observed to perform well in the Padang earthquake. In particular, confinement of masonry was observed to result in a marked improvement in seismic performance when compared with ordinary unreinforced masonry.

5) That earthquake engineering principles be promoted with building professionals through industry seminars where the learnings of the Padang earthquake can be shared and the role of the code regulations in precluding premature failure highlighted. The choice of earthquake engineering as an elective in universities also needs to be promoted more strongly so new professionals will enter the industry with a greater awareness of the underpinning principles.

6) That post-disaster surveys continue to be undertaken in Indonesia to capture the variability in building vulnerability across the region and country. This should be all-hazards and encompass all the engineering and science contributions required to understand the nature of the causative natural events. The process would benefit greatly from deriving a regional expert consensus of the optimal approaches for investigating each hazard event type and the subsequent dissemination of the processes and methodologies to interested participants in Indonesia.

7) That targeted research be sponsored in key Indonesian research institutions to develop an improved understanding of the vulnerability of Indonesian construction to severe hazard. The work should also identify cost-effective strategies for reducing the vulnerability of current buildings and for developing affordable construction approaches for new development that will enhance structural resilience. Furthermore, the research program should develop and mentor earthquake engineering expertise within Indonesia to further augment the national skill base for built environment design.

The Padang Earthquake reconnaissance involved a significant allocation of resources, both in terms of the direct costs met by the AIFDR and in the time contributed by a large group of engineers, academics, scientists, AIFDR staff and engineering students. It also constitutes what is understood to be the largest systematic population-based study of an earthquake impact undertaken to date in the South East Asian and Pacific regions. While the investment has been considerable, the outcomes have been commensurate with this. The two survey strategies used, coupled with the post-survey activities, have provided insights into the nature of the built environment in Padang, its vulnerability to severe earthquakes, the factors behind this and how these can be effectively addressed through new and legacy construction. The reconnaissance has demonstrated the value of effective post-disaster surveys in informing the understanding and mitigation of natural disaster risk and as a tool for supporting emergency management preparedness and planning.

Acknowledgements

The Padang survey activity and subsequent data processing and analysis entailed the deployment of considerable resources and contributions made by many individuals. The support of the Australia-Indonesia Facility for Disaster Reduction (AIFDR) is firstly acknowledged for their liaison with key Indonesian Agencies, facilitation of access to the region and for their direct funding of the activity. Similarly, the mission would not have been possible without the support of the Indonesian Disaster Management Agency (BNPB) and the engagement and facilitation of the World Bank.

The survey leadership jointly provided by the Centre for Disaster Mitigation at the Institut Teknologi Bandung and Geoscience Australia is also acknowledged as well as the significant contribution of expertise and students from Andalas University, Padang. Specifically the contributions of the following people in this reconnaissance are acknowledged.

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Richard Weller	Cardno
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The survey activity was followed by a workshop convened at Geoscience Australia in Canberra from 28 to 29 April 2010. The outcomes of the workshop activity are included in this report and the individual workshop attendees who contributed to these are acknowledged below.

Padang Earthquake Reconnaissance Workshop

Dr. I Wayan Sengara	Institut Teknologi Bandung
Dr. Made Suarjana	Institut Teknologi Bandung
Dick Beetham	GNS New Zealand
Roger Charng	Geoscience Australia
Neil Corby	Geoscience Australia
Phil Cummins	Geoscience Australia / ANU
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Mark Edwards	Geoscience Australia
Gerhard Horoschun	Australian Defence Force Academy
Jason Ingham	University of Auckland
Martin Wehner	Geoscience Australia
Richard Weller	Cardno

1 Introduction

The establishment of the Australia-Indonesia Facility for Disaster Reduction (AIFDR) was jointly announced by Australia and Indonesia on 22 November 2008. AIFDR aims to work with Indonesian counterparts to quantify the prevailing natural disaster hazards and risks in Indonesia and then use this information to support activities, training and planning exercises for national-level and provincial-level disaster managers. The Facility reflects Indonesia's and Australia's concern over the growing impact of disasters in the region, including their potential for human suffering and the reversal of hard-won development gains.

Natural hazard risk is typically high in Indonesia as a result of the nature of its building stock coupled with large populations and severe natural hazards. This risk is manifested in severe events which sometimes have devastating consequences. Understanding hazard, exposure and vulnerability can enable the identification of key factors contributing to community risk and assist in developing appropriate strategies for risk reduction.

On 30 September 2009 a magnitude 7.6 earthquake struck West Sumatra in the Padang and Pariaman regions. It caused widespread damage to buildings and resulted in an estimated 1,117 fatalities. Thankfully the event was not accompanied by a tsunami that could have had additional devastating impacts and led to an increased mortality. Under its mandate the AIFDR responded to the earthquake event with the objective of deriving an understanding of the factors that had contributed to the effects of the earthquake. It supported a team of Indonesian and international engineers and scientists who collected and analysed damage information that could be used for future disaster risk reduction in West Sumatra and Indonesia more broadly. The activity was jointly led by the Centre for Disaster Mitigation at the Institut Teknologi Bandung (ITB) and Geoscience Australia.

This report provides a background to the region, describes the nature of the earthquake and its impacts, details the survey activity and outlines the significant outcomes that have come from it. Importantly, a number of recommendations are proposed to assist in the regional reconstruction after the event and to guide future development in the Padang region and Indonesia more generally.

2 Padang Region

2.1 HISTORICAL DEVELOPMENT

Since the 16th century Padang has been a centre of trade. During the 16th and 17th centuries pepper was cultivated and traded with India, Portugal, the United Kingdom and the Netherlands. In 1663 the settlement came under the authority of the Dutch, who built a trading post at Padang in 1680. The town came under British authority twice, the first time from 1781 to 1784 during the Fourth Anglo-Dutch War, and again from 1795 to 1819 during the Napoleonic Wars. Afterwards the city was transferred back to the Netherlands. At the time of independence in 1949 the town had around 50,000 inhabitants. Strong population growth has followed since that time, largely due to the migration within Indonesia of the rural populace to major cities. This has resulted in a present day Padang population of approximately 1 million. The development of Padang over time is summarised in Figure 2.1.

The city of Padang is spread across the low lying coastal plain at the foot of the Barisan Mountains. The city is divided into 11 subdistricts (kecamatan): Bungus Teluk Kabung, Koto Tangah, Kuranji, Lubuk Begalung, Lubuk Kilangan, Nanggalo, Padang Barat, Padang Selatan, Padang Timur, Padang Utara and Pauh. The city is served by the newly-opened Minangkabau International Airport in Ketaping, Padang Pariaman. It replaced the old Tabing Airport which is now used as a military base. Padang's Teluk Bayur harbor is the largest and busiest harbour on the west coast of Sumatra. Figure 2.2 provides a present-day picture of the coastal spread of the city.

2.2 BUILT ENVIRONMENT VULNERABILITY

The progressive development of the Padang region over 400 years has resulted in a range of construction types with differing vulnerabilities. The older parts of the city that date to colonial times feature heavy unreinforced masonry construction with thick walls, significant pre-existing earthquake damage and high vulnerability. Unreinforced construction has persisted since that time with similar vulnerability and older poorly detailed reinforced concrete construction. Material availability has also influenced construction styles. In the Pariaman region the availability of rounded cobble sized stones from the local rivers has promoted their use in wall construction. This practice has introduced a greater vulnerability to earthquake than where fired bricks are used. Light timber framed construction, which inherently performs better when subjected to strong ground motion, is a traditional construction type in the region.

More recently the confinement of unreinforced masonry using reinforced concrete boundary elements has become more widely used for smaller residential buildings imparting improved bracing behaviour and the reduction of out-of-plane failure. These changes have resulted from the development and implementation of construction guidelines for house construction. Furthermore, the construction of larger reinforced concrete buildings has been influenced by the progressive development of Indonesian structural design and construction regulations that are well aligned with the standards of other seismically active countries.

Overall, a greater vulnerability to earthquake is anticipated for the older masonry structures with minimal to moderate damage expected for code-compliant buildings when subjected to ground motions approaching the design event.

2.3 REGIONAL SEISMICITY AND HAZARD IMPLICATIONS

The tectonic context of the Padang region is responsible for a high regional level of seismicity and hazard. Regular mega-thrust earthquakes (with tsunami) and active volcanism along the Sumatran section of the Sunda Arc are associated with the subduction of the Indo-Australian plate beneath the over-riding Sunda plate. Figure 2.3 shows the epicentres of earthquakes that have occurred over the past 17 years and the high level of activity along the subduction zone south of Sumatra. Given the relative oblique plate motion rate of ~50mm per year combined with the locking of the plate interface, mega-thrust earthquakes are likely to occur once every few hundred years. The historic earthquake record indicates such a recurrence for major and great earthquakes in the region (Figure 2.4).

The regional seismicity is classified as high in global terms (Giardini 1999) and is reflected in the local history of damaging earthquakes and tsunami. Following an earthquake off the coast in 1797 (estimated to be M_w8.5 to 8.7) (Natawidjaja et al 2006) Padang was inundated by a tsunami with an estimated flow depth of 5 to 10m. Boats moored in the Arau River ended up on dry land, including a 200 ton sailing ship which was deposited about 1 km upstream. In 1833 another tsunami inundated Padang with an estimated flow depth of 3 to 4m as a result of an earthquake which occurred off Bengkulu estimated to be M_w8.6 to 8.9 (Natawidjaja et al 2006). More recently on 6 March 2007 a M_w6.4 earthquake occurred between Padang Panjang and the north end of Lake Singkarak. This “Singkarak” earthquake is the 5th strongest earthquake to occur in the Singkarak area along the Great Sumatran Fault over the last 100 years. The previous earthquakes were M6.5 and M6.75 three hours apart on 28 June, 1926 and M7.2 and M7.5 seven hours apart on 8 and 9 June, 1943 (M in these cases is the Richter Magnitude as listed by USGS on its web site).

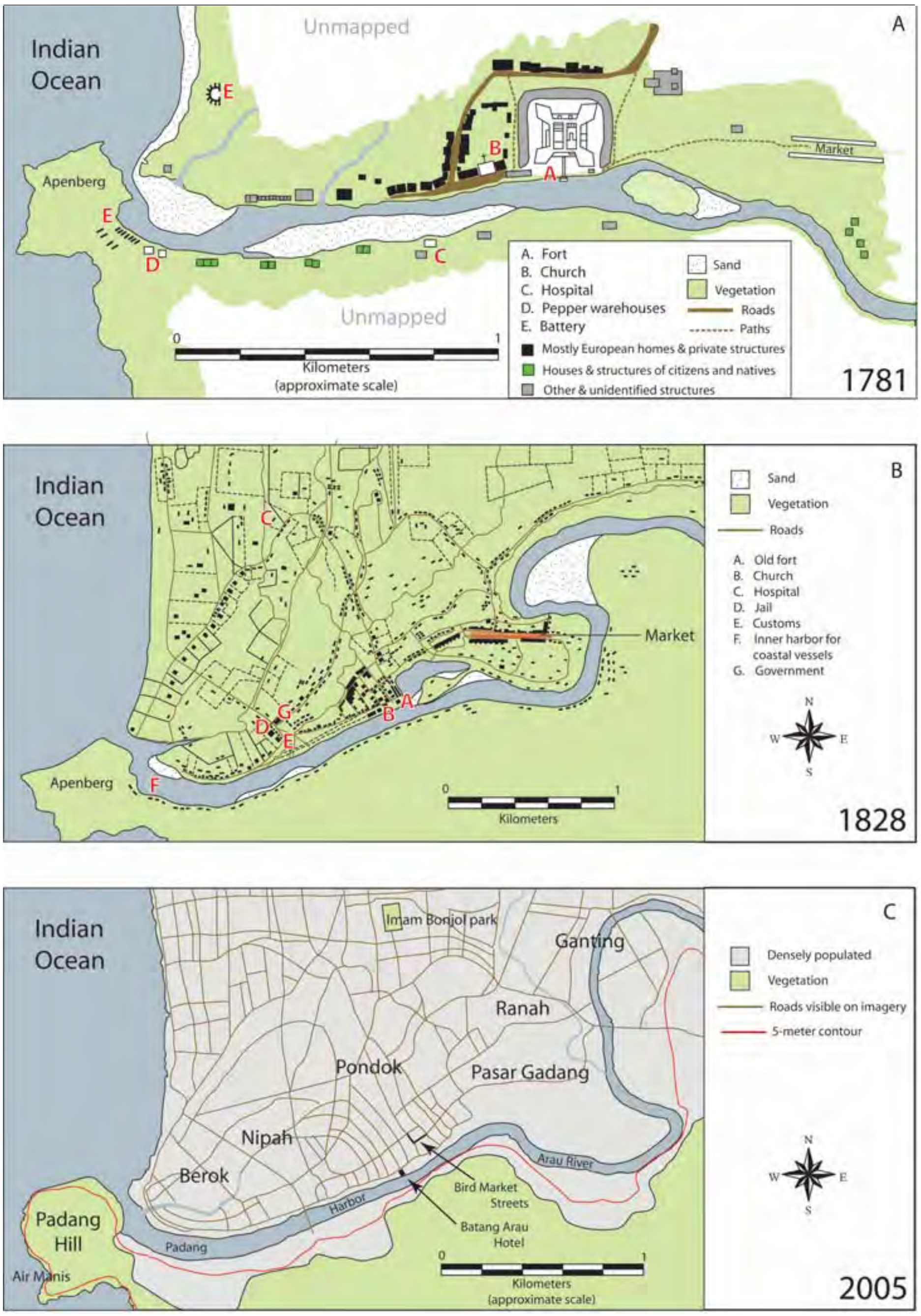

Figure 2.1: Maps of Padang that include locations mentioned in historical accounts of the 1797 and 1833 earthquakes and tsunamis. (a) Padang in 1781, which was a small settlement of a few dozen private and government structures about a kilometre from the sea. (b) Padang in 1828, which was a larger settlement but still concentrated upstream from the river mouth. (c) Map of the modern city of Padang showing that dense settlement extends from the shoreline landward for more than 3 km and is mostly less than 5 m above sea level – from Natawidjaja et al (2006).

2.3.1 Ground Motion

The geomorphology of the Padang area provides a good indication of the likely response of local regolith to bedrock shaking. Over the very recent geological past, the coastal plain on which Padang city is located has been built up of accumulated sediments eroded from the volcanic cones and plateau inland to the east. The rivers from the hills have meandered across the flat coastal plain depositing and sorting loose, uniform and soft sediments in swampy areas behind prominent coastal beach ridges. To accommodate urban growth the city has spread over large areas of low-lying coastal land, much of which was formerly swampy and consists of soft and weak soils, such as sands, silts and muds. These materials are prone to liquefaction during strong earthquake shaking and can significantly amplify bedrock ground motions.

Much of the land on which Padang is built would be classified as site classes D (deep or soft soil sites) and E (very soft soil sites) under NZS 1170.5 (2004) or AS 1170.4 (2007), while some of the better areas may be site class C (shallow soil sites). This site-classification for Padang city is identified from Sengara et al. (2009). In New Zealand soils in these site classes would require specific site investigations, and design may even necessitate a site-specific seismic hazard assessment for important structures (such as hospitals and schools).

Figure 2.2: *North north-westerly view across coastal Padang today showing coastal fore dunes and low lying topography behind.*

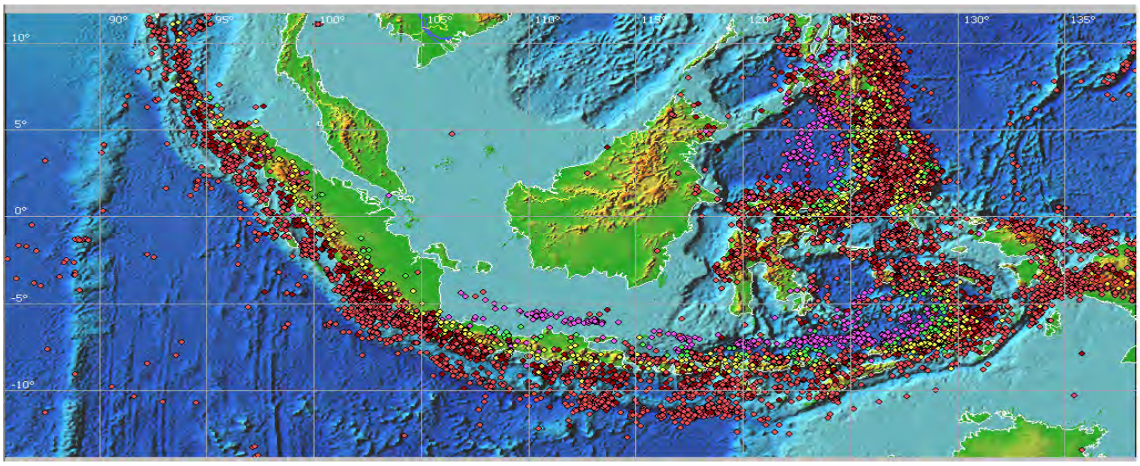

Figure 2.3: *Earthquake events in the Indonesian region over the past 17 years. Sumatra can be clearly seen centre left with the concentration of seismic events on the southern coast evident.*

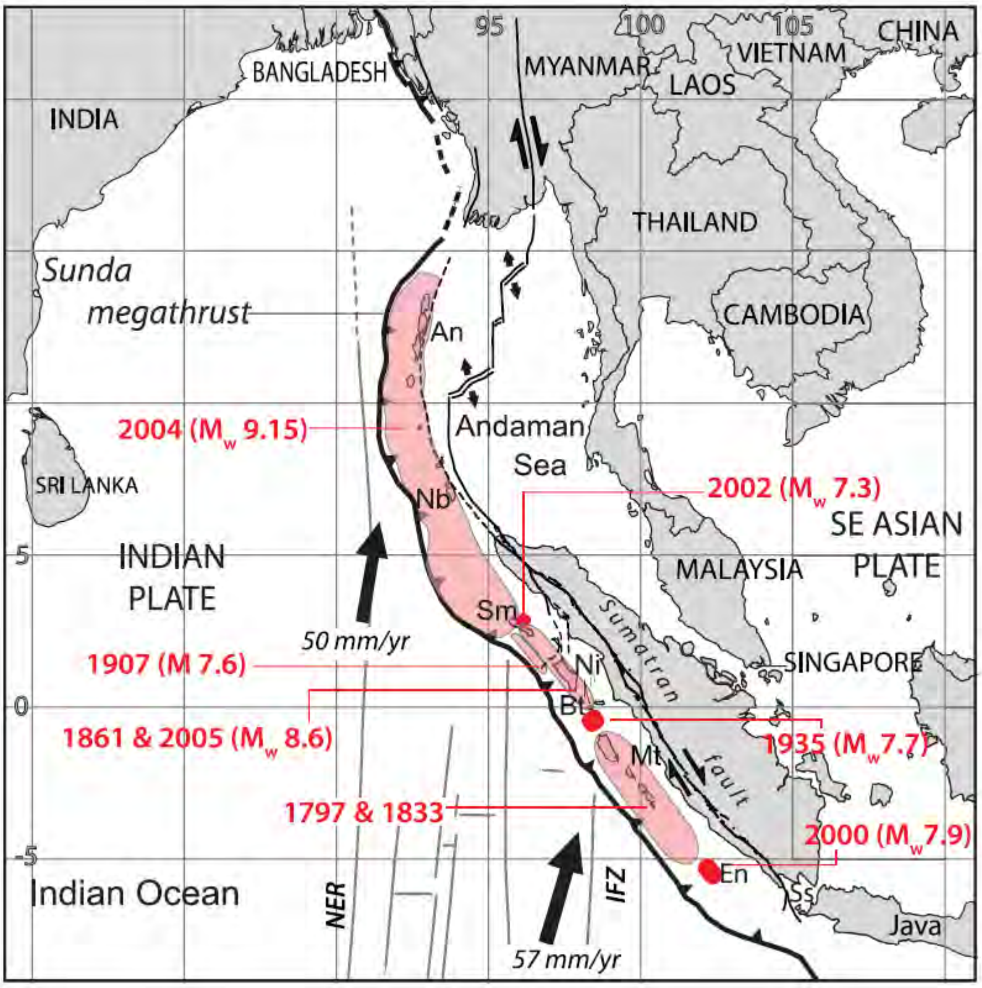

Figure 2.4: *Geological setting of Padang showing historical major and great earthquakes in the region (from Natawidjaja et al., 2006).*

2.3.2 Liquefaction

The deposition process by low energy, meandering river action across the coastal plains has resulted in thick layers of loose, well sorted sands and coarse silts. The low-lying coastal topography with swamps developed behind broad beach ridges is also results in high watertables. Collectively the liquefaction potential across much of Padang is high and liquefaction is expected to become evident when felt intensities exceed MMI 6. Liquefaction can result in sand boils, catastrophic loss of foundation bearing capacity and lateral spreading of terraces alongside watercourses.

2.3.3 Landslide

The geological setting of Padang involves the Indian plate subducting beneath the South East Asian plate offshore (Figures 2.3 & 2.4). Uplift of the Barisan mountain range and the development of volcanic centres are the result of this subduction. The uplifting topography, in combination with a high precipitation climate, has led to rapid and significant volumes of erosion material, and the consequent development of steep slopes. This environment of mixed geology and high relief is typically associated with marginally stable slopes which are susceptible to earthquake triggered landsliding.

2.3.4 Tsunami

The Sunda Arc subduction zone to the south west of Padang is a major source of tsunamigenic earthquakes. Tectonic plate movement in the subduction zone results in a gradual build up of crustal stress and deformation along the interface between the plates which is then suddenly relieved when a major earthquake occurs. Rebound of the seafloor during the earthquake displaces the column of water above the subduction zone. This can then create devastating tsunami waves as the ocean surface returns to its original level. Crustal stress relief is also often accompanied by coastal subsidence which may be as great as 0.5m in Padang, and which would exacerbate the tsunami inundation and create future issues relating to storm surge and flooding. Since the Sunda Arc subduction zone runs parallel to the coast (see Figure 2.4) most of the wave energy from the tsunami will be directed towards Sumatra. The initial wave would arrive approximately 30mins after the time of the earthquake, but large waves could continue to impact the coast for many hours after the event. The Padang region has a very high tsunami hazard and, as discussed in Section 2.3, the region has experienced a number of tsunami historically.

3 Earthquake Event

3.1 EPICENTRE

The 2009 Padang earthquake occurred about 50km off the southern coast of Sumatra, Indonesia. The main shock was recorded at 17:16:10 local time on 30 September 2009 (10:16:10 UTC, September 30). It registered a moment magnitude of 7.6 making it similar in size to the 1906 San Francisco earthquake, the 1935 Quetta earthquake, the 2001 Gujarat earthquake, and the 2005 Kashmir earthquake. The epicenter was 50 kilometres west-northwest of Padang, Sumatra, and 220 kilometres southwest of Pekanbaru, Sumatra. According to the USGS (USGS 2009) the hypocentre was approximately 80 km deep and below the subduction zone interface which is at about 50km depth in that region. Figure 3.1 shows the epicentre of the main event and its proximity to Padang and the closer community of Pariaman.

A second earthquake measuring M_w 6.6, referred to as the Jambi Earthquake, struck the province of Jambi in central Sumatra at 08:52:29 local time on 1 October 2009. The hypocentre was reported at a depth of 15 kilometres, about 46 kilometres south-east of Sungai Penuh. This earthquake appears to relate to the Great Sumatran Fault, but in an area with a low population. Damage would be expected with an earthquake of this magnitude and shallow depth. Little attention appears to have been given to it, possibly because the earthquake occurred in a sparsely populated area and soon (~14.5 hours) after the far more damaging Padang Earthquake.

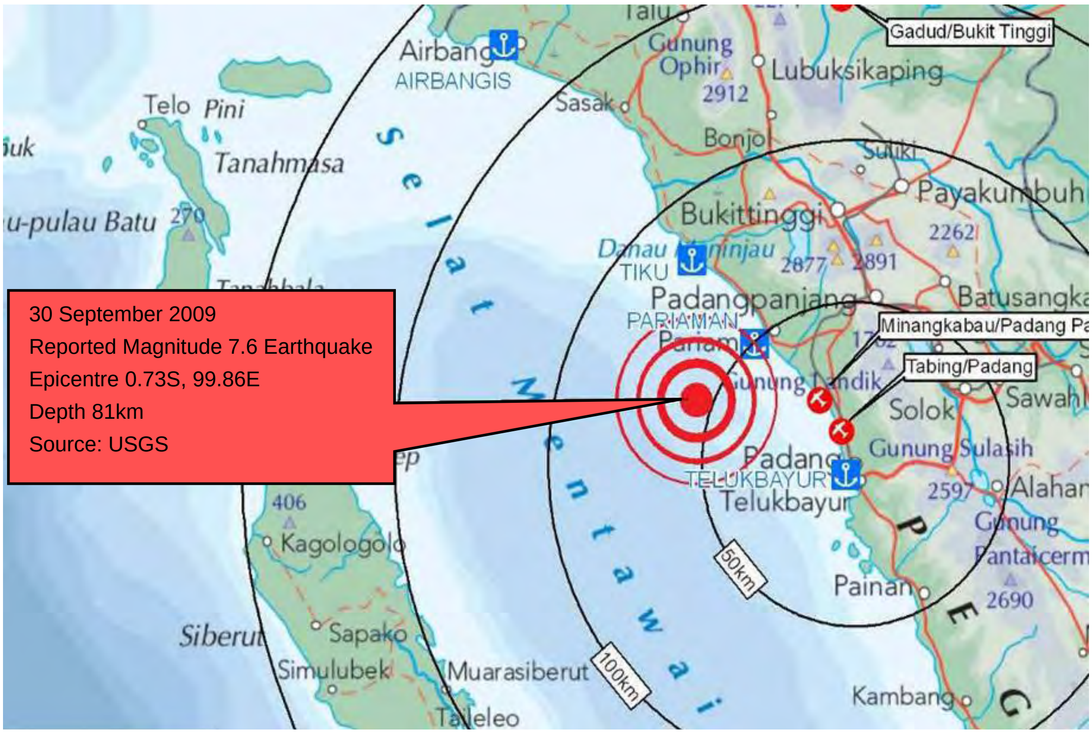

Figure 3.1: *Location of the Sumatran (Padang) 30 September 2010 earthquake epicentre showing proximity to coastal communities.*

3.2 NATURE OF FAULTING

Earthquakes are common along the plate interface between the Indo-Australian and Sunda plates, but the Padang region has not experienced a mega-thrust earthquake since 1833, and another major event is anticipated. However, the M_w 7.6, 30 September earthquake was not a mega-thrust event and it did not generate a tsunami. It was located at a depth of 80 km within the descending oceanic slab of the Indo-Australia plate. Figure 3.2 is a cross section through the subduction zone prepared by the USGS which shows the subducting plate boundary relative to the earthquake focus. The rupture zone of the earthquake is small and roughly circular with a radius of about 15 km. Similar to other intra-slab high stress drop earthquakes, it is considered to be a result of the brittle rupture of relatively strong rock and it produced a predominance of high-frequency ground motions (EERI, 2009). However, its focal mechanism is unusual indicating high angle oblique thrust faulting due to internal buckling and compression of the descending oceanic lithosphere. A maximum of 9 m of slip is indicated at the source as well as strongly radiated energy with very few aftershocks, as is typical of such sub-crustal earthquakes.

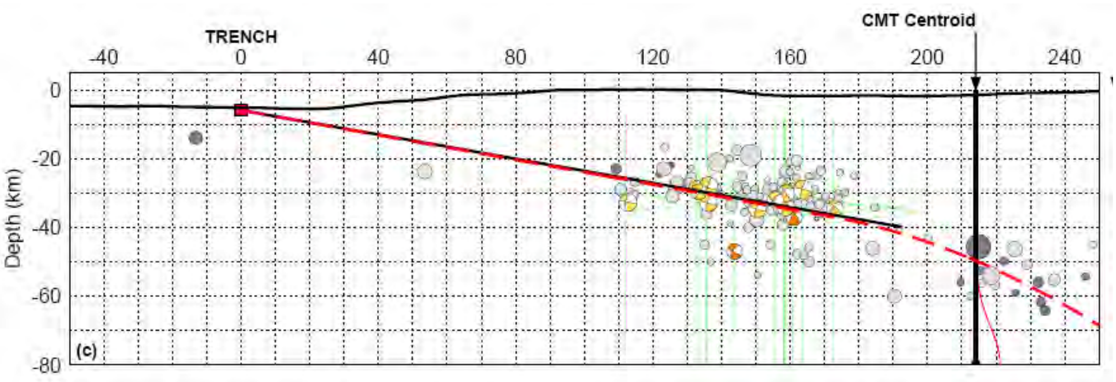

Figure 3.2: *A cross-section by the USGS through the subduction zone at Padang, showing the subduction interface (dotted red line) and the focus, at 80km depth below the epicentre of the Sumatran Earthquake.*

3.3 HAZARD FOOTPRINT

3.3.1 Severity of ground motion

The *ShakeMap* produced by USGS soon after the event is presented in Figure 3.3 (USGS 2009). It shows shows a general MMI range of 7 to 8 in Padang region, and that the earthquake was widely felt in Sumatra and the Mentawai Islands. Earthquake damage to the environment (liquefaction) and to structures on the coastal plain of the Padang area was consistent with an intensity of at least MMI 7. To the south at Teluk Bayur, the port of Padang, damage to structures and rockfall from steep escarpments, were consistent with an intensities of MMI 6 to 7. To the east of Padang the road into the hills showed small landslides on very steep slopes, consistent with MMI 6, while there was no obvious damage to the environment or buildings in the town of Solok on the inland plateau, or around Lake Singkarak. On the highway north of Padang across the coastal plains and into the low foothills, reaching the district of Pariaman, which was closest to the epicentre, environmental and building damage was consistent with an intensity of at least MMI 7 and as high as MMI 8 in Pariaman. However, by Padang Panjang on the upland escarpment there was no visible damage to buildings or the environment. In the large town of Bukit Tinggi, the only visible signs of the earthquake were hairline cracking of brittle parts of large structures, such as plastered columns and brick infill panels, indicating an intensity of approximately MMI 5.

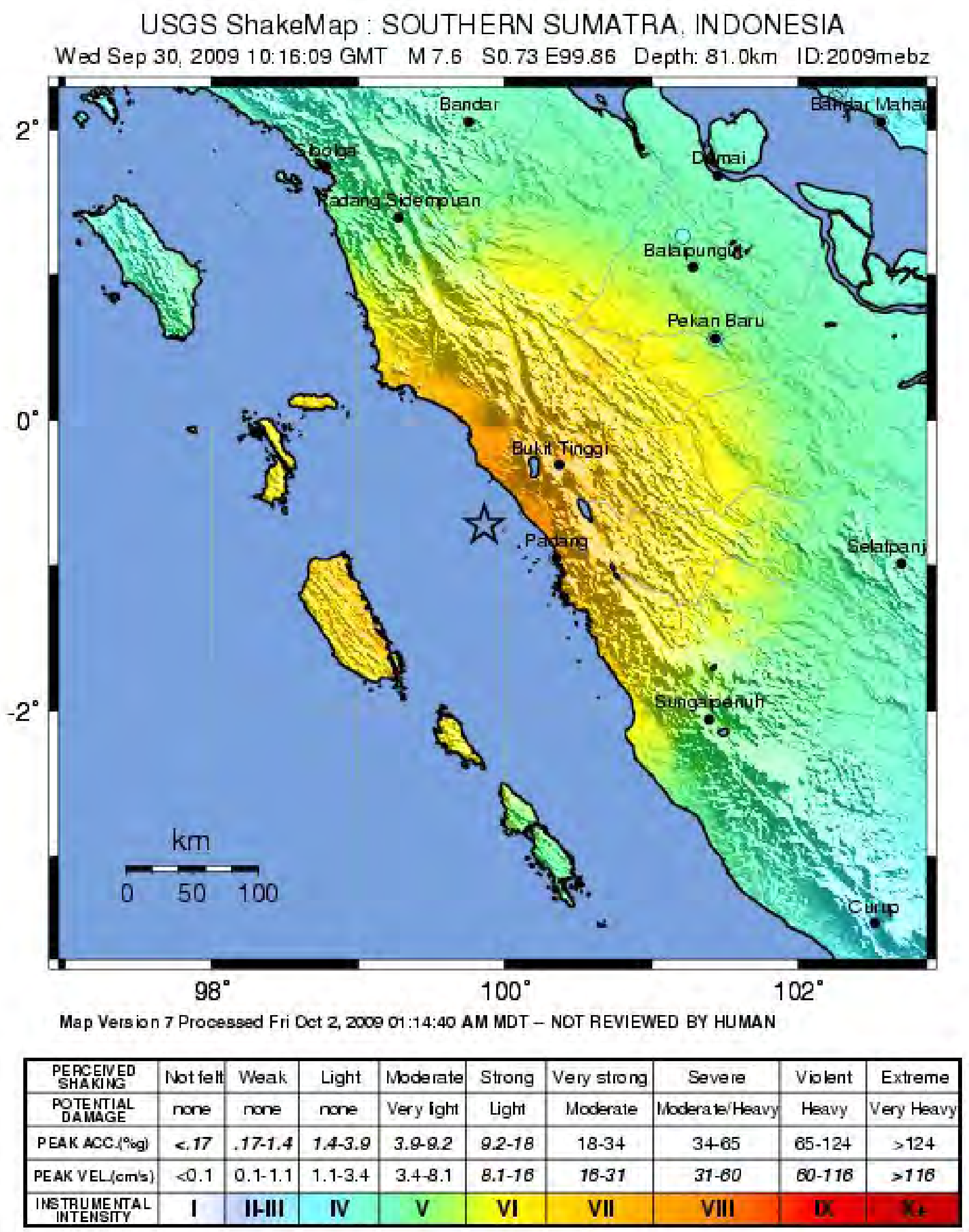

Figure 3.3: ShakeMap *predictions of approximate ground motion severity as derived by the USGS. Intensities in the MMI range 7 to 8 are indicated across the Padang Pariaman regions resulting from the flat coastal topography and the assumptions in the USGS site response model.*

3.3.2 Liquefaction

Extensive liquefaction was experienced across the coastal plain. Sand boils, settlement of building structures and lateral spreading were evident. Figure 3.4 shows the extent of liquefaction as identified by the field survey teams.

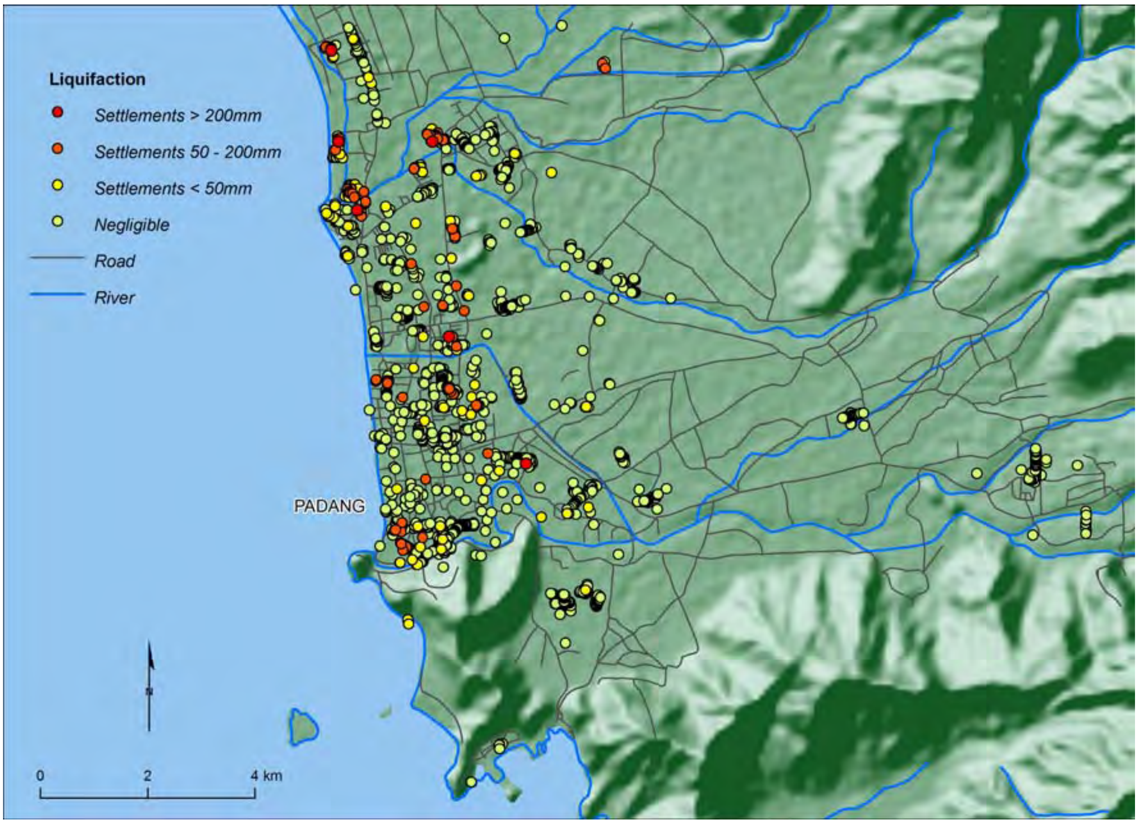

Figure 3.4: *Locations of liquefaction occurrences as identified by field survey activity.*

3.3.3 Landslides

Landslides along the steeper winding roads leading through the hills from the coastal plain to the volcanic plateau were common and moderately damaging. Numerous large rockfalls and flows also occurred from the susceptible caldera escarpment surrounding Lake Maninjau and from the very steep slopes in the gorge between Secincin and Padang Panjang. Figures 3.5 to 3.7 show examples of the slope instability resulting from the event.

Of greatest consequence were the large devastating earthflows triggered by the earthquake which buried villages and were responsible for over 600 deaths, more than half of the earthquake fatalities. These were triggered within volcanic tuff soil deposits in moderately steep, rounded hills, the instability of which is difficult to predict. It is possible that such landslides in saturated soils may be more readily triggered by the predominance of high frequency ground motions generated by this earthquake. However, with the expected future megathrust earthquakes and perhaps even stronger shaking intensity, it is important for detailed studies to assess the causes of the devastating earthflows and to identify the areas at risk from possible future events.

Figure 3.5: *Rockfall and flow from the caldera rim which surround Lake Manijau*

Figure 3.6: *The source area of large devastating earthflows triggered by the earthquake. These earthflows buried villages and were responsible for over 600 deaths, more than half the reported earthquake fatalities.*

Figure 3.7: *Rock fall from the escarpment behind the port (Teluk Bayur)*

3.4 BROAD CONSEQUENCES

3.4.1 Buildings

Damage to buildings was widespread and greatest in the region of Pariaman which was closer to the earthquake epicentre and experienced more severe ground motion. On 14 October (2 weeks after the event) the Indonesian news agency **ANTARA**NEWS (http://www.antaranews.com/en/print/1255472809) reported the damage range summarised in Table 3.1. Some 135,000 homes were seriously damaged representing a huge triaging exercise to assess the safety of buildings for entry and possible occupancy. The temporary housing requirements were even more challenging for the emergency services.

Table 3.1: *Damage severity to homes as reported in* **ANTARA**NEWS *of 14 October 2009.*

Damage Severity	Number of Houses
Serious	135,299
Light	65,306
Minor	78,591
Total	***279,196***

3.4.2 Casualties

In total 1,117 people lost their lives as a result of the earthquake. Over 600 of these died as a result of earthflows triggered by the earthquake which buried a number of villages. The casualty figures reported by the news agency **ANTARA**NEWS (http://www.antaranews.com/en/print/1255472809) are summarised in Table 3.2 and the regional distribution of the fatalities from the same source is summarised in Table 3.3. The total fatalities in Table 3.3 do not strictly correspond with the total fatalities in the same news report but are very similar. It is evident that most of the fatalities that occurred outside of the larger urban areas were greatly influenced by the landslide impacts which accounted for more than half of the total deaths. However, landslide deaths aside, the balance of the loss of life was largely associated with the avoidable collapse of building structures.

Final and more accurate figures were published by the Indonesian Ministry of Health on 28 October, 2009 (http://www.ppk-depkes.org/english-content/recent-news/1594-crisis-up-date-of-west-sumatera-earthquake-on-october-28-2009.html) which gave the death toll as 1,117. This figure and other injury statistics are included in Table 3.2.

Table 3.2: *Casualty figures for the West Sumatra Earthquake of 30 September 2009 as reported by* **ANTARA**NEWS *of 14 October 2009 and as later published by the Ministry of Health on the 28 October 2009.*

Injury Category	**ANTARA**NEWS	Ministry of Health
Fatalities	1,115	1,117
Seriously Injured	1,214	788
Lightly Injured	1,688	2,727
Missing	1	-

Table 3.3: *Spatial distribution of fatalities as reported by* **ANTARA**NEWS *of 14 October 2009*

Location	Fatalities
Padang City	313
Padang Pariaman regency	675
Pariaman City	37
Pesisir Selatan regency	11
Solok City	3
Agam regency	80
Pasaman Barta regency	3
Total	***1,122***

3.4.3 Infrastructure Disruption

Critical infrastructure was disrupted by the earthquake. Transportation assets were less affected but utility services were disrupted to many homes for several days. Telecommunications were also impacted with temporary transmitter facilities installed soon after the event. By the time of the field survey temporary measures and restoration activities had largely restored reliable utility services to the Padang region.

3.4.4 Public Response

As a major subduction earthquake is anticipated, considerable effort has gone into public tsunami awareness and evacuation planning. When the September 30 earthquake occurred, the public response was to evacuate, resulting in chaos as hundreds of thousands of people in Padang took to rubble strewn lanes and roads on foot, motorbikes and in cars.

It was noted that buildings marked and intended for vertical evacuation from tsunami were damaged and some collapsed during the earthquake. Evidently the public did not enter buildings for vertical evacuation if they were even superficially damaged after the earthquake. Instead they took the potentially riskier option of joining chaotic streams of evacuees taking a longer escape route from any tsunami.

4 Post - Disaster Survey

4.1 OBJECTIVES

The disaster survey had two primary objectives:-

1. to undertake a detailed survey of damage to public buildings such as schools and medical facilities to assess performance. The survey could inform recommendations on improvements that could be made to design and construction practices so that a recurrence of the types of damage observed in Padang might be avoided. This activity would also provide interim contributions to the World Bank Damage and Loss Assessment (DALA) reporting; and,

2. to undertake a population-based survey of buildings of all types and all damage levels within a region. From the results knowledge could be derived of the vulnerability of a range of building types present in the Padang region and representative of others in Indonesia.

The detailed survey teams surveyed approximately 400 buildings (300 schools and 100 medical facilities) which formed a subset of the approximately 4000 buildings surveyed for the population-based survey. After the first week of surveying a draft report of recommendations was submitted to the World Bank and AIFDR.

4.2 TEAMS AND DEPLOYMENT

The arrival of the foreign survey participants was coordinated through the AIFDR. The Australian and New Zealand participants arrived in Jakarta on 22 October 2009 for an initial briefing on the situation in Padang and on strategies for local engagement. The combined party then travelled to Padang on 23 October and commenced field survey work on 24 October, almost 4 weeks after the earthquake.

The survey was undertaken by ten field teams supported by a team of logistical staff. The detailed survey was undertaken by two teams comprising experienced engineers and scientists from Indonesia, Australia, New Zealand and Singapore. The population survey was undertaken by the other eight teams consisting of a mix of three or four Indonesian professional engineers, postgraduate students and undergraduate engineering students together with experienced engineers and scientists from Indonesia, Australia, New Zealand and Singapore. The teams were supported by Indonesian translators and drivers.

The support team provided liaison, logistical support and GIS services. The team, partly staffed by the AIFDR, ensured that the survey work could proceed with minimal impediment and took responsibility for the digitising of the captured survey information on a daily basis. The team also coordinated the contributions made by the logistical support company sourced by the AIFDR that provided the basic accommodation, food and transport needs of the large team. The support of this team was found to be vital given the disaster zone nature of the Padang region.

4.3 SURVEY METHODOLOGIES

Survey methodologies were developed and reviewed through email and telephone conferencing prior to deployment. The approach was aimed at meeting the needs of the DALA, of obtaining more detailed knowledge of the performance of important public buildings, and to obtain statistically useful information on building performance. Reference was made to other published survey approaches (EERI 1996, FEMA 306 1998, FEMA 307 1998, Goretti and Di Pasquale 2002) which typically were aimed at a greater level of damage detail capture from individual structures than could be accommodated in Padang. The approach reported by Goretti and Di Pasquale on Italian survey activity was found particularly useful given similarities in building construction. The methodology developed and its key elements are described below.

4.3.1 Building Stock Categorisation

The expected range of building types in Indonesia was classified into a schema consisting of 54 types. Buildings were classified into residential / non-residential and residential buildings were then subdivided on the basis of roofing type and primary structural type. Non-residential buildings were classified by age and then by height/primary structural type combination. Types 51 to 54 were added during the survey as the new types were encountered. The schema is shown in Table 4.1. Each surveyed building was assigned a classification number at the time of survey to simplify attribution on the survey form in the field.

Table 4.1: *Building schema used for the survey with the classification number for each type shown in the respective cells*

Indonesia Building Stock Categorisation Version III

1-2 Storey Residential Buildings (shaded cells not common in Padang, < 10 points)

Structural System	Metal / Timber Roof	Heavy Tile Roof
URM HAZUS URML	1	2
Confined masonry	3	4
Full timber frame + lightweight cladding HAZUS W1	5	6
Bamboo frame + lightweight cladding	7	N/A
URM bottom storey / timber frame upper storey (common in Philippines, maybe not present in Indonesia?)	9	10
RC frame with in-fill masonry HAZUS C3L Characterised by rc frame elements thicker than in-fill	11	12
Modern, code-compliant, all structural systems	13	14
Padang Special: 700mm tall dado masonry wall, timber posts, coarse chain wire mesh between posts plastered with cement stucco, sheet metal or pressed metal tile roof.	51	N/A

Non Residential Buildings and Residential 3+ Storeys (shaded cells not common in Padang, <10 points)

Structural System	Pre 1981	1981 - 2002	2003 +
Concrete moment frame 1-3 storeys HAZUS C1L	15	16	17
Concrete moment frame 4 -7 storeys HAZUS C1M	18	19	20
Concrete moment frame 8+ storeys HAZUS C1H	21	22	23
Concrete shear wall 1-3 storeys HAZUS C2L	24	25	26
Concrete shear wall 4-7 storeys HAZUS C2M	27	28	29
Concrete shear wall 8-15 storeys HAZUS C2H	30	31	32
Concrete shear wall 16-25 storeys HAZUS C2H	N/A	34	35
Concrete shear wall 26-35 storeys HAZUS C2H	N/A	37	38
Concrete shear wall 36+ storeys HAZUS C2H	N/A	N/A	41
URM 1-3 storeys HAZUS URML / URMM	42	43	44
Timber 1-3 storeys HAZUS W1 / W2	45	46	47
Steel frame 1-3 storeys HAZUS S1L	48	49	50
Confined Masonry 1-3 storeys	52	53	54

4.3.2 Detailed Survey of Schools and Medical Facilities

The detailed survey teams conducted inspections of school and medical facility buildings. About one hour was spent surveying each building. Although they completed the population survey form (Section 4.3.3, Figures 4.5 and 4.6) at each building, their requirement to record a greater level of detail regarding the earthquake damage led to the development of the detailed survey form shown in Figure 4.3. This form was targeted at the particular types of building structure used in Padang for school and medical facility buildings; commonly reinforced concrete frames with masonry infill and, to a lesser extent, confined masonry. The detailed survey teams were assisted by the provision of maps showing the location of the target buildings together with their GPS coordinates.

Campus name: Building No.: Total No. of buildings:

Circle appropriate facility:

Medical facility	Kindergarten (TK)	Elementary (SD)
Junior (SMP)	Middle School (SMA)	University

Building Plan: Rough campus map showing building:

Observations:	Y	N
No damage Non-structural damage Structural damage repairable Structural damage non-repairable Collapse		
Non structural damage: Gable end parapet OOPF of infill ceiling damage		
Roof failure: dislodged tiles sagging frames collapse		
Permanent lateral deformation of building: Longitudinal Transverse Minor Major Comments:		
Plastic hinging at: top bottom columns walls Ground floor Second floor Partial full Longitudinal Transverse Comments:		
Spalling of: concrete render columns beams walls		
Diagonal shear cracking: columns piers joints walls long. Trans minor major		
Separation cracking between frame and walls		
Stirrups: Absent too few joint column 90° bends 135° bends short tails Comments:		
Reinforcement: Round Deformed Bar sizes: Insufficient development length		
Concrete honeycomb poor concrete poor aggregates - rounded Insufficient cover		
Foundation settlement liquefaction sand boils		

Figure 4.3: *Detailed survey form (single face) used for schools and medical facilities.*

4.3.3 Population-based Survey

The eight detailed survey teams operated in two groups of four teams. The survey area within Padang was split into nine sectors, shown in Figure 4.4, that were then assigned separately to the two groups. Typically each group would spend two days surveying a sector in which representative streets would be chosen and every building in those streets would be surveyed by the teams (damaged or undamaged). Towards the end of the survey period the detailed survey teams ventured outside the city area to survey buildings further afield to the east and south. This provided data over a wider geographic range and terrain/sub-soil types. It also sought to capture a greater range of shaking intensity.

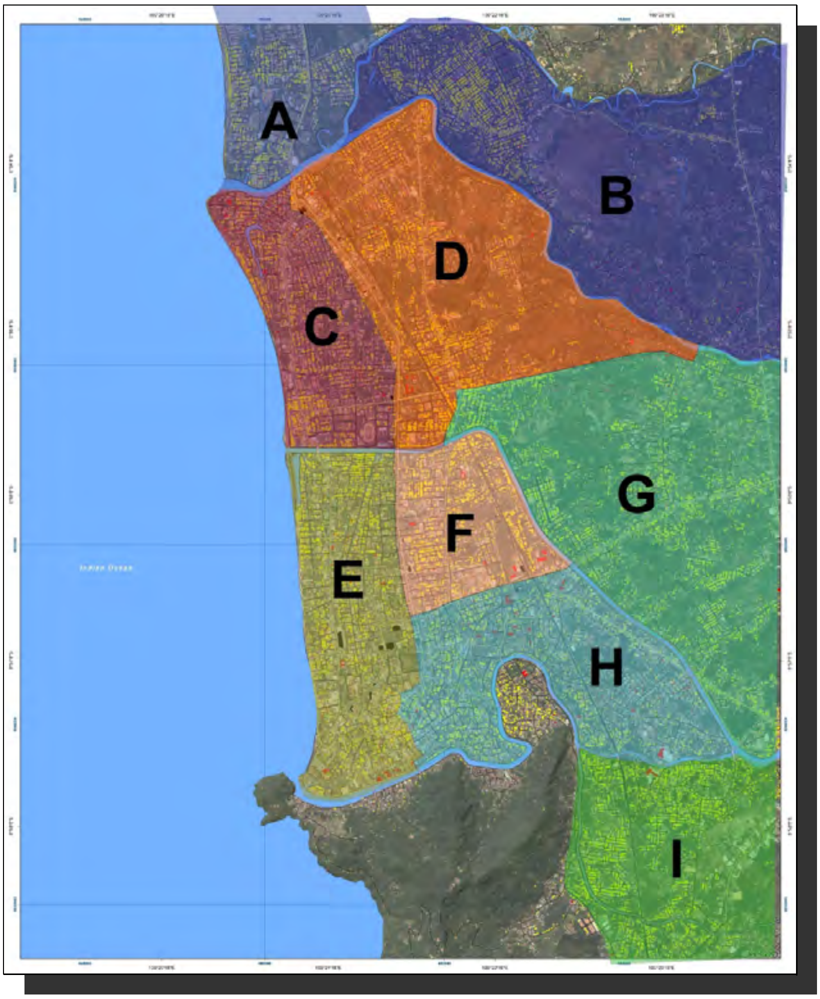

Figure 4.4: *Padang survey sectors for population based survey planning.*

The population survey teams utilised a standard paper form consisting of both sides of a single sheet of A4 paper. The form is shown in Figures 4.5 and 4.6 with the separate reference sheet of MMI descriptions and irregularity codes presented in Appendix A1. The design of the form was a difficult balance of capturing the maximum level of detailed information and the space available on the paper sheet; it was desired to keep the form to a single sheet of two-sided A4 paper. Position of surveyed buildings was recorded by means of a GPS device with the latitude and longitude manually recorded onto the paper form. Photos were taken with digital camera. Each team surveyed approximately 20 buildings per day. Each day the support team transcribed the information from the paper forms into an electronic database and linked the photos to each record. Feedback from the support team was useful in detecting any systematic errors in field survey data recording.

Padang Region Post 30.09.09 Earthquake Damage Survey

Bldg ID no.	Date	Team	Sequence No	
Address / Location				
GPS Co-ordinates	Lat : S		Long : E	
Filenames	First Photograph	100-	Last photograph	100-

Description							Same as last?	
Usage (1,2,3,..)		**Structural system**		**Wall type**		**Roofing type**		
Residential		URM		Mud brick/daub		Thatch, etc		
Commercial (office)		Confined masonry		Bamboo		Tile		
School		RM		Unreinf'd masonry		Wood shingle		
Retail		Timber frame		Reinf'd Masonry		Metal		
Medical facility		Bamboo		Timber on subfram		Concrete		
Hotel		Steel frame		Metal on subframe		Other		
Warehouse		RC frame / walls		Insitu Concrete		**Age**		
Other industrial		**Floor type**		**Number of Storeys**		0-10 years		
Church /Mosque		Timber		1		11-20years		
Other		RC		2		21-49years		
		Other		3		50+ years		
Length (m)				4-7		Unknown		
Width (m)				8+				
Irregularity codes				Long axis bearing		Plan shape code		

Miscellaneous							Same as last?	
Site morphology	Hill top		Steep slope		Mild slope		Flat	
MMI from interview		**Seismically separated?**		**Schema version no.**		**Building type number**		
Notes on bldg and damage to non-bldg structures: garden walls, footpaths, roads, power poles, etc.								
Inspection accuracy	Outside only		Partial interior		Complete			

Damage								Same as last?
URM			**Confined masonry**			**Bamboo / Timber**		
0	Negligible		0	Negligible		0	Negligible	
1	Some cracks at openings		1	Hairline cracks in in-fill.		1	Small lining cracks at opening corners & cornices	
2	Some diagonal cracks in walls & parapet bases		2	Hairline cracks in confining structure		2	Small cracks in masonry elements	
3	Diagonal cracks in most walls		3	Larger cracks in some in-fill		3	Large lining cracks	
4	Some separation of walls from floors. Small amounts of fallen masonry		4	Larger cracks in confining structure		4	Toppling of some tall elements, small diagonal cracks in bracing walls	
5	Extensive cracking to all walls		5	Large cracks in most walls, minor masonry falls		5	Large diagonal cracks across bracing walls	
6	Parapets and gable walls fallen		6	Failure of some confining structure		6	Slippage over foundations	
7	Some collapse of bearing walls		7	Most walls show falling masonry or severe cracking		7	Large permanent lateral displacement, partial collapse	
8	Full structure in danger of collapse		8	Full structure in danger of collapse.		8	Full structure in danger of collapse	
9	Destruction		9	Destruction		9	Destruction	

Figure 4.5: *Population survey form – front face*

Damage continued								
RC Frame / Walls			**Steel Frame**			**Geotechnical**		
0	Negligible		0	Negligible		0	Negligible	
1	Hairline cracks at in-fill / column joints		1	Minor plate deformations or brace deformation		A1	Liquefaction settlements <50mm	
2	Hairline cracks in structure & in-fill		2	Minor hairline cracking in welds		A2	Liquefaction settlements 50 - 200mm	
3	Some frame elements yielded. Larger cracks in in-fill.		3	Some permanent joint rotations, few major cracks in welds		A3	Liquefaction settlements >200mm	
4	Larger flexural cracks and spalling. Some crushing of in-fill at corners.		4	Some broken bolts and welds or enlarged holes, some yielded braces		B1	Vertical foundation movement <50mm	
5	Some failures to non-ductile elements. Most in-fill exhibits large cracks, minor falls		5	Most members yielded, anchor bolts stretched		B2	Vertical foundation movement 50 - 100mm	
6	Many failures to non-ductile elements. Some in-fill fallen or bulged		6	Some critical connections and members failed. Partial collapse of portions.		B3	Vertical foundation movement >100mm	
7	Most non-ductile elements failed. Severe deformation. Most in-fill fallen or severely damaged.		7	Most elements exceeded yield capacity. Dangerous lateral displacement. Partial collapse.		C1	Slight horizontal spreading <25mm	
8	Full structure in danger of collapse		8	Full structure in danger of collapse		C2	Moderate horizontal spreading 25 to 100mm	
9	Destruction		9	Destruction		C3	Severe horizontal spreading >100mm	

Population						Same as last?	
No of inhabitants in bldg				**Temporary accommodation**		**Injuries**	
Day		Night		None (homeless)		No of persons injured	
				Friends / family		Severe cuts, minor burns	
Bldg evacuated during Earthquake?				Local community bldg		Severe injuries, breaks, burns requiring hospitalisation or surgery	
Yes		No		Aid agency		Life threatening requiring quick intensive treatment to avoid death	
Bldg evacuated after Earthquake?				Govt temporary accommodation		Deaths	
Yes		No		Unknown			
Did inhabitants have an EQ evacuation plan?				Distance to temp accommodation from home (km)		**% Floor area collapsed (count roof as a floor)**	
Yes		No		NA (non residential building)			
How long before bldg reoccupied?						**Loss of utilities**	
Days						Service	Days / Weeks
Weeks						Water	
Unable						Power	
						Gas	
						Telecom	

Figure 4.6: *Population survey form – back face*

Data on the inhabitants and their experiences during the earthquake were captured by interview where possible. The interview was also used to assign a MMI value to the building being surveyed.

The numbers of buildings collectively surveyed with regards to their predominant usage type are presented in Table 4.2. The spatial distribution of the building types surveyed in the Padang region is presented in Figure 4.7. The region of Pariaman to the north was also surveyed.

Table 4.2: *Surveyed building usage types (primary) and total numbers for detailed and population based surveys combined*

PRIMARY BUILDING USAGE	NUMBER SURVEYED
Church/Mosque	34
Commercial (office)	183
Hotel	11
Medical Facility	108
Industrial	10
Retail	285
Warehouse	74
School	460
Residential	2,667
Other	54
Unknown	10
Total	***3,896***

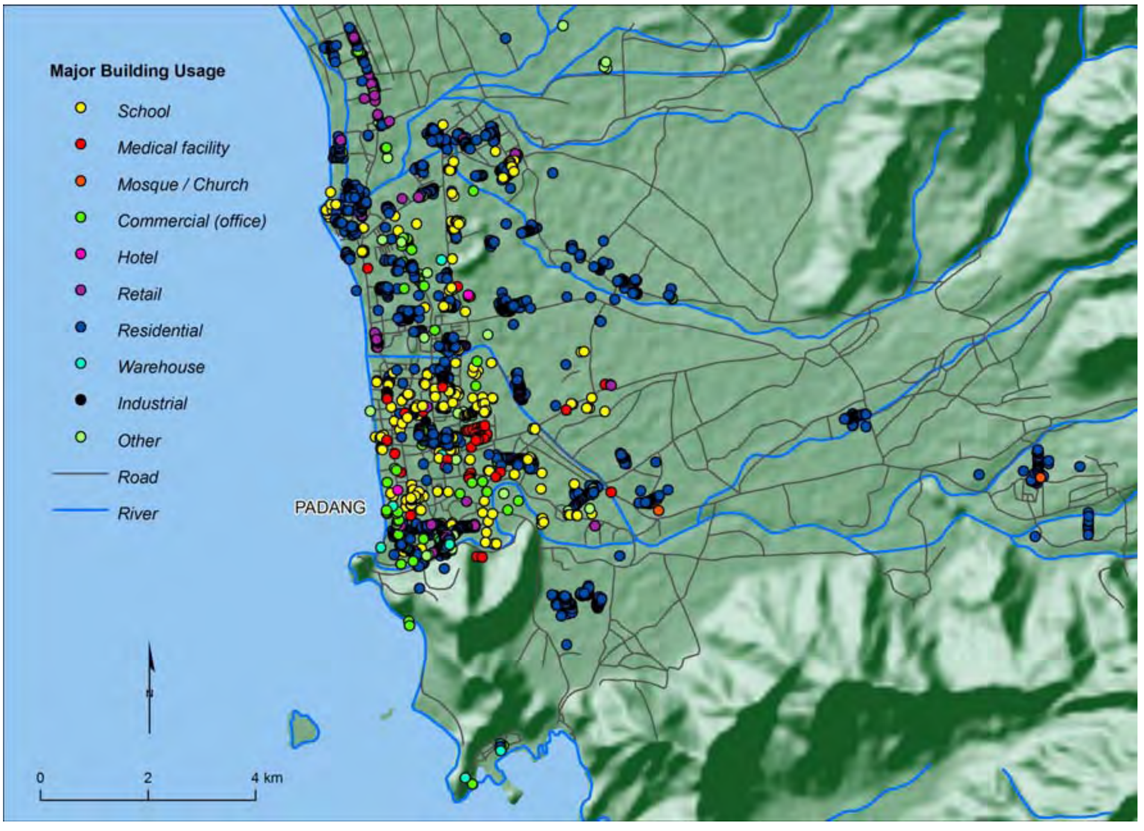

Figure 4.7: *Surveyed building types and spatial distribution in Padang region.*

5 MASW Survey and Spatial PGA Estimate

5.1 AIM & OBJECTIVES

The aim of this work is to estimate the distribution of peak ground acceleration (PGA) values resulting from the 30 September 2009 earthquake. These have been determined for buildings covered in the post-disaster survey in the cities of Padang and Pariaman. Specific objectives of the work were to:

- Conduct multi-channel analysis of surface wave (MASW) survey within the cities of Padang and Pariaman.
- Determine levels of peak ground acceleration on reference bedrock using earthquake source properties for the 30 September 2009 event and ground motion prediction equations.
- Estimate site amplification effects by analysing wave propagation analysis from bedrock to the ground surface.

5.2 TEAMS

The earthquake ground motion analysis and MASW survey to estimate a spatial PGA for the City of Padang and Pariaman was conducted by the Center for Disaster Mitigation - Institut Teknologi Bandung (CDM-ITB) team, with support from University of Andalas-Padang.

5.3 SURVEY AND ANALYSIS METHODOLOGY

The following sections describe the survey and analysis methodology applied.

5.3.1 MASW Survey

The Multi-channel Analysis of Surface Waves (MASW) technique is a seismic survey method for evaluating the elastic condition (stiffness) of the ground for geotechnical engineering purposes. MASW first measures seismic surface waves generated from various types of seismic sources, such as a sledge hammer, analyses the propagation velocities of those surface waves, and then calculates shear-wave velocity (V_s) variations below the surveyed area that are a best fit for the analysed propagation velocity pattern of surface waves.

MASW surveys usually consist of three steps detailed below and shown diagrammatically in Figure 5.1:

1. Data Acquisition: field collection of multichannel data (commonly called shot gathers in conventional seismic exploration)
2. Dispersion Analysis: extracting dispersion curves (one from each record)
3. Inversion: back-calculating shear-wave velocity (V_s) variation with depth (called 1-D V_s profile) that gives theoretical dispersion curves closest to the extracted curves (one 1-D V_s profile from each curve).

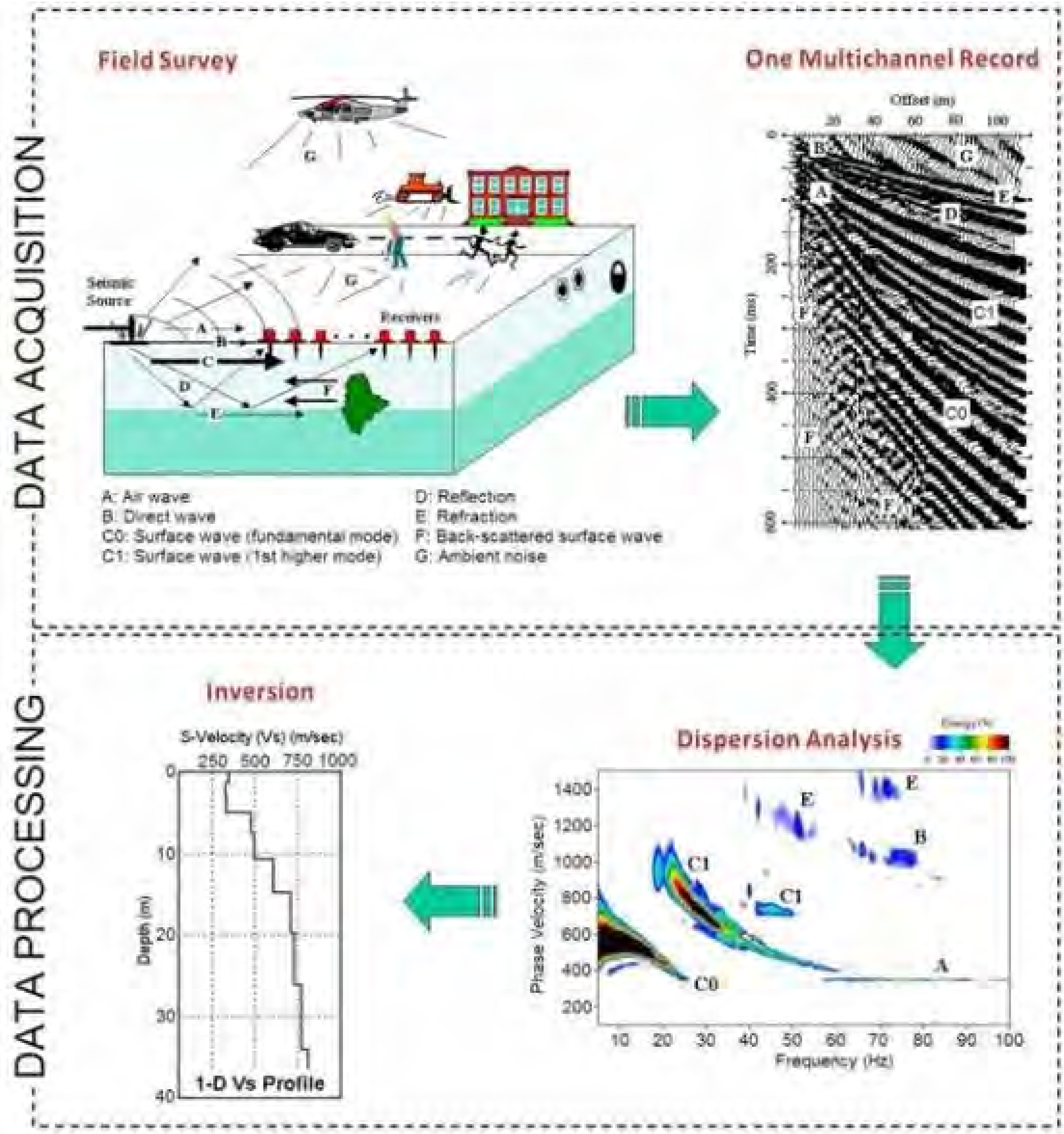

Figure 5.1: *The overall procedure of Multi Channel Analysis of Surface Waves (MASW).*

Field equipment and parameters used in the MASW survey are listed below.

- Near offset (distance between hammer blows and first geophone): 18 m.
- Number of geophones: 12.
- Geophone spacing: 3 m.
- Energy source: drop weight of 60kg.
- Recording: 24 bit digital recorder (Seistronix RAS-24 Exploration Seismograph).

The goal of the field survey and the subsequent data processing prior to inversion is to establish the fundamental mode (M0) dispersion curve as accurately as possible. Historically this has been one of the key issues with data acquisition and processing in surface wave applications. Theoretical M0 curves are then calculated for different earth models by using a forward modelling scheme to be compared against the measured (experimental) curve. This inversion approach is based on the assumption that the measured dispersion curve represents the M0 curve and that it is not influenced by any other modes of surface waves.

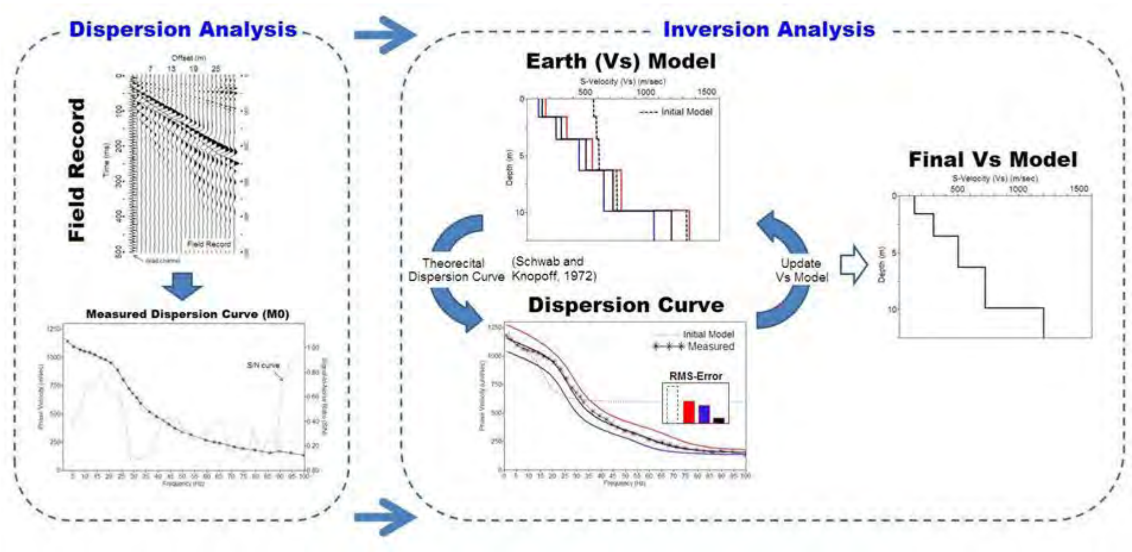

Figure 5.2: *The inversion process to produce the shear wave velocity profile*

A key issue with this inversion approach, shown in Figure 5.2, is the efficiency of the optimisation technique used to search for the most probable earth model. The root-mean-square (RMS) error is usually used as an indicator of the closeness-of-fit between the two dispersion curves (measured and theoretical), and the final solution is chosen as the 1D V_s profile resulting in a preset (small) value of RMS error. Either a deterministic method such as the least-squares method or a random approach is taken for the optimisation. Least squares is often faster than a random approach but at the expense of an increased risk of finding a local, instead of a global, minimum.

The MASW survey was conducted at 30 different locations covering surveyed buildings within the city of Padang. The survey was also conducted at 3 different locations within the city of Pariaman. Figure 5.3 shows the spatial locations of MASW survey sites in Padang. In addition, existing geotechnical data for the city of Padang was collected. Shear wave velocity (V_s) profiles were developed for the top 30m (V_{s30}) based on the MASW survey and using existing geotechnical data. This V_{s30} data was then used to inform a site classification by referring to the site classification criteria of SNI 1726-2002 (2002) or IBC 2006 (2006).

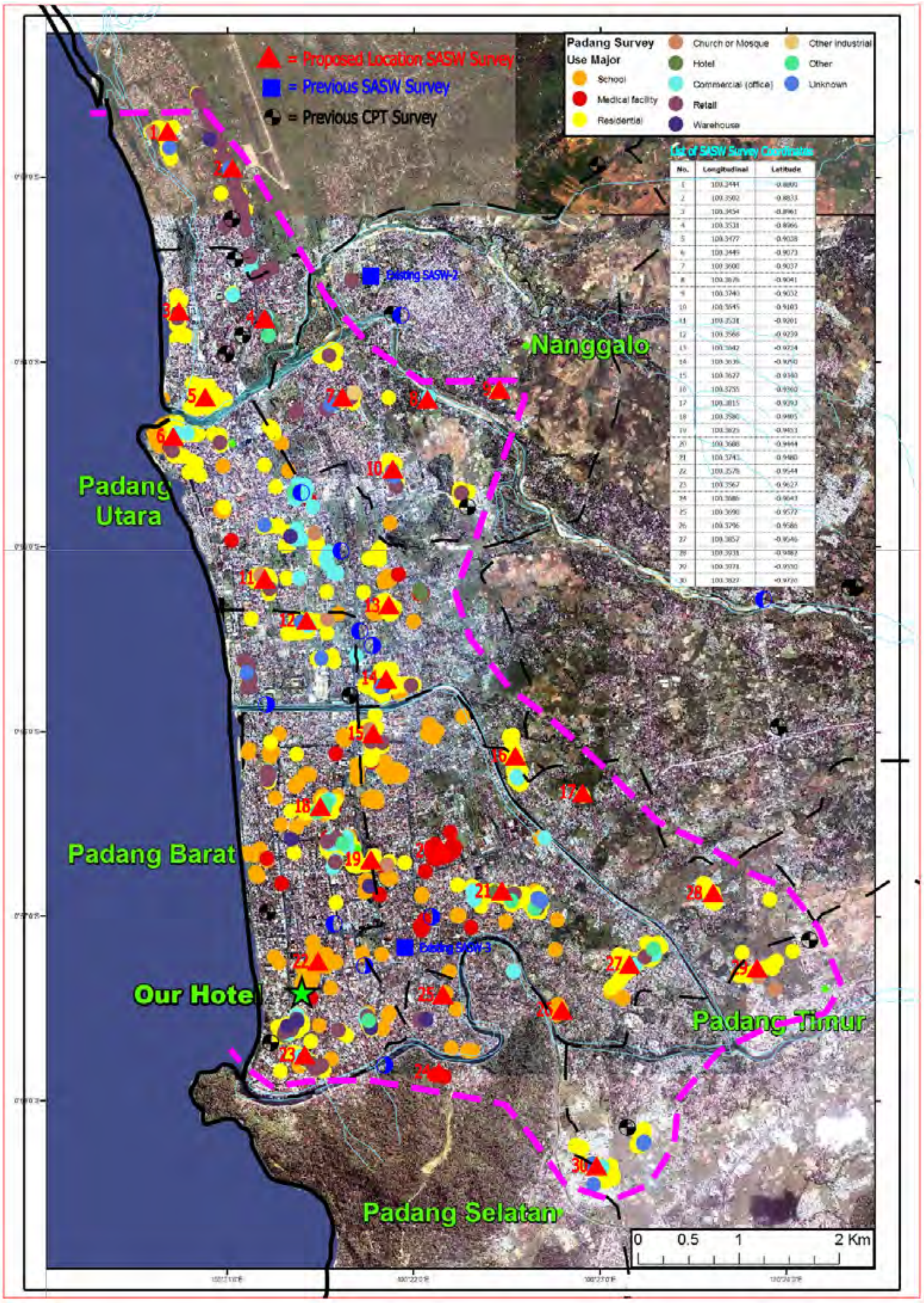

Figure 5.3: *Location of MASW survey sites in the city of Padang indicated by red triangles.*

The complete earthquake event analysis and MASW seismic survey results are presented in Appendix A3.

5.3.2 PGA Estimation

Firstly, a seismic attenuation analysis of the 30 September 2009 earthquake event was undertaken. The analysis was conducted by identifying the earthquake source characteristics and distances to sites of interest. In this process a deterministic seismic hazard analysis (DSHA) was completed to estimate the distribution of peak ground acceleration (PGA) at base-rock. The analysis was conducted using EZ-FRISK 7.32 software (Risk Engineering Inc., 2004). Attenuation functions by published by Youngs et al (1997) [Young intraslab] were adopted to represent the subduction earthquake sources.

Secondly, a site-response analysis (SRA) was carried out to estimate peak ground surface acceleration and response-spectra by considering predicted input motions and dynamic soil properties of the sites. In the case of the cities of Padang and Pariaman, there is no strong motion data available, therefore the simplest conventional method of generating input motions by scaling available strong motion records from other sites was applied. Strong motion records are commonly scaled to match target PGA of the site of interest by spectral-matching techniques. In this study, spectral-matching techniques proposed by Abrahamson (Abrahamson 1998) and adopted and built into the EZ-FRISK Computer Program Version 7.2 were utilised. Time-domain wave propagation analyses from bedrock to ground surface were then completed using the NERA (nonlinear earthquake response analysis) computer program (Bardet and Tobita, 2001). Complete site-response analysis results are presented in Appendix A3.

5.4 PGA SPATIAL DISTRIBUTION RESULTS

Based on the results of seismic wave propagation analysis, which were carried out by considering the V_{s30} data for each location in the sub-district and the estimated earthquake PGA on bedrock, maps of the spatial distribution of PGA at the ground surface for the cities of Padang and Pariaman have been developed and are presented in Figures 5.4 and 5.5.

The complete analysis and results of the PGA spatial distribution assessment are presented in Appendix A3.

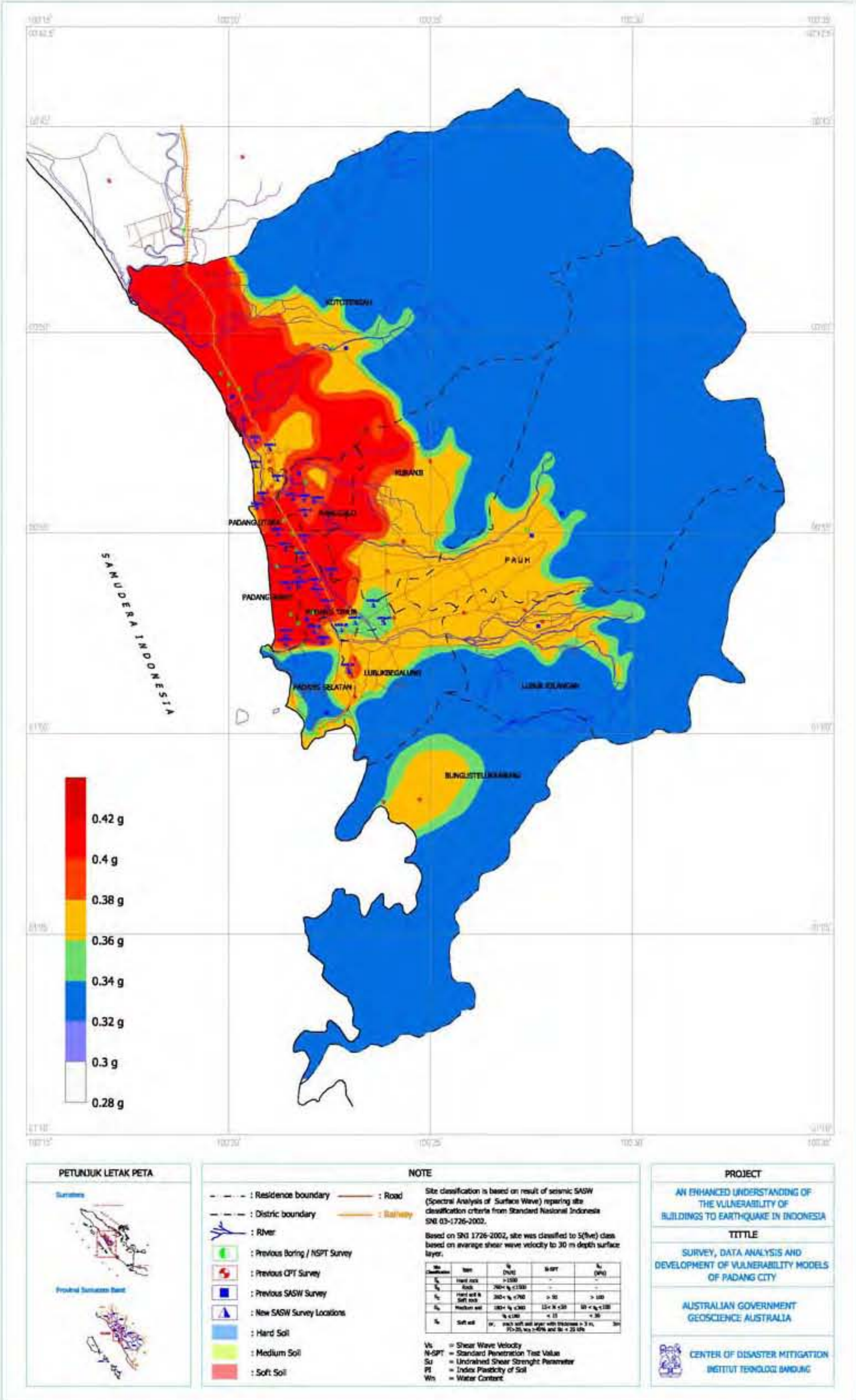

Figure 5.4: *Spatial distribution of ground surface PGA for the city of Padang*

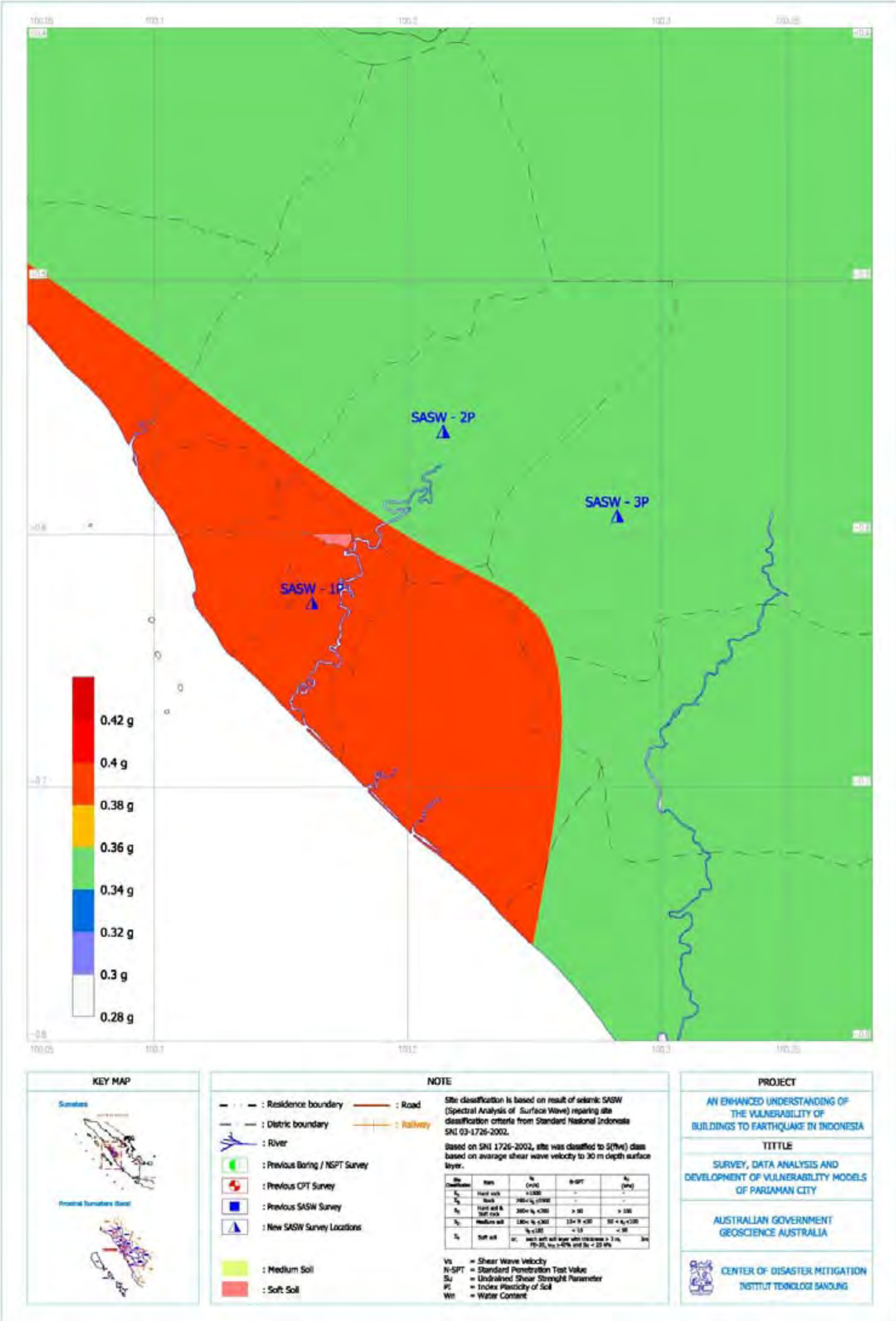

Figure 5.5: *Spatial distribution of ground surface PGA for the city of Pariaman*

6 Post-Survey Analysis

6.1 DALA REPORTING

While the survey activity was progressing a parallel assessment process was being advanced by a World Bank engineering team. Following major natural disasters the World Bank typically arranges for a Damage and Loss Assessment (DALA) to be made to inform strategies for promoting recovery in the affected region. Through the coordinating effort of the AIFDR a brief report was prepared by the detailed survey team to augment the structural assessment commentary of the DALA. The expert team contributions addressed what should be done as part of the recovery and what will be needed for regional development into the future. The DALA recommendations made by the expert (detailed) engineering team are contained as an addendum to their separate report in Appendix A2.

The key recommendations made in the DALA contributions were:-

Regulatory

- The design criteria in the current building regulations should be reviewed to ensure that facilities intended to provide refuge and/or to have a post-disaster function will be functional in the event of the expected mega-thrust earthquake in the region. Ordinary buildings of three storeys height or greater should also be designed to a higher standard (e.g. to act as tsunami refuges following a large earthquake).
- Existing key facilities that performed adequately in the 30 September earthquake should be checked for adequacy in the context of the expected mega-thrust earthquake and strategies for retrofit developed and implemented where required.
- Other non-engineered structures should be reviewed and strategies developed to improve structurally deficient buildings.
- Some apparently heavily damaged structures should be assessed in greater detail as they may not require demolition.
- Confined masonry should be promoted for new masonry construction.
- Detailed hazard mapping should be carried out covering earthquake amplification, soil liquefaction potential and landslide susceptibility for use in local development planning by government.

Enforcement of Regulations

- The overall building construction and quality assurance process in West Sumatra should be assessed and modified to ensure buildings are designed and constructed to the required level. This will require education on appropriate construction techniques as well as a regime of building inspections during construction of engineered and non-engineered structures.
- Building Permits should be required for all work to assist in quality control. An advisory team of experts and professionals would assist Provincial and Mayoral Offices to improve scrutiny of proposed designs.
- A mandated inspection regime is required to ensure buildings are constructed to the design with particular attention to reinforcement placement and concrete quality.
- Training in fundamentals of reinforced concrete construction and seismic detailing should be provided throughout the professional and construction communities in West Sumatra (and Indonesia) to improve design and construction quality. Training of building workers and the education of building owners will assist in the reform process.

Specific Engineering Design Issues

- Provide gaps between buildings to reduce “pounding”;
- Include shear walls on ground and other floors to reduce “soft storey” type behaviour.
- Use quality deformed reinforcement bars to improve bond and reinforced concrete performance;
- Improve reinforced concrete joint detailing
- Provide countermeasures for liquefaction and other foundation problems.

6.2 FIELD DATA VALIDATION/VERIFICATION

Validation of the data collected by the many field teams was a large task. The initial task was to check the recorded data at survey record level with reference to the corresponding photos. Importantly the MMI levels attributed during the field survey were reassessed as many had been biased by the damage to the surveyed building rather than the broader neighbourhood outcome. Additional survey entries were also obtained by transcribing approximately 400 survey records made by a New Zealand team into the format of the population survey form. The team was in Padang prior to the AIFDR sponsored survey and their activity had a primary focus on the triaging of buildings for safe access and habitability.

6.3 EARTHQUAKE INTENSITY REASSESSMENT

The survey of earthquake damage in the Padang region carried out by the survey team indicated a felt intensity of MMI 7 or 8 in the city with a maximum felt intensity of MMI 9 in Pariaman. An intensity of MMI 6 to 7 is associated with the onset of environmental damage (liquefaction, lateral spreading, landsliding) and damage to non-earthquake resistant structures, with these indicators all becoming increasingly severe with further increases in intensity. Using these indications along with occupant interview observations the intensity map shown in Figure 6.1 was developed. It indicates an MMI of 8 across most of Padang and Pariaman dropping off to MMI 7 with distance inland.

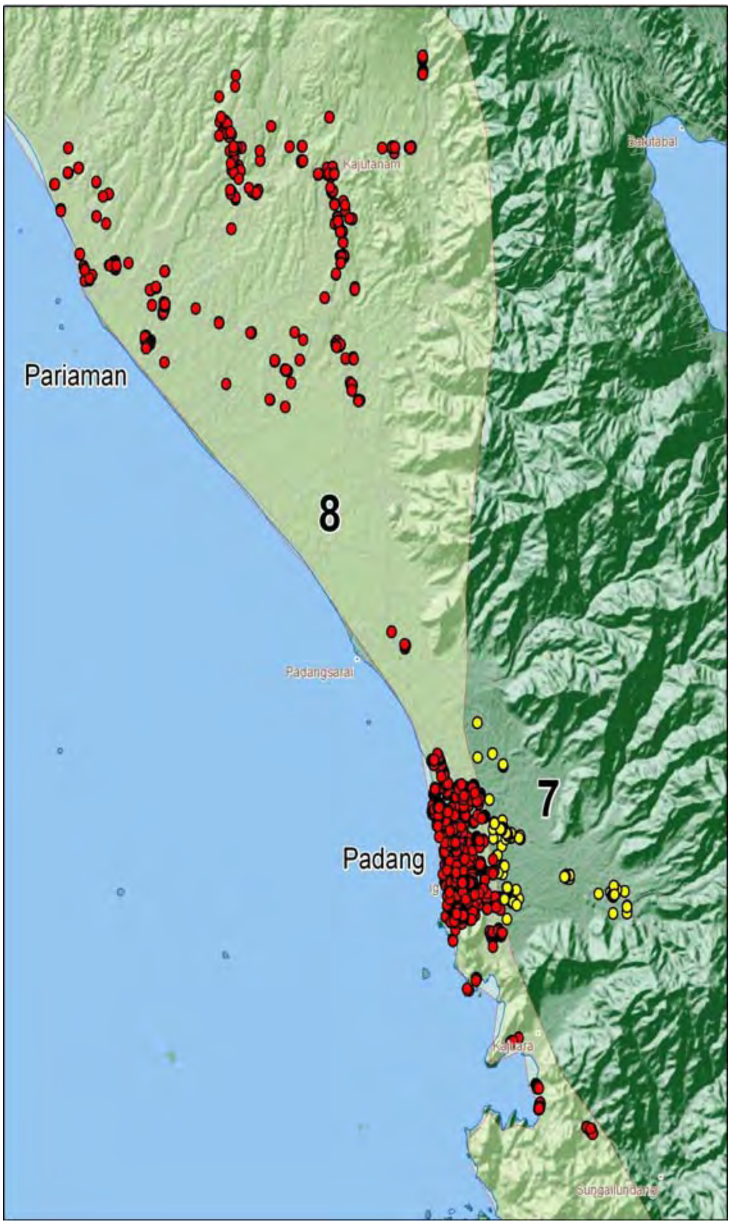

Figure 6.1: *MMI attribution based on observed liquefaction, lateral spreading, landsliding and building damage along with resident interviews conducted by the survey team. Red dots show locations where an MMI of 8 was recorded. Yellow dots show locations where an MMI of 7 was recorded.*

The severity of ground motion was subsequently reassessed by the Institut Teknologi Bandung (ITB) as reported in Chapter 5. The ground motion modelling produced a PGA map for both Padang and Pariaman which are presented in Figures 5.4 and 5.5 respectively. Utilising the predicted accelerations and the conversion factors developed by Atkinson and Kaka (2007) the indicative MMI values presented in Table 6.1 were obtained. The results, used in conjunction with the PGA maps, suggested that the shaking across the region was relatively uniform with an intensity of MMI 8. This value was adopted for vulnerability model development.

Table 6.1: *MMI attribution to the PGA values predicted by the Institut Teknologi Bandung using the results from the MASW survey. Conversion factors were derived from the equations developed by Atkinson and Kaka (2007).*

MASW PGA RANGE	INDICATIVE MMI	
	Padang	Pariaman
0.26 to 028	7.9	7.7
0.28 to 0.30	8.0	7.8
0.30 to 0.32	8.1	7.9
0.32 to 0.34	8.2	8.0
0.34 to 0.36	8.3	8.1
0.36 to 0.38	8.4	8.2
0.38 to 0.40	8.5	8.3
0.40 to 0.42	8.6	8.4
0.42 to 0.44	8.7	8.5

6.4 ECONOMIC MEASURES FOR DAMAGE

Rigour was required for the attribution of the damage index (defined as repair cost / total building reconstruction cost) to the damage state number assigned in the field during the population survey. The fundamental measure of impact is the physical damage itself which is described systematically in HAZUS (2003) for sequentially increasing damage severity to different building types (refer Appendix A6). However, the economic implications of physical damage are influenced by the local construction costs, demand surge related inflation and the level of repair (cosmetic, restitution or upgrade). Initially the HAZUS (2003) reparation costs for the damage states presented in Appendix A6 were used but these reflect the cost and standard of repair in North America. Hence, for this research the approach adopted was to assess repair costs on the repair strategies observed being implemented in Padang after the event where restitution rather than upgrade was typical. Furthermore, repair costs and total reconstruction costs were assessed with a demand surge factor of unity thereby assuming neutral building industry conditions. Vulnerability curves developed from this approach could be subsequently adjusted in an impact modelling process to account for demand surge.

Quantity surveyor style costing of repairs to damaged buildings was undertaken for two types of buildings: a 3 storey reinforced concrete frame office building and a generic single storey confined masonry building. Detailed measurements were taken in the field of a representative 3-storey office building and representative dimensions were assigned for a single storey confined masonry building. Detailed descriptions of physical damage to each building were assigned to each element of the building fabric for each damage state together with the required work to effect repairs to a reinstatement standard similar to that observed in Padang. The repairs for each damage state were costed using Padang repair rates supplied by ITB reflecting neutral demand surge conditions. The damage index versus damage state results are presented in Figures 6.2 and 6.3.

Note that for the concrete framed building some expensive elements (e.g. deep foundations) were not costed to be replaced and hence the calculated damage index (DI) failed to reach unity. For the residential building the DI was able to exceed 1.0 because the demolition costs made up a significant component of full repair. Smooth curves were fitted to the plotted values of damage index versus the damage state number in Figures 6.2 and 6.3. Also presented on the figures are the equivalent DI curves based on a HAZUS mapping of damage state number to HAZUS damage state (refer Table 6.3 and Appendix A6). The HAZUS damage indices are much higher for intermediate damage state numbers as could be expected. The regressed curves where then subsequently assigned to the five structural types identified on the population survey form (Figure 4.5 and 4.6). The regressed relationship for the office building was used for reinforced concrete and steel framed structure repairs. The residential building curve was used for the repairs to the other three building types on the survey form.

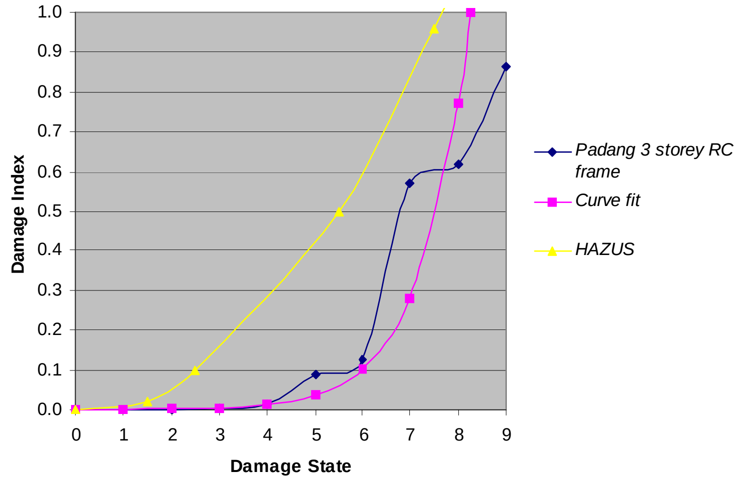

Figure 6.2: *Damage index versus damage state number for the 3 storey office building. DI=0.000229*2.76^(Damage State Number)*

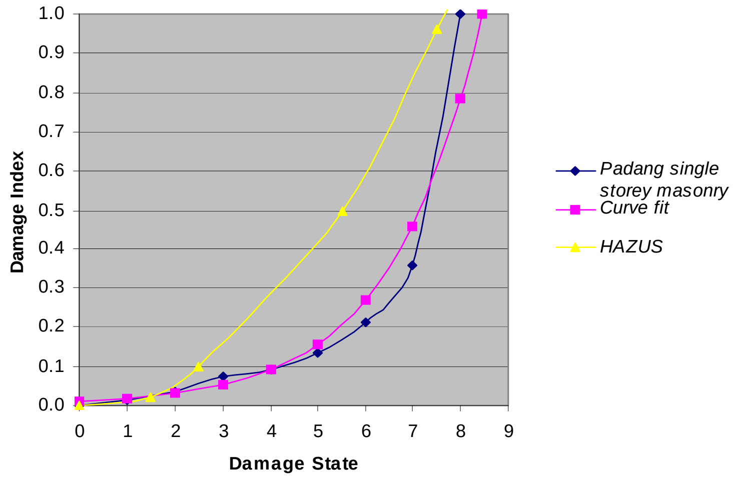

Figure 6.3: *Damage index versus damage state number for the generic residential building. DI=0.0106*1.72^(Damage State Number).*

6.5 VULNERABILITY ASSESSMENT

Vulnerability represents the average damage to a population of buildings as a function of hazard magnitude. It is normally provided as a Damage Index for a population of structurally similar buildings. The hazard magnitude adopted for this research was Modified Mercalli Intensity (MMI) which is a measure of the intensity of ground shaking. At the outset of the survey it was anticipated that a variation in MMI would be observed across the survey area. However, as noted in Section 6.3, very little variation in MMI was observed in the region with nearly all locations initially assessed as MMI 8 with a small proportion (9%) assessed as MMI 7. The reassessment of felt intensity using the MASW predictions of PGA (refer Section 6.3) resulted in the entire survey region being assessed as MMI 8 typically. Hence all surveyed points were grouped into a single set of results and vulnerability was calculated for the single hazard magnitude of MMI 8. The vulnerability results are presented in Table 6.2

Fragility represents the probability of a given building sustaining a predetermined level of damage for a given hazard magnitude. Fragilities were calculated for well represented building categories in the building schema using the damage state loss ranges summarised in Table 6.3. These were building type specific and were derived from the fitted curves shown in Figure 6.2 and 6.3. Also presented in Table 6.3 are the HAZUS damage index ranges for comparison purposes only. The fragility results are shown graphically in Figure 6.4 and presented in Table 6.4. It can be noted in Table 6.4 that the DI range for complete damage was les than 1.0. While this suggests that buildings that were completely damaged in a physical sense were repairable, in practice these were demolished in Padang rather than repaired. For this reason, the fragility categorisation herein presented does reflect the observed outcomes for damaged structures.

Table 6.2: *Vulnerability for well-represented building types in Padang at MMI 8. DI = Damage Index.*

SCHEMA DESCRIPTION	AVERAGE DI
URM / metal roof	0.35
URM / tile roof	0.48
Confined masonry residential / metal roof	0.07
Confined masonry residential / tile roof	0.04
Timber frame residential	0.07
RC frame residential / metal roof	0.06
RC frame residential / tile roof	0.09
C1L pre 1981	0.07
C1L 1981 - 2002	0.07
C1L 2003+	0.06
C1M pre 1981	0.11
C1M 1981 - 2002	0.12
C1M 2003+	0.29
URML / URMM	0.31
W1 / W2	0.19
Timber frame with stucco infill	0.10

Table 6.3: *Range of damage indices used to define damage states*

DAMAGE STATE	PADANG DAMAGE LOSSES				HAZUS DAMAGE INDICES RANGE
	REINFORCED CONCRETE AND STEEL FRAMED CONSTRUCTION		MASONRY AND BAMBOO/ TIMBER CONSTRUCTION		
	DAMAGE STATE NUMBER	DAMAGE INDICES RANGE	DAMAGE STATE NUMBER	DAMAGE INDICES RANGE	
None	0, 1	0.000 to 0.001	0, 1	0.000 to 0.0240	0.000 to 0.019
Slight	2	0.0011 to 0.003	2	0.0241 to 0.041	0.020 to 0.099
Moderate	3, 4, 5	0.0031 to 0.061	3, 4, 5	0.0411 to 0.21	0.100 to 0.499
Extensive	6, 7	0.062 to 0.460	6, 7	0.211 to 0.60	0.500 to 0.999
Complete	8, 9	0.461 to 1.0	8, 9	0.601 to 1.0	1.0+

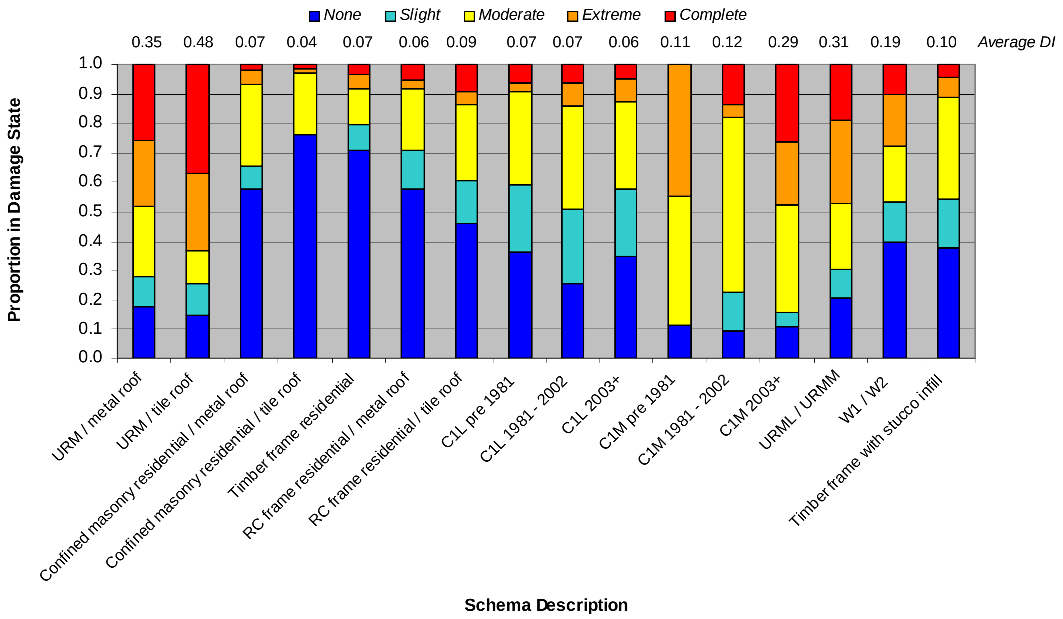

Figure 6.4: *Fragilities for well represented building types in Padang subjected to MMI 8 shaking.*

Table 6.4: *Fragilities for well represented building types in Padang subjected to MMI 8 shaking.*

SCHEMA NO.	SCHEMA DESCRIPTION	NO OF BLDGS	DAMAGE STATE				
			None	Slight	Moderate	Extreme	Complete
1	URM / metal roof	365	0.18	0.10	0.24	0.22	0.26
2	URM / tile roof	27	0.15	0.11	0.11	0.26	0.37
3	Confined masonry residential / metal roof	1577	0.58	0.08	0.28	0.05	0.02
4	Confined masonry residential / tile roof	67	0.76	0.00	0.21	0.01	0.01
5	Timber frame residential	264	0.71	0.09	0.12	0.05	0.03
11	RC frame residential / metal roof	264	0.58	0.13	0.21	0.03	0.05
12	RC frame residential / tile roof	74	0.46	0.15	0.26	0.04	0.09
15	C1L pre 1981	206	0.36	0.23	0.32	0.03	0.06
16	C1L 1981 - 2002	226	0.26	0.25	0.35	0.08	0.06
17	C1L 2003+	151	0.35	0.23	0.30	0.08	0.05
18	C1M pre 1981	9	0.11	0.00	0.44	0.44	0.00
19	C1M 1981 - 2002	22	0.09	0.14	0.59	0.05	0.14
20	C1M 2003+	19	0.11	0.05	0.37	0.21	0.26
42	URML / URMM	138	0.21	0.09	0.22	0.28	0.19
45	W1 / W2	58	0.40	0.14	0.19	0.17	0.10
51	Timber frame with stucco infill	176	0.38	0.16	0.34	0.07	0.05

The vulnerability and fragility data derived from the survey activity yield several results that are of particular importance.

Result 1.

The data indicate that there has been no significant improvement in reinforced concrete frame building performance with construction date. More recently constructed buildings performed no better than older buildings of the same type. This can be observed in the data in Figure 6.5 which presents fragilities for 1 to 3 storeys (C1L) and 4 to 7 storeys (C1M) reinforced concrete frame buildings in three age brackets (pre 1981, 1981 to 2002 and later than 2003). The age brackets chosen relate to the introduction of improved building design standards in Indonesia. It would be expected that the more modern buildings would perform better if they had been designed and built in accordance with the more rigorous, modern standards. It is of interest that the 4 to 7 storey buildings displayed an increase in vulnerability with age and were shown to be more vulnerable as a class than the 1 to 3 storey equivalent buildings. It was noted, however, that a significantly smaller number of buildings in the taller height category were surveyed that may have introduced sample size issues.

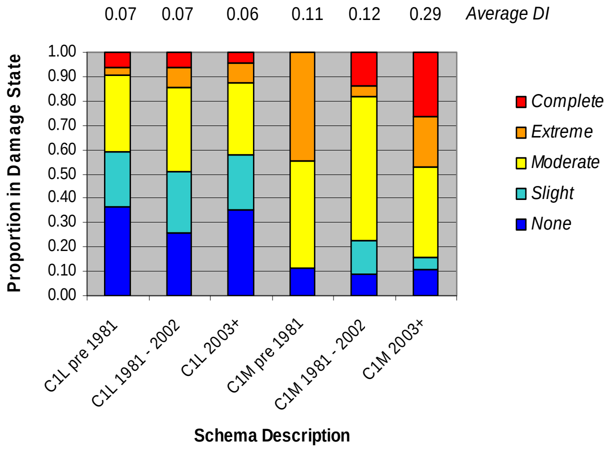

Figure 6.5: *Variation in fragilities of reinforced concrete framed buildings with age*

Result 2.
The data indicate that confined masonry buildings perform distinctly better than unreinforced masonry (URM) buildings. The data in Figure 6.6 present overall damage indices for residential buildings having both heavy tile and light metal roofs along with two different structural systems: URM and confined masonry. There is a clear superiority of performance that was demonstrated by the confined masonry buildings. Overall, there was an observed 10 fold increase in damage (DI) at MMI 8 in moving from confined masonry to unreinforced masonry for heavy tiled roof building types. The difference was also significant but smaller for the equivalent structures with lighter metal roofs.

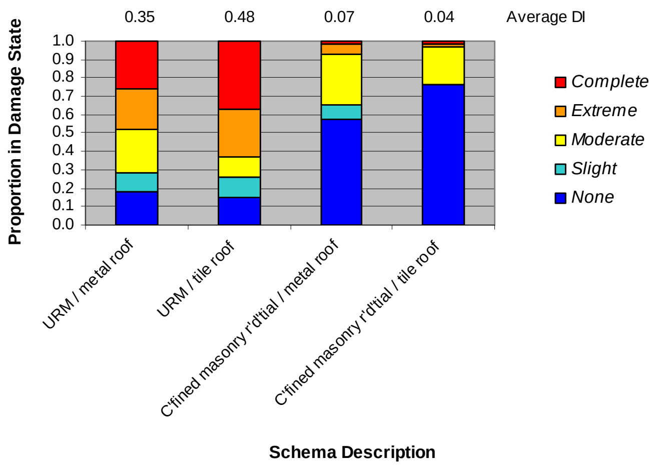

Figure 6.6: *Variation of fragility of residential buildings with structure type*

Result 3.
Unreinforced masonry buildings of any type perform poorly when subjected to earthquake actions. The data in Figure 6.7 show fragilities for three types of URM buildings: residential with metal roof, residential with tile roof and non-residential URM. All three categories show poor performance with significant proportions of the population falling into the extreme and complete damage states.

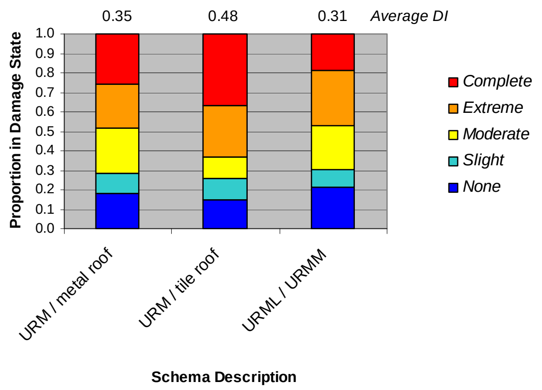

Figure 6.7: *Consistency of fragility across different types of unreinforced masonry (URM) buildings*

Result 4.

The data indicate that a structural system with framing of any type will perform significantly better than load bearing unreinforced masonry wall buildings. This is an important result when considering reconstruction activities in Padang; new residential buildings should have a structural frame and URM type buildings should be avoided. Consider the data in Figure 6.8 showing fragilities for residential buildings of all types. Clearly buildings with a structural frame, irrespective of the type (reinforced concrete, timber, confined masonry), perform better than URM buildings.

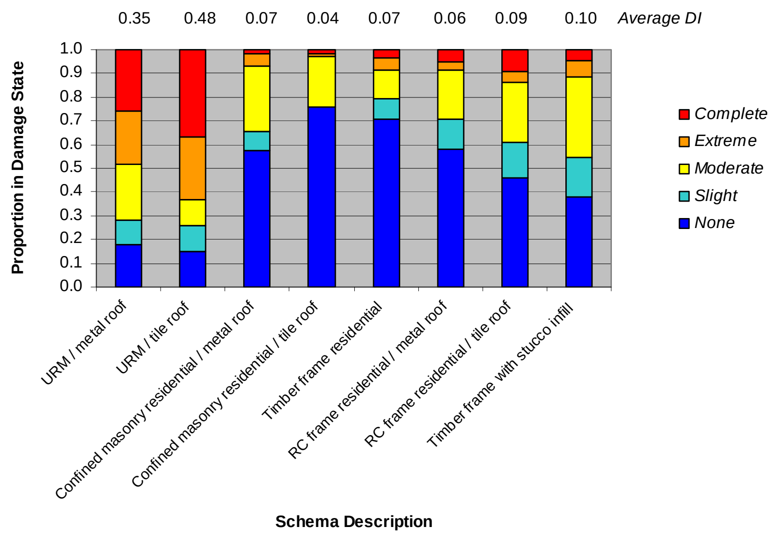

Figure 6.8: *Variation in fragilities across different types of residential buildings.*

6.6 INFRASTRUCTURE DISRUPTION

Critical infrastructure damage was not the focus of the post disaster-survey activity. Notwithstanding this, damage and disruption immediately after the event was evident from the residential survey questions (refer Section 6.7) where both water and electricity were disrupted for typical periods of 20 and 9 days respectively. Disruption to telecommunications was also evident but largely restored to a reliable service by the time of commencing the field survey. It was necessary to install temporary communication assets as was observed in the carpark of the hotel where the survey party was accommodated. Figure 6.9 shows a picture of a substantial temporary transmitter tower erected there to bolster local communications.

Transport sector assets generally fared better. Little if any bridge damage was observed and the large port facility and the airport experienced little disruption. Infrastructure associated with these assets typically is the subject of specific engineering design which often considers rarer events than those considered for ordinary buildings. The minor damage to these assets may be evidence of this design process coupled with the supervision of construction to ensure that the as-built facility complies with the design.

Figure 6.9: *Temporary communications tower erected in the hotel carpark*

6.7 SOCIAL IMPACTS

The survey included a set of questions aimed at determining the impacts of the earthquake on the inhabitants of Padang. Questions addressed the number and type of injuries, the loss of services and the need for temporary housing. This part of the survey form was only filled out when an interview with the inhabitants could be conducted. Approximately one quarter of surveyed sites recorded information about injuries and approximately one half of the surveyed sites recorded information about loss of services. Other fields were more sparsely recorded and hence have not been analysed.

The expected number of injuries due to earthquake damage to buildings is generally considered to correlate to floor collapse. Figure 6.10 shows the results for the Padang survey of average number of injuries per building plotted against percentage floor collapse. There is no discernable relationship.

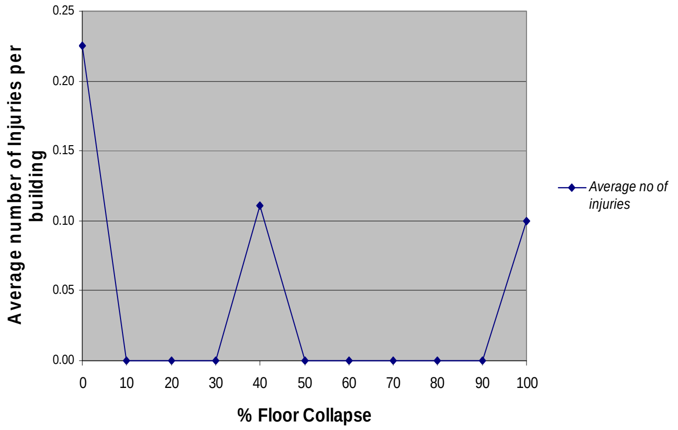

Figure 6.10: *Average number of injuries per building versus percentage floor collapse.*

The expected number of injuries due to earthquake damage to buildings would be expected to increase with increasing building damage. Figure 6.11 shows the results for the Padang survey of average number of injuries per building potted against surveyed damage state number. Some trend in the number of injuries can be discerned as the damage state severity increases from extensive (6, 7) to complete (8, 9). The unexpected result for Damage State 9 (complete collapse) may have been influenced by an absence of inhabitants for interview at sites of completely collapsed buildings.

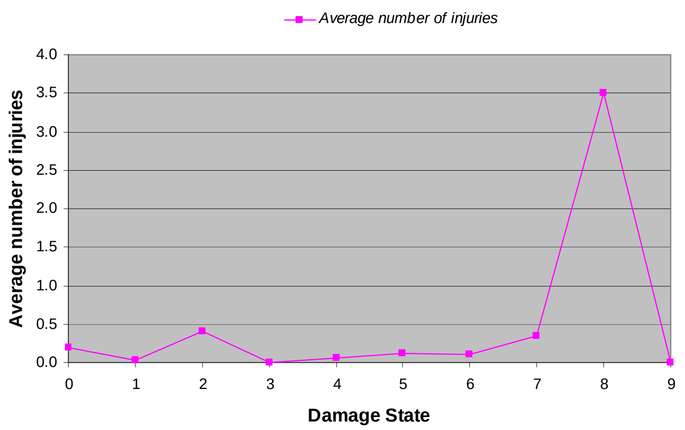

Figure 6.11: *Average number of injuries per building versus damage state number.*

The survey results for loss of services displayed no correlation to type of building, building usage or severity of damage. Figures 6.12, 6.13 and 6.14 show the average number of days without service plotted against each of these criteria. The general lack of correlation of service disruption to building type or damage suggest that the loss of services was due to failures within the upstream supply system rather than building specific factors.

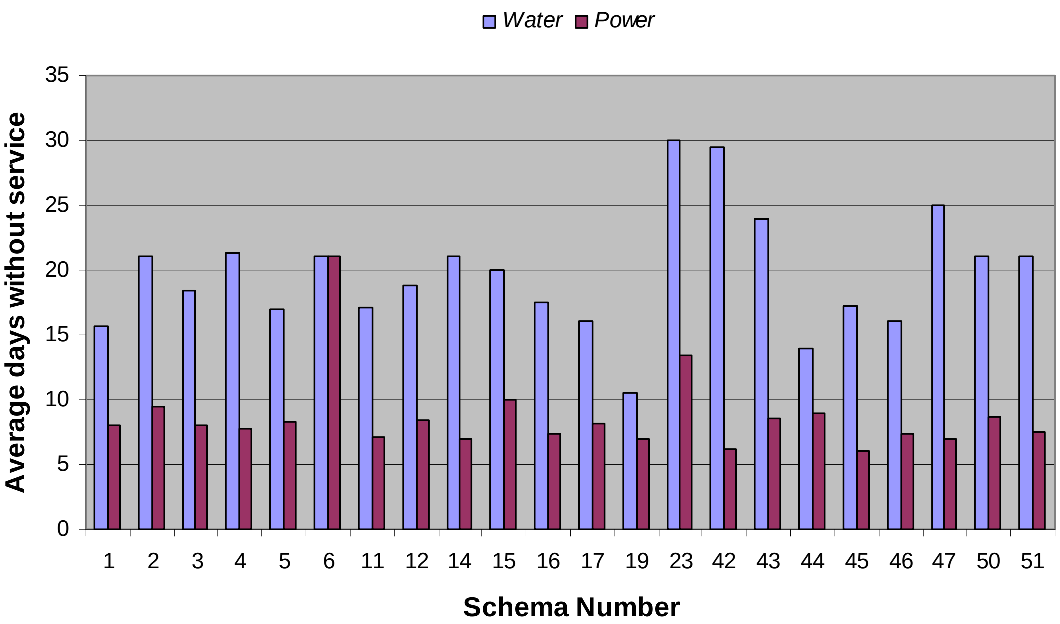

Figure 6.12: *Average number of days without service plotted against type of building..*

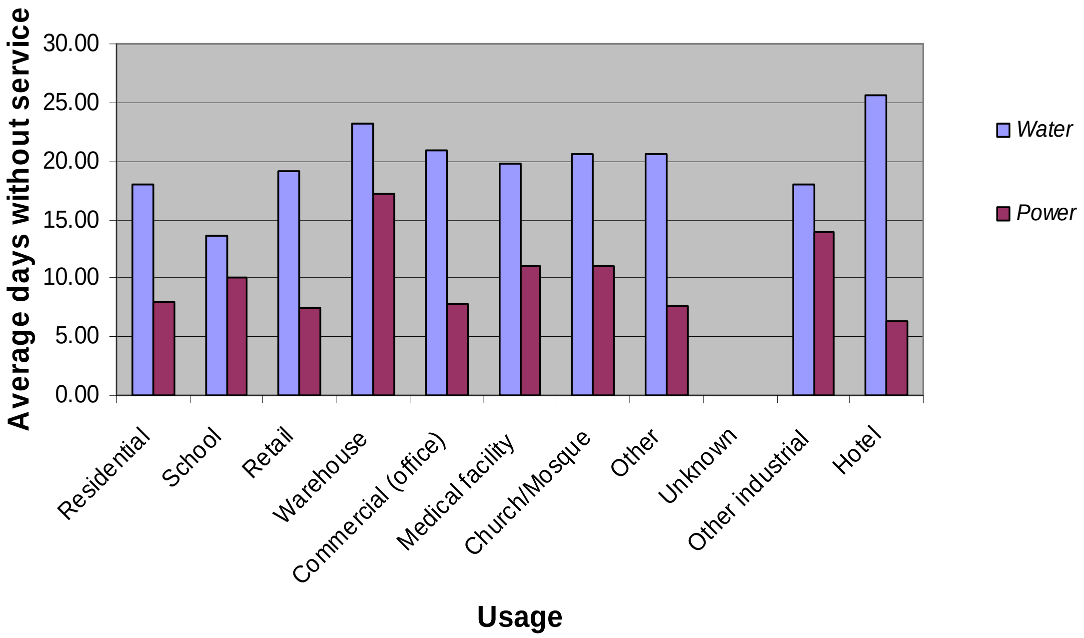

Figure 6.13: *Average number of days without service plotted against building usage.*

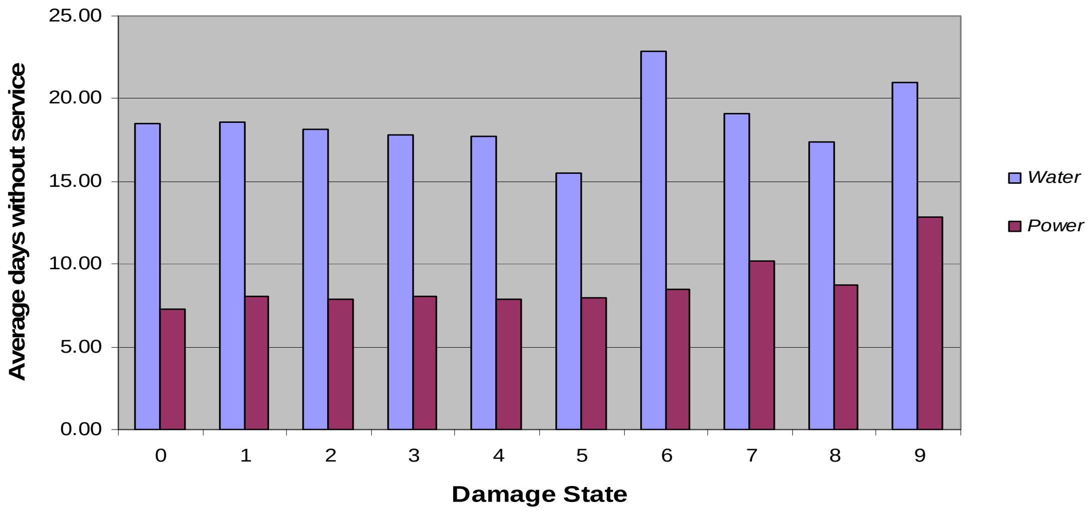

Figure 6.14: *Average number of days without service plotted against building damage severity.*

7 Padang Earthquake Reconnaissance Workshop

7.1 WORKSHOP ACTIVITY

An AIFDR sponsored workshop was held at Geoscience Australia on 28 and 29 April, 2010 which brought together many of the participants of the Padang Earthquake Reconnaissance Survey Team. The workshop reviewed Indonesian seismicity, the development of building regulations, historical building performance, the survey methodology, the survey outcomes, and the results of post survey analyses. It further considered the next steps for utilising the information to refine vulnerability knowledge and for disseminating the lessons learnt. The workshop report is presented in Appendix A4.

7.2 WORKSHOP OUTCOMES

The workshop was structured along several themes with key presentations made to "seed" workshop discussion. The outcomes from the presentations and the ensuing workshop discussion are presented under thematic headings below.

7.2.1 Indonesian Seismicity and Regulation Development

The following key points were noted on the seismicity of Indonesia and Padang and on the development of seismic design regulations:-

- Padang lies in the second most severe region defined in the current earthquake loadings code.
- The Padang earthquake was close to a design earthquake event for Padang but was short of the latest assessment of seismic hazard which is more than 20% higher.
- Limit state design with capacity design approaches came into effect in the 1983 standard. The later 2002 code significantly increased the seismic hazard for design through changes to both design return period and improved seismic hazard assessment. However, this was offset by concurrent changes to response modification factors (available ductility and reserve strength) that, together, resulted in little change to design loadings for engineered buildings.
- Historical earthquakes have shown similar deficiencies to those observed in Padang which include; poor performance of unreinforced masonry, poor structural configuration leading to soft storey, short column and torsional response, poor response due to a lack of separation of non-structural elements; inadequate building separation leading to pounding; poor reinforcement detailing and poor material quality.

7.2.2 Padang Earthquake and Survey Activity

The effectiveness of the survey activity was reviewed and the following observations made:-

- The two-stream approach with detailed survey work alongside population based survey proved very effective.
- The benefit of a third logistical support team was very clear.
- The need for agreed survey protocols prior to deployment was noted. At the commencement of the field work time was required with the survey participants from various organisations to ensure alignment of processes. This time could have been otherwise spent on productive survey work
- There were many refinements identified to processes for future survey work. These are listed in detail in Appendix A4, but, in particular, the benefits of local interpreters for each team and access to adequate field transport were highlighted. Furthermore, several field safety issues were raised associated with the entering of damaged buildings and knowing the location of each surveyor in a badly damaged structure. Finally, the IT savvy nature of local survey personnel was noted pointing to the option of hand-held computers as a substitute for the paper templates used.

7.2.3 MASW and PGA Estimate

The multi-channel analysis of surface waves (MASW) field survey and the utilisation of the outcomes in a simulation of the earthquake event provided valuable estimates of the local peak ground motions. This represented a significant improvement on the quantification of the effect of regolith amplification beyond the surface geology/liquefaction approach that was used prior to receipt of the outcomes of this work. It pointed to the need for future work to reassess felt intensities and refine vulnerability models in terms of spectral values of demand.

7.2.4 Post-Survey Analysis

The following was noted in the post survey analysis:-

- Cleaning and validation of the data collected by a large survey group was a major task. More attention to detail is needed to ensure consistency of capture including more extensive initial training and the incorporation of "data dictionaries" to provide reference information in the field to facilitate the correct selection of survey fields.
- The MMI attribution was particularly problematic and could be aided by better descriptors which should also be written in Indonesian for the benefit of local surveyors.
- The association of reparation cost with damage state needs to be improved. The cleaning and validation of hazard and damage data yielded a suite of very valuable information on effective structural forms and the present efficacy of building regulations to influence as-built structural vulnerability.
- The number of respondents to the resident interviews was very high (greater than 50%) and yielded useful information on the social impacts of the event. Correlation of the social impacts with damage outcomes to buildings was not typically observed.

7.2.5 Building Stock Categorisation

Post-survey analysis of data and workshop discussion indicated that the division between residential and non-residential was not descriptive of the observed trend in earthquake damage. A better classification was found to be by the standard of design and storey height irrespective of usage. Additionally, a finer division of the URM category to reflect variations in construction that were found to influence damage outcomes was also considered an appropriate schema refinement. Through an out-of-session process a revised schema was developed which is presented in Tables 7.1 and 7.2. It was proposed that these be used for future surveys but be subject to modification as identified through future survey activity in Indonesia.

Table 7.1: *Building Schema for non-engineered buildings that was revised post-survey*

NON-ENGINEERED BUILDINGS 1 STOREY (NEL)					
STRUCTURAL SYSTEM	**SUB-TYPE**	**ROOF TYPE**			
		1. Sheet metal, metal tile or synthetic	2. Heavy tile	3. Concrete slab	4. Thatch / leaves
1. URM	1.1 Mud brick	NEL 1.1.1	NEL 1.1.2	NA	NEL 1.1.4
	1.2 River stone	NEL 1.2.1	NEL 1.2.2	NA	NEL 1.2.4
	1.3 Thick fired brick	NEL 1.3.1	NEL 1.3.2	NEL 1.3.3	NEL 1.2.4
	1.4 Thin fired brick	NEL 1.4.1	NEL 1.4.2	NEL 1.4.3	NEL 1.4.4
2. Reinforced masonry	2.1 Confined masonry	NEL 2.1.1	NEL 2.1.2	NEL 2.1.3	NEL 2.1.4
	2.2 Reinforced block	NEL 2.2.1	NEL 2.2.2	NEL 2.2.3	NEL 2.2.4
3. Timber frame	3.1 Light clad	NEL 3.1.1	NEL 3.1.2	NA	NEL 3.1.4
	3.2 Stucco infill	NEL 3.2.1	NEL 3.2.2	NA	NEL 3.2.4
	3.3 Masonry infill	NEL 3.3.1	NEL 3.3.2	NA	NEL 3.3.4
4. Reinforced concrete frame	4.1 Masonry infill	NEL 4.1.1	NEL 4.1.2	NEL 4.1.3	NEL 4.1.4
	4.2 Other cladding	NEL 4.2.1	NEL 4.2.2	NEL 4.2.3	NEL 4.2.4

NON-ENGINEERED BUILDINGS 2 TO 4 STOREYS (NEH)					
STRUCTURAL SYSTEM	**SUB-TYPE**	**ROOF TYPE**			
		1. Sheet metal, metal tile or synthetic	2. Heavy tile	3. Concrete slab	4. Thatch / leaves
1. URM	1.1 Mud brick	NEH 1.1.1	NEH 1.1.2	NA	NEH 1.1.4
	1.2 River stone	NEH 1.2.1	NEH 1.2.2	NA	NEH 1.2.4
	1.3 Thick fired brick	NEH 1.3.1	NEH 1.3.2	NEH 1.3.3	NEH 1.2.4
	1.4 Thin fired brick	NEH 1.4.1	NEH 1.4.2	NEH 1.4.3	NEH 1.4.4
2. Reinforced masonry	2.1 Confined masonry	NEH 2.1.1	NEH 2.1.2	NEH 2.1.3	NEH 2.1.4
	2.2 Reinforced block	NEH 2.2.1	NEH 2.2.2	NEH 2.2.3	NEH 2.2.4
3. Timber frame	3.1 Light clad	NEH 3.1.1	NEH 3.1.2	NA	NEH 3.1.4
	3.2 Stucco infill	NEH 3.2.1	NEH 3.2.2	NA	NEH 3.2.4
	3.3 Masonry infill	NEH 3.3.1	NEH 3.3.2	NA	NEH 3.3.4
4. Reinforced concrete frame	4.1 Masonry infill	NEH 4.1.1	NEH 4.1.2	NEH 4.1.3	NEL 4.1.4
	4.2 Other cladding	NEH 4.2.1	NEH 4.2.2	NEH 4.2.3	NEL 4.2.4

Table 7.2: *Building Schema for engineered buildings that was revised post-survey*

ENGINEERED BUILDINGS – CAPITAL CITY (>4 STOREYS) (EC)					
STRUCTURAL SYSTEM	**HEIGHT / STOREYS**	**FACADE TYPE AND SEPARATION**	**AGE BRACKET**		
			1. Pre 1981	2. 1981-2002	3. 2003+
1. Reinforced Concrete Moment Frame	1.1 / 5-8	1.1.1 URM	EC 1.1.1.1	EC 1.1.1.2	EC1.1.1.3
		1.1.2 Non-URM or separated URM	EC 1.1.2.1	EC 1.1.2.2	EC1.1.2.3
	1.2 / 9-25	1.2.1 URM	EC 1.2.1.1	EC 1.2.1.2	EC 1.2.1.3
		1.2.2 Non-URM or separated URM	EC 1.2.2.1	EC 1.2.2.2	EC 1.2.2.3
2. Reinforced Concrete Shear Wall	2.1 / 5-8	2.1.1 URM	EC 2.1.1.1	EC 2.1.1.2	EC 2.1.1.3
		2.1.2 Non-URM or separated URM	EC 2.1.2.1	EC 2.1.2.2	EC 2.1.2.3
	2.2. / 9-25	2.2.1 URM	EC 2.2.1.1	EC 2.2.1.2	EC 2.2.1.3
		2.2.2 Non-URM or separated URM	EC 2.2.2.1	EC 2.2.2.2	EC 2.2.2.3
	2.3 / 25+	2.3.1 URM	EC 2.3.1.1	EC 2.3.1.2	EC 2.3.1.3
		2.3.2 Non-URM or separated URM	EC 2.3.2.1	EC2.3.2.2	EC 2.3.2.3
3. Steel moment frame	3.1 / 1-2	3.1.1 Any	EC 3.1.1.1	EC 3.1.1.2	EC 3.1.1.3
	3.2 / 3+	3.2.1 Any	EC 3.2.1.1	EC 3.2.1.2	EC 3.2.1.3
4. Steel braced frame	4.1 / 1-2	4.1.1 Any	EC 4.1.1.1	EC 4.1.1.2	EC 4.1.1.3
	4.2 / 3+	4.2.1 Any	EC 4.2.1.1	EC 4.2.1.2	EC 4.2.1.3

ENGINEERED BUILDINGS – REGIONAL (>4 STOREYS) (ER)					
STRUCTURAL SYSTEM	**HEIGHT / STOREYS**	**FACADE TYPE AND SEPARATION**	**AGE BRACKET**		
			1. Pre 1981	2. 1981-2002	3. 2003+
1. Reinforced Concrete Moment Frame	1.1 / 5-8	1.1.1 URM	ER 1.1.1.1	ER 1.1.1.2	ER1.1.1.3
		1.1.2 Non-URM or separated URM	ER 1.1.2.1	ER 1.1.2.2	ER1.1.2.3
	1.2 / 9-25	1.2.1 URM	ER 1.2.1.1	ER 1.2.1.2	ER 1.2.1.3
		1.2.2 Non-URM or separated URM	ER 1.2.2.1	ER 1.2.2.2	ER 1.2.2.3
2. Reinforced Concrete Shear Wall	2.1 / 5-8	2.1.1 URM	ER 2.1.1.1	ER 2.1.1.2	ER 2.1.1.3
		2.1.2 Non-URM or separated URM	ER 2.1.2.1	ER 2.1.2.2	ER 2.1.2.3
	2.2. / 9-25	2.2.1 URM	ER 2.2.1.1	ER 2.2.1.2	ER 2.2.1.3
		2.2.2 Non-URM or separated URM	ER 2.2.2.1	ER 2.2.2.2	ER 2.2.2.3
	2.3 / 25+	2.3.1 URM	ER 2.3.1.1	ER 2.3.1.2	ER 2.3.1.3
		2.3.2 Non-URM or separated URM	ER 2.3.2.1	ER2.3.2.2	ER 2.3.2.3
3. Steel moment frame	3.1 / 1-2	3.1.1 Any	ER 3.1.1.1	ER 3.1.1.2	ER 3.1.1.3
	3.2 / 3+	3.2.1 Any	ER 3.2.1.1	ER 3.2.1.2	ER 3.2.1.3
4. Steel braced frame	4.1 / 1-2	4.1.1 Any	ER 4.1.1.1	ER 4.1.1.2	ER 4.1.1.3
	4.2 / 3+	4.2.1 Any	ER 4.2.1.1	ER 4.2.1.2	ER 4.2.1.3

7.2.6 Preliminary Vulnerability Models

The damage indices and fragility outcomes at MMI 8 for nine building types were used to develop benchmark curves. This was done through a heuristic process and the utilisation of a curve fitting software tool developed by Geoscience Australia called *Eloss*. During this process the damage threshold for each building type was agreed upon and two other damage level versus MMI intensity adopted which supplemented the Padang survey outcome at MMI 8. These were input into *ELoss* and a cumulative log-normal curve was fitted through them. Table 7.3 summarises the target values used, Table 7.4 presents the fitted curve parameters and Figure 7.1 is a screen shot of the *Eloss* curve fit. The combined suite of curves is shown in Figure 7.2

Table 7.3: *Target MMI / Damage Index values to define benchmark heuristic vulnerability curves developed during the workshop.*

BUILDING TYPE	MMI	DAMAGE INDEX
URM with metal roof	6.0	0.0
	7.25	0.10
	8.0	0.35
	9.5	1.0
RC low rise frame with masonry in-fill walls	6.75	0.0
	8.0	0.07
	8.75	0.35
	11	1.0
Confined masonry	6.5	0.0
	8.0	0.07
	9.0	0.6
	11.0	1.0
RC medium rise frame with masonry in-fill walls	6.75	0.0
	8.0	0.18
	8.5	0.6
	10.0	1.0
Timber frame with stucco in-fill	6.0	0.0
	8.0	0.10
	9.5	0.60
	11.0	1.0
URM with river rock walls	5.5	0.0
	6.5	0.1
	8.0	0.7
	9.0	1.0
HAZUS C2H	6.5	0.0
	8.0	0.1
	10.0	0.6
	12.0	1.0
Timber frame residential	7.0	0.0
	8.0	0.07
	11.0	0.6
	12.0	1.0
Timber frame with masonry in-fill	6.0	0.0
	8.0	0.19
	9.0	0.6
	11.0	1.0

Table 7.4: *Median and variance (beta) values derived from the definition of benchmark vulnerability curves as cumulative log-normal probability distributions.*

BUILDING TYPE	MEDIAN (MMI)	BETA (MMI)
URM with metal roof	8.3	0.10
RC low rise frame with masonry in-fill walls	9.0	0.08
Confined masonry	8.9	0.07
RC medium rise frame with masonry in-fill walls	8.4	0.05
Timber frame with stucco in-fill	9.2	0.11
URM with river rock walls	7.5	0.11
HAZUS C2H	9.7	0.15
Timber frame residential	10.5	0.15
Timber frame with masonry in-fill	8.8	0.11

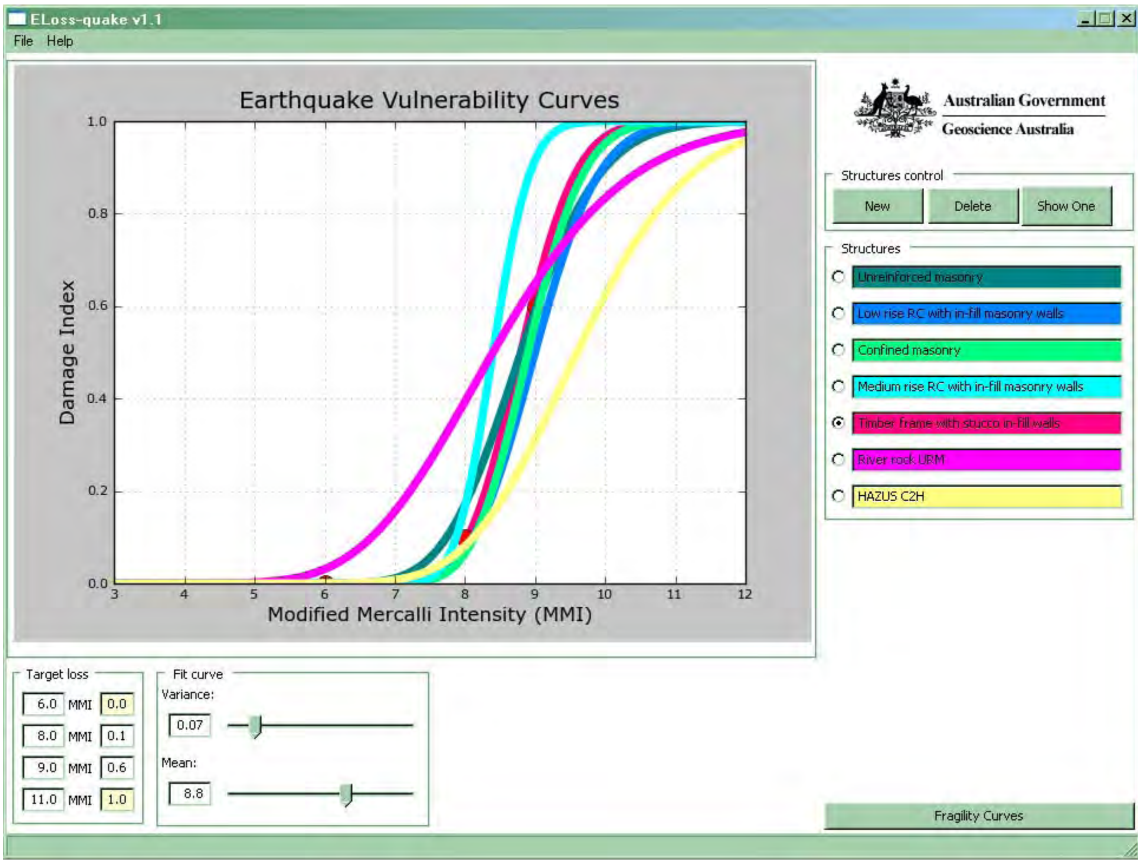

Figure 7.1: *Screen view of the Eloss vulnerability attribution software*

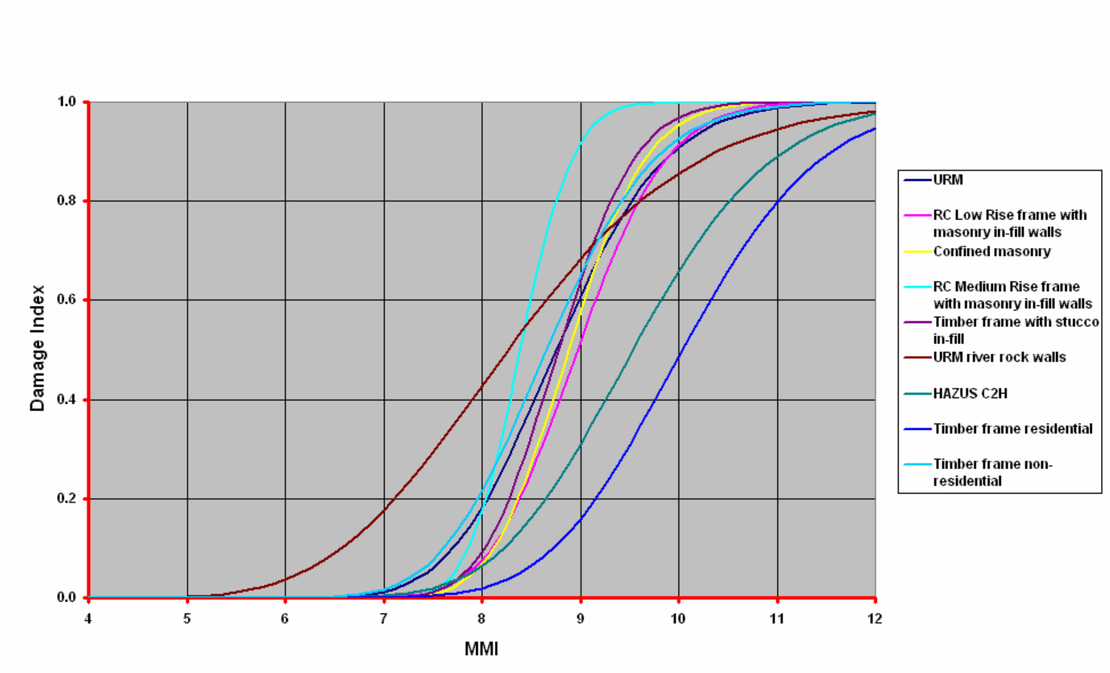

Figure 7.2: *Workshop developed benchmark vulnerability curves derived from the Padang Earthquake damage observations.*

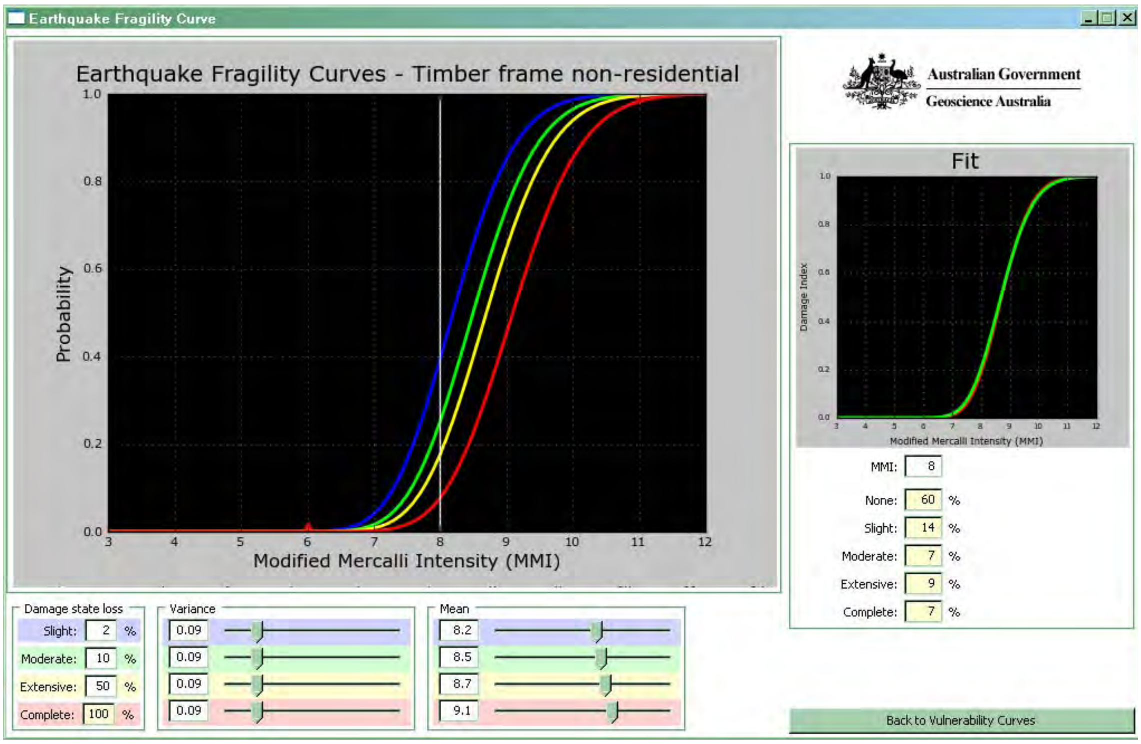

Figure 7.3: *Screen view of Eloss fragility curve suite attribution software. Damage threshold curves are presented on the left graph based on heuristically selecting the median and variance values that collectively match the target damage state mix from Padang at MMI 8 (refer bottom right). The match of the curves to the previously adopted vulnerability curve is shown on the smaller graph to the right.*

The second stage of the process developed a suite of cumulative probability damage threshold curves (fragility curves) which define the likelihood of a damage state threshold being reached or exceeded. The fragility curves were consistent with both the MMI 8 damage state results observed in Padang and the overall vulnerability curve derived in the first stage so at to give the same overall economic losses. Table 7.5 presents the fragility curve parameters derived and Figure 7.3 shows the corresponding *Eloss* interface for this process.

Table 7.5: *Median and beta values for the fragility curves derived for each benchmark vulnerability curve and defined as cumulative log-normal probability distributions. The fragility curves are consistent with the vulnerability curves defined in Table 7.4. The damage indices used for the different damage states are consistent with Table 6.3.*

BUILDING TYPE	SLIGHT		MODERATE		EXTENSIVE		COMPLETE	
	MEDIAN	BETA	MEDIAN	BETA	MEDIAN	BETA	MEDIAN	BETA
URM with metal roof	7.4	0.07	7.7	0.07	8.2	0.08	8.7	0.10
RC low rise frame with masonry in-fill walls	7.7	0.09	8.1	0.08	8.7	0.07	9.1	0.07
Confined masonry	8.1	0.05	8.2	0.05	8.7	0.06	9.2	0.06
RC medium rise frame with masonry in-fill walls	7.6	0.04	7.7	0.04	8.2	0.05	8.5	0.06
Timber frame with stucco in-fill	7.8	0.07	8.0	0.07	9.1	0.11	9.4	0.10
URM with river rock walls	6.3	0.07	6.9	0.07	7.6	0.09	7.8	0.10
HAZUS C2H	8.4	0.11	8.8	0.11	9.4	0.14	9.9	0.16
Timber frame residential	8.8	0.11	9.9	0.11	10.7	0.13	11.1	0.15
Timber frame with masonry in-fill	7.5	0.06	8.2	0.06	8.7	0.08	9.5	0.09

7.3 OUT-OF-SESSION VULNERABILITY RANKING

The nine benchmark curves developed at the workshop populated only a small portion of the total building categorisation schema types. Consequently the process for populating the full revised schema with reference to the benchmark curves derived was demonstrated and discussed. The primary tool is a spreadsheet with the benchmark curves pre-loaded. Each workshop attendee agreed to assign a relative vulnerability to each unpopulated building vulnerability category based on a correct relativity to the benchmark curves directly derived from the Padang reconnaissance. The relative ranking process is underway and will be reported separately once complete. Significantly the process will enable an automated update of the national suite of vulnerability curves with improvements to the benchmark curves.

7.4 WORKSHOP RECOMMENDATIONS

The workshop made the following recommendations:-

- That the AIFDR facilitate a workshop to be convened in Indonesia to communicate the results of the Padang reconnaissance to the Indonesian engineering community;
- That the AIFDR facilitate a workshop be held in Indonesia to train Indonesian engineers in post-earthquake survey techniques. The scarcity of trained staff was perceived as an impediment to efficient and productive future surveys;
- It appears that there is a scarcity of earthquake resistant design expertise within the Indonesian engineering profession. For example, it is understood that earthquake design is only taught as an elective subject that many students do not take. This could be addressed by AIFDR sponsoring the promotion of earthquake engineering in schools of engineering and through their sponsorship of post-graduate courses in earthquake design;
- That AIFDR consider sponsoring research covering the suggested topics noted under Earthquake Vulnerability Research Opportunities; and,
- The ‘Build Back Better’ campaign must address the widespread construction deficiencies noted in the World Bank report.

8 Survey Findings

8.1 DETAILED SURVEY OF SCHOOLS AND MEDICAL FACILITIES

The detailed survey activity resulted in a number of observations, findings and recommendations. Some were conveyed in the DALA reporting (ref. 6.1) and later expanded on in a separate report to the AIFDR contained in Appendix A2. The findings reported are summarised as follows.

8.1.1 Observations and findings

Observed damage included collapsed buildings, many close to collapse and a larger number of buildings damaged but repairable. The building types that were inspected in large numbers included concrete frame with infill brick walls, load bearing brick with confining concrete columns and beams (confined masonry type), and timber framed buildings with infill masonry below the window sills.

The survey team classed the weaknesses of the building stock as resulting from the following causation groupings:

- Quality of Materials (e.g. soft bricks, mortar substituted for concrete, aggregates that were rounded and too large, low cement content in concrete)
- Poor Overall Structural System Layout (e.g. ground floor of "soft storey" type, lack of shear walls, short columns above masonry infill)
- Lack of Building Controls (e.g. large buildings built in areas prone to liquefaction, lack of compliance to design codes, lack of inspection/supervision)
- Poor Detailing of Structures (e.g. poor connections between elements, short 90 degree tails in stirrups, gaps not provided between portions of buildings resulting in "pounding" of one structure against the other)

It was apparent that the hazard criteria in the Indonesian Building Code may need to be revised for West Sumatra due to the increased hazard posed by a large earthquake in the region. The latest National Seismic Building Code (SNI-03-1726-2002) increased the design seismic hazard (spectral value at T=1.0s) for the West Sumatra area in 2002 from 0.07g to 0.30g. The Indonesian expert members of the team indicated that the current understanding of hazard derived from recent modelling suggests the hazard for Padang might be as high as 0.4-0.5g (for 10% probability of exceedence in 50 years) for a spectral period of 1 sec. The 2002 Code change means that any design work carried out prior to 2002 is likely to have seriously underestimated the actual hazard to which the buildings are subjected. This emphasises the need to establish a seismic strengthening program in conjunction with reconstruction initiatives.

The majority of buildings surveyed were single storey unreinforced masonry or with confining small-sized concrete members (confined masonry buildings). The confinement was typically in the form of reinforced concrete members of a standard type cast in place after the masonry walls are constructed. It was clear that most of the collapsed minor buildings involved failure of un-reinforced masonry. While in-plane failures were recorded in many buildings, out-of-plane failures were more numerous and more severe. The housing near Pariaman and Secincin that collapsed was mostly in rural areas and generally of unreinforced load-bearing masonry. The masonry was rendered standard brick or rounded river rocks or stones (approx. 150 mm – 300 mm in size) that were stacked and mortared in place. Many "river stone" walls were observed to have sustained damage with many fallen.

Where confined masonry was observed to be damaged (including collapse) there was a lack of the following reinforcement detailing:-

- adequate reinforcing bars at joints;
- anchorage of bars;
- leg length of hooks;
- spacing/diameter of ties and anchorage of ties.

Where the joints are poorly detailed, the confinement of the masonry walls would be ineffective, leading to poor performance during an earthquake. Plain round, mild steel bar (undeformed) was invariably observed (except in the most recent multistorey concrete structures) which further exacerbated concerns regarding reinforcement anchorage.

For the larger concrete structures, the most common failures involved the development of concentrated flexural deformation (plastic hinges) at the tops and bottoms of ground floor columns. Reinforcement in most structures was observed to be plain round bar of mild steel. Only in some newer structures was deformed reinforcement bar observed. Invariably, multi-storey concrete structures had infill walls of unreinforced masonry throughout the building constructed hard up against the concrete structure (no seismic separation gaps). In most structures unreinforced masonry walls appeared to be the only lateral force resisting elements as no reinforced concrete shear walls were evident. Short columns had been created in many structures by the infill masonry not extending to the underside of the beams above and, therefore, not forming an effective shear wall. In some cases the infill unreinforced masonry saved the structure by acting as shear walls and absorbing most of the lateral deformation energy with resulting crushing and diagonal cracking of the infill.

Poor material properties were often observed. The bricks used throughout the Padang building industry were of orange/red clay with the majority appearing to be incompletely fired. Typically bricks could be easily broken and the fired clay crumbled with the fingers. In other cases the centre of the bricks appeared un-fired with the centre able to be hollowed with the thumbnail. The hollow concrete blocks observed in a number of the school buildings were approximately 90mm thick and unsuitable for installing reinforcement and the pouring of grout. Finally, concrete quality was poor with rounded aggregate sometimes used, incomplete compaction of concrete evident and strengths so low that reinforcing steel was easily recovered after the earthquake from fallen structures by beating the concrete members by hand with hammers.

Enquiries during the survey indicated that site investigations for large buildings are rarely carried out and that the deepest foundations for any building are unlikely to exceed a “standard” 5 m depth caisson. This type of site investigation and foundation design is considered unsuitable for the predominant ground conditions in the city of Padang, and much of the observed earthquake damage to both houses and to larger buildings was exacerbated by differential ground movements associated with liquefaction and lateral spreading. Liquefiable deposits need to be identified and the founding depth will need to be deeper than the zone of liquefaction for larger structures. To “build back better”, not only should the earthquake resistant design of structures and the quality of construction improve, there also should be greatly improved site investigations followed by a appropriate foundation design.

8.1.2 Recommendations

To prepare Padang and other communities along the west coast of Sumatra for the expected large magnitude earthquake and tsunami, it is imperative that good engineering is supported by regulatory quality assurance processes. The following recommendations are made which are considered fundamental for reducing community risk.

1. Improve the usage and enforcement of existing Building Codes by the following:-
    - training for all levels of the construction industry (government officials, design engineers, contractors, masons, etc)
    - preparation of geotechnical investigations prior to design
    - inspection of buildings during construction
    - quality control of building materials
    - the utilisation of a Building Permit scheme to police non-compliance.

2. Prepare new documentation to improve the built environment including:-
    - preparation of 'minimum standard' guidance documents for non-engineered buildings (e.g. confined masonry housing),
    - new guidelines to ensure that designers of new buildings are cognisant of the tsunami hazard
    - review of West Sumatra hazard level with hazard maps and new guidelines for the design and construction of post-disaster recovery facilities such as schools and medical facilities.

3. Training of design engineers and contractors in specific engineering practices including:-
    - design of appropriate foundation systems or foundation treatments for sites underlain by soft soil and liquefiable deposits
    - detailing reinforcement for seismic actions, especially detailing of stirrups in beams and columns with 135 degree hooks and appropriate leg lengths,
    - use of shear walls and the provision of continuous structural ties throughout the structure,
    - avoidance of poor building geometry such as the close proximity to adjoining buildings and short columns.

4.. The implementation of the above recommendations in repair works, re-building as well as new for future development by a "build back better" campaign.

8.2 POPULATION BASED SURVEY

The population based survey consistently captured damage data outcomes for 16 building types well represented in Padang and Pariaman. The data captured permitted a statistically useful analysis of the most represented types which resulted in benchmark vulnerability and fragility functions for nine building types.

The consistency of the data enables comparisons between building types. Notably the following observations were made:-

- The changes to building regulations in 1983 and 2002 have had little measurable impact on the vulnerability of as-built engineered reinforced concrete buildings.
- The confinement of masonry construction has markedly reduced earthquake vulnerability when compared to unreinforced masonry construction
- Unreinforced masonry performed poorly for all types.
- Framed residential construction (reinforced concrete and timber) resulted in lower vulnerability to earthquake.

Finally, the population based survey activity has highlighted issues with how damage is quantified in economic terms. The level of repair has a direct impact on cost as does the local construction costs.

While reparation to pre-earthquake standard has been the approach adopted for this research, other repair objectives may be more appropriate in the assessment and reduction of risk.

9 Recommendations and Future Work

The following specific recommendations are made:-

1. Buildings damaged in the 30 September earthquake should be repaired and strengthened to a high standard to be capable of withstanding a future forecast earthquake and tsunami.
2. New buildings intended to provide vertical evacuation from a tsunami should be designed and built to a standard where they will be undamaged after a worst-case future mega-thrust earthquake.
3. Other new buildings should be designed and constructed in accordance with current standards. This particularly relates to the quality of construction materials that were observed to be very poor. Enforcement mechanisms may require review to ensure compliance.
4. New residential construction should utilise cost-effective systems that performed well in the Padang earthquake. In particular, confinement of masonry showed a marked improvement in seismic performance over ordinary unreinforced masonry.
5. Earthquake engineering principles should be promoted with building professionals through industry seminars where the learnings of the Padang earthquake can be shared and the role of the code regulations to preclude premature failure highlighted. The choice of earthquake engineering as an elective also needs to be promoted more strongly so new professionals will enter the industry with a greater awareness of the underpinning principles.
6. Post-disaster surveys in Indonesia should be continued to capture the variability in building vulnerability across the region and country. This should be all-hazards and encompass all the engineering and science contributions required to understand the nature of the events. The process would benefit greatly from deriving an expert consensus of the optimal approaches for each hazard type and the subsequent dissemination of the processes and methodologies to interested participants in Indonesia.

The following work is proposed for the Padang survey data analysis. Specific tasks include:-

1. The completion of the national first order suite of vulnerability curves.
2. The prediction by ITB of a broader range of spectral ground motion values for the event to enable an assessment of MMI levels using values from the constant velocity region of the spectrum. This may lead to a greater differentiation in ground motion severity and additional validation points.
3. The assessment of improved correlation between damage outcomes and other spectral values as a basis for more sophisticated vulnerability functions.
4. The back analysis of other well documented Indonesian earthquake events and post-disaster reconnaissance surveys.

Other future work may be pursuant to the recommendations made in this report but depend upon the approval of the AIFDR.

10 Summary of Outcomes

The Padang Earthquake reconnaissance has represented a significant allocation of resources, both in the direct costs met by the AIFDR and in the time contributed by a large group engineers, academics, scientists, AIFDR staff and engineering students. It also constitutes what is understood to be the largest systematic population based study of an earthquake impact undertaken to date in the South East Asian and Pacific regions. While the investment has been considerable the outcomes have been commensurate with it. The two survey strategies used involved expert detailed study alongside comprehensive population based study. Consistency between the two has furnished both insights on the causes of poor performance as well as statistically meaningful information on the likelihood of the realisation of damage in an earthquake.

The survey work, post-survey analysis and workshop engagement have provided an illuminating picture of the evolution of building regulations in Indonesia and tangible evidence on the effectiveness of their implementation in local design and construction. While the current regulations align with best-practice in other highly seismic countries, they are not fully benefiting the communities in the Padang region due to shortfalls in their uptake. The Western Sumatra Earthquake did not exceed the design level event implied in the code for Padang but caused widespread devastation to modern engineered structures and associated loss of life. Many schools and medical facilities also fared badly due to inadequate design and construction. The expert groups were able to identify a number of factors contributing to this outcome which included poor structural configuration, poor detailing of reinforcement, the use of very poor construction materials, inadequate site investigations and unsuitable foundation design for weak and liquefiable soils.

The survey has also highlighted some more recently adopted construction practices that have significantly reduced the likelihood of building damage and casualties. Confined masonry construction in particular suffered lower damage levels than the unreinforced masonry equivalent. Promotion of cost-effective construction practices which reduce vulnerability and the development of other structural systems with these attributes is central to reducing earthquake risk. Other traditional forms of construction such as timber framed homes were also shown to have lower vulnerability consistent with experience in other countries.

The activity has also resulted in a categorisation of the broad Indonesian building stock nationally and the commencement of a process that will furnish a full national suite of models that define their vulnerability to earthquake ground motion. Padang damage data was directly used in the workshop process to develop nine benchmark models that define both economic loss and the likelihood of physical damage. Further, consensus was reached on the process for ranking other building types in the schema against these benchmark behaviours with the utilisation of other Padang loss data. The process for delivering a national suite of earthquake vulnerability curves for Indonesia is presently underway.

Finally, processes for capturing post-disaster information have been reviewed on the basis of the Padang reconnaissance and recommendations made for more effective and informative surveys in the future. The benefits of reaching a regional consensus on methodologies, survey templates and tools to cover a range of severe hazards have been highlighted and recommendations made for how these protocols could be transferred to Indonesian professionals and academics.

In summary, the AIFDR response to the West Sumatra earthquake of the 30 September 2009 has furnished an understanding the vulnerability of typical Indonesian buildings to earthquake ground motion, has informed the development of better building codes and their effective implementation, has enabled more realistic earthquake risk assessments for national and sub-national disaster risk management, and will locally inform improved contingency planning and earthquake safety education campaigns.

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Appendices

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Appendix A1

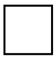
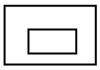
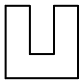
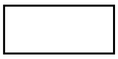
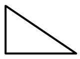
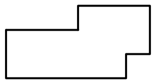
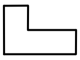
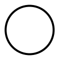
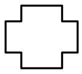
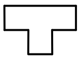
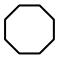
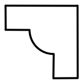
Modified Mercalli Intensity Scale and Irregularity Codes

MMI Scale

MMI VALUE	DESCRIPTION OF SHAKING	FULL DESCRIPTION
1		Not felt. Marginal and long period effects of large earthquakes.
2		Felt by persons at rest, on upper floors, or favorably placed.
3		Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
4		Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV, wooden walls and frame creak.
5	Light	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.
6	Moderate	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle).
7	Strong	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
8	Very Strong	Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
9	Violent	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluvial areas sand and mud ejected, earthquake fountains, sand craters.
10	Very Violent	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
11		Rails bent greatly. Underground pipelines completely out of service.
12		Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

Masonry A: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.
Masonry B: Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.
Masonry C: Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.
Masonry D: Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

Plan Shape Codes

Square 	Hollow 	U shaped 
Rectangular 	A triangular 	X cranked 
L shaped 	Circular 	K cruciform 
T shaped 	Polygonal 	Irregular 

Wall Crack Types

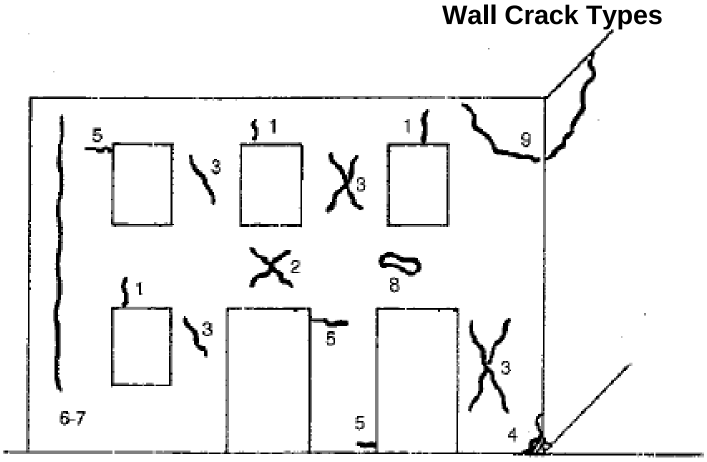


Figure 7: types of cracks in masonry bearing walls:
1) vertical cracks on openings; 2) diagonal cracks on parapets and on doors and windows lintels; 3) diagonal cracks on vertical walls between openings; 4) local masonry crushing with or without spalling; 5) horizontal flexural cracks on top or bottom of vertical walls between openings; 6) vertical cracks at wall intersections; 7) passing through vertical cracks at wall intersections; 8) spalling of material due to beam or floor pounding; 9) separation and expulsion of two corner walls.

(Ref: Goretti & Di Pasquale, 2002, EERI Invitational Workshop)

Building Irregularity Codes

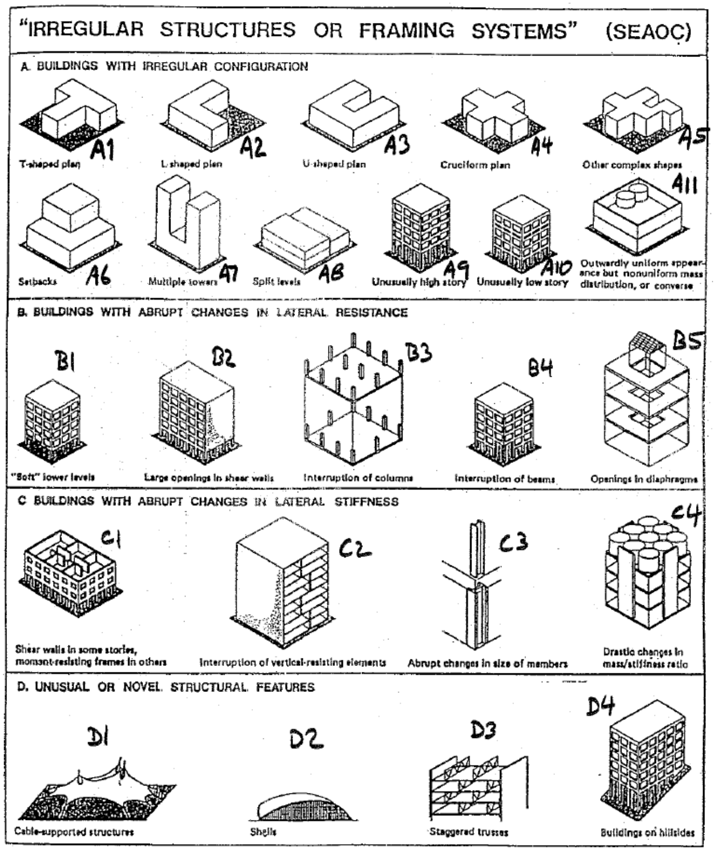


Figure 6.2 Graphic interpretation of "irregular structures or framing systems" from the commentary to the SEAOC Recommended Lateral Force Requirements and Commentary. From "Building Configuration and Seismic Design" by Arnold and Reitherman (Ref 6.27)

A12 Long cantilever

A13 Tall tower / chimney

A14 Heavy ornament

Appendix A2

Expert Group Reporting

AUSTRALIA-INDONESIA FACILITY FOR DISASTER REDUCTION, EXPERT ENGINEERING TEAM

Draft West Sumatra Building Recommendations

6 November 2009
Padang Survey - Oct 2009

AIFDR/AusAid/GA

AUSTRALIA-INDONESIA FACILITY FOR DISASTER REDUCTION,

EXPERT ENGINEERING TEAM

DRAFT WEST SUMATRA BUILDING RECOMMENDATIONS

EXECUTIVE SUMMARY

Following the earthquake of 30 Sept 2009, a team of experts from Indonesia, Australia, New Zealand and Singapore organized through the Australia-Indonesia Facility for Disaster Reduction (AIFDR) carried out a survey of buildings across Padang to investigate the level of earthquake damage and to collect information on the probable causes of the damage. This Report includes the preliminary recommendations of the Survey Team to support the re-construction and recovery process.

Seismologists are expecting a magnitude 8.5 plate boundary earthquake in the coming decades that could be accompanied by a large tsunami. The high risk of significant impacts on Padang should be anticipated by “Building Back Better”.

The survey found that damage to buildings resulted from:-

- Poor Quality Materials (e.g. soft bricks, mortar substituted for concrete, aggregates rounded and too large, low cement content in concrete, etc)
- Poor Overall Formation of the Structure (e.g. ground floor “soft storey”, lack of shear walls, short columns above masonry infill)
- Lack of Building Controls (e.g. large buildings built in areas prone to liquefaction, lack of compliance to design codes, lack of inspection/supervision)
- Poor Detailing of Structures (e.g. poor connections between elements, short 90 degree tails in stirrups, gaps not provided between portions of buildings resulting in “pounding” of one structure against the other)

The report includes discussion of the specific problems of typical building methods and materials and suggests many engineering and construction improvements. For example, buildings designed to the National Code prior to 2002 would have suffered extensive damage due to the very low specified earthquake hazard in the earlier code. Many engineer designed multi-storey buildings performed poorly compared to more traditional single storey construction.

The recommendations are summarised under the following headings:

Regulatory recommendations:

Review of Building Codes (design earthquake hazard may be increased)
Building Back Better (new construction should be better than what went before)
Post-disaster recovery facilities improved (e.g. medical)
Tsunami hazard incorporated into planning and in design of recovery facilities
Non-engineered buildings to have minimum standard design
Hazard Based Spatial Planning
Geotechnical investigation (building foundations) improved

Enforcement:

Non-compliance to be policed
Re-construction and repair to be supervised (building permits)
Improved design controls
Training for all levels of construction industry
Professional Engineer Licensing
Inspection
Materials

Specific Engineering Recommendations:

Reinforcement detailing to be improved
Bracing of roof structure
Tie the structure together with stronger joints
Gable walls, parapets and balcony barriers to be light materials/laterally tied
Pounding to be avoided by providing gaps
Short columns to be adequately designed and detailed
Deformed reinforcement to be used
Shear walls (reinforced concrete) to be encouraged
Shop fronts to have shear walls
Column/beam concrete joint detailing to be improved
Mis-match of floor levels to be avoided or gaps provided to allow separate movement
Fixed stairs to be appropriately designed

It is clear from the level of damage observed during the survey and from the loss of life, that many buildings of West Sumatra will be damaged in the projected large earthquake expected to occur in coming decades. Current re-construction is an important opportunity to “Build Back Better”.

To prepare for the expected large magnitude earthquake and tsunami, good engineering must be supported by regulatory quality assurance processes. The recommendations in this report are fundamental for reducing community risk and need to be swiftly integrated and implemented into the recovery and reconstruction process.

AUSTRALIA-INDONESIA FACILITY FOR DISASTER REDUCTION, EXPERT ENGINEERING TEAM

DRAFT WEST SUMATRA BUILDING RECOMMENDATIONS

Introduction

Following the earthquake of 30 Sept 2009, a team of experts from Indonesia, Australia, New Zealand and Singapore organized through the Australia-Indonesia Facility for Disaster Reduction (AIFDR) arrived in Padang 23rd October 2009. They began a survey of buildings across Padang to investigate the level of earthquake damage and to collect information on the probable causes of the damage. The intention was to collect data to assist in predicting damage to buildings in future earthquakes and to provide general advice on the re-construction effort.

This Report includes the preliminary recommendations of the Survey Team to support the re-construction and recovery process and thereby reduce the human, social and infrastructure losses in any future earthquake.

Background

Risk of Future Earthquake

A 7.6 magnitude earthquake occurred on 30 September 2009 on the subduction zone of the Indo-Australian and Euro-Asian plates. It was located 80 km below the surface along a rupture distance approximately 50 km long that extended below the coastline near Padang. It resulted in relatively high ground shaking in Padang and up the coast to the north with felt intensities of VII (MMI) and higher reported.

Padang has been a focus of natural hazard scientists and disaster managers over the last five years. This is a result of increased evidence suggesting a high potential for an ~Mw 8.5 earthquake on the nearby subduction zone that could trigger a devastating tsunami. *Significantly, the earthquake on the 30th September was not this 'anticipated' event.*

Hence a tsunamigenic earthquake still remains a significant threat to Padang and surrounding coastal areas. Recent assessment of earthquake risk along the plate boundary suggests it is possible that the earthquake on the 30th September has created additional stress on the subduction zone, *increasing* the probability of this tsunamigenic earthquake occurring in future decades.

A magnitude 8.5 event could generate a higher peak acceleration compared to that specified in the current (and previous) Indonesian Building Codes. The possibility of a ~Mw 7.5 earthquake on the Sumatra Fault Zone also exists (see red line on Figure 1). The time-frame for these events is well within the expected design life of any re-construction.

Should the ~Mw 8.5 earthquake occur, settlement of half a metre may occur along the coastline of West Sumatra (land behind the subduction zone). This should be included in any threat analysis from tsunami or ocean inundation flooding (e.g. risk from Sea Level Rise).

The re-construction and long-term development of the City of Padang and generally in West Sumatra needs to be based on this increased seismic and tsunami hazard. This increase in the recognized hazard makes the need to “Build Back Better” even more important than usual. The current building stock will gradually be replaced as development continues, so “Building Back Better” is important to improving the resilience of the Sumatra community to future earthquakes.

Observations and findings

Damage

At the time of issue of this report, the Survey Group had spent a number of days in the field and inspected several hundred buildings in Padang. The damage seen includes many buildings collapsed, many close to collapse and a larger number damaged but repairable. Building types inspected in large numbers include concrete frame with infill brick walls, load bearing brick with confining concrete columns and beams (confined masonry type) and timber framed buildings with infill masonry below the window sills.

The Survey Group classed the weaknesses of the building stock as resulting from causes that fall into the following groupings:

- Poor Quality Materials (e.g. soft bricks, mortar substituted for concrete, aggregates rounded and too large, low cement content in concrete, etc)
- Poor Overall Formation of the Structure (e.g. ground floor “soft storey”, lack of shear walls, short columns above masonry infill)
- Lack of Building Controls (e.g. large buildings built in areas prone to liquefaction, lack of compliance to design codes, lack of inspection/supervision)
- Poor Detailing of Structures (e.g. poor connections between elements, short 90 degree tails in stirrups, gaps not provided between portions of buildings resulting in “pounding” of one structure against the other)

It was apparent that the hazard criteria in the Indonesian Building Code may need to be revised for West Sumatra due to the increased hazard of a large earthquake in the region. Also, the stock of existing buildings includes many that would not be approved under current regulations due to their age or natural deterioration. It should be noted that the 2002 edition of the National Seismic Building Codes (SNI-03-1726-2002) increased the design hazard level from 0.07 to 0.3 (a factor of 4).

Types of construction observed

The survey team found that the building types fitted into a number of broad descriptions related to design and construction methods. The main types included:-

- Confined masonry (load bearing brick masonry walls with a confining concrete beam and column frame cast directly against the brick);

- Concrete frame with masonry infill walls – this type included single storey buildings where the concrete frame serves to confine the brick masonry and major multi-storey buildings with a large column and beam structure; and
- Traditional single storey construction using timber frame with infill of either masonry or cement daub on “K-wire” mesh.

Detailed engineering recommendations and standards should be produced for the single storey common types of construction. These common building types appear to be favoured due to the cheapness of the construction and the availability of the materials used in their construction. Simple improvements in their design and execution may lead to a significant increase in resilience to earthquake of the general population of buildings.

Evidence of liquefaction was noted at widely varying locations within the City of Padang. Liquefaction has caused ground settlement (300mm noted at one location). This type of settlement triggered serious damage to building structures. It affected the larger heavier structures more than single storey buildings and was more prevalent on the loose to medium sands near the coastline and along the edges of rivers. It is considered to have triggered the collapse of some large buildings due to the magnitude of displacements to building frames resulting from non-uniform levels of settlement throughout the structure.

Recommendations

To improve the safety of the West Sumatra community the following recommendations are made to maximise building performance, assist recovery and reduce the impact on populations during the next earthquake. The recommendations are grouped under regulations, enforcement and specific engineering issues.

Regulatory recommendations:

1. Review of Building Codes—Collapse of many buildings and the high level of ground shaking experienced indicate that the current National Seismic Building Codes, SNI-03-1726-2002 (and the previous Seismic Building Code SNI-1981) require review. In particular the hazard level for West Sumatra may need to be increased. This should be undertaken as soon as possible to provide for both reconstruction and long-term development of West Sumatra. Recent earthquake hazard analysis indicates a high potential for a major earthquake in the next few decades (~Mw8.5). This research should form the basis for revision of the Codes used in West Sumatra.

2. Building Back Better—Rapid establishment of up-dated earthquake design requirements and quality controls for West Sumatra is critical to reducing future earthquake disaster risk. This is the “*build-back-better*” philosophy.

3. Post-disaster recovery facilities—New post-disaster recovery facilities such as schools, hospitals, police stations, evacuation buildings, community centres, etc should be designed and constructed to the higher seismic hazard identified. Existing post-disaster recovery structures should be reviewed/inspected with regard to the common flaws identified in this report and strengthening to the increased seismic hazard should be considered.

4. Tsunami hazard—For buildings required for post-disaster recovery, design should include resistance to tsunami as well as design for earthquake. All buildings of 3 stories or more should be designed to survive the predicted tsunami event. For

Padang, the provision of taller buildings (3 storeys or more) to provide for vertical evacuation should be considered in the construction of public facilities such as schools, hospitals, etc. Construction of specific tsunami evacuation structures should be considered for areas with few or no tall buildings. Evacuation buildings will need to survive the earthquake as well as the tsunami and so should be designed for a higher hazard than the “normal” buildings that they need to “out-survive”. Current performance of taller buildings in Padang was shown by the survey to be poor.

5. Non-engineered buildings—A minimum Standard should be prepared for non-engineered buildings (such as small business and housing). The standard drawings for confined masonry for schools could be used as a starting point for development of such a “standard” design with improvements relating to the provision of corner bars and appropriate laps and development lengths for bars. Existing structural design standards could be referenced for such information.

6. Hazard Based Spatial Planning—Seismic micro-zonation, liquefaction potential maps and tsunami hazard maps for the City of Padang should be developed as input to hazard based spatial planning.

7. Geotechnical investigation (Building Foundation)—All sites should be assessed for geotechnical conditions prior to design including site soil classification and any necessary ground improvement methods described. Proposals for new buildings should include assessment of the potential for liquefaction and any methods proposed to address the risk. The survey team saw little evidence of footing design and were informed that piling for tall structures was limited.

Enforcement:

8. Non-compliance—Non-compliance of construction with the current Design Codes or with the construction drawings and the use of poor quality materials has caused the collapse of many buildings. Therefore, increased enforcement is required during the process of Building Permit review and during construction. The latest Building Codes and Standards need to be distributed to government officials and capacity building of local staff is required. Capacity building could be implemented in the form of training from experts and professionals. Particular focus should be made on multi-storey construction, schools, medical facilities, ambulance stations, bridges, major roads and other important post-disaster recovery and life-line structures.

9. Re-construction and repair—A Building Permit should be required for all new construction work or repair of existing buildings and should be supervised by a suitably qualified Professional Engineer. (It is understood that currently only new buildings require a Permit.)

10. Improved design controls—An Advisory Team of Professional Engineers and University level expertise should be formed to evaluate building designs prior to Building Permits being issued. This should include assessment of compliance with the new Building Code hazard level for West Sumatra and provision of advice to Mayoral Offices on individual building designs.

11. Training—Training should be provided as soon as possible (prior to the re-construction process) for local engineers, building consultants, inspectors, and contractors (including masons and local communities involved in building). Training should include why specific detailing requirements exist and what happens if they are not implemented (plenty of photographic evidence has been collected to assist in this

process). Continuing Professional Development processes should be established for Engineers and other building professionals.

12. Professional Engineer Licensing— Licensing of Professional Engineers should be extended to all Provinces, particularly West Sumatra, to ensure on-going quality of design and construction.

13. Inspection—Many buildings were found to be poorly constructed or not in accordance with the design. An “Occupation Certificate” should be required establishing that the building has been constructed in accordance with the design prior to allowing occupation of the building. This would require compulsory inspection by suitably qualified Professional Engineers at the following stages during construction.

    13.1. Foundations before design (e.g. Geotechnical investigation);
    13.2. Footings prior to back-filling;
    13.3. Concrete reinforcement prior to pouring;
    13.4. Steelwork connections (welds/bolts);
    13.5. Connections of walls;
    13.6. Hold-down connections of roof;
    13.7. Bracing of structure.

14. Materials—In many cases of collapse or heavy damage the use of poor quality materials contributed to the damage. Inspection during construction should include checking of supply of materials to ensure the strength of the building is as designed (e.g. checking of concrete quality at point of use, quality control of reinforcement).

Engineering of Buildings

General Discussion

The following comments are offered following a survey of approximately 1800 buildings in and around Padang including buildings surveyed to the north (around Pariaman and Secincin) where the damage was reported to be most severe.

The latest National Seismic Building Code (SNI-03-1726-2002) increased the design seismic hazard for the West Sumatra area in 2002 from 0.07g to 0.3g. The Indonesian expert members of the team indicated that current understanding following recent modelling suggests the hazard for Padang might be as high as 0.4 to 0.5 (for 10% PE in 50 years and T= 1 sec (long period) spectral value).

The 2002 Code change means that any design work carried out prior to 2002 is likely to have seriously underestimated the actual hazard to which the buildings are subjected. This emphasises the need to institute a seismic strengthening program in conjunction with reconstruction initiatives.

Regardless of the low design hazard levels prior to 2002, the general practice of confining masonry walls with reinforced concrete has been followed for some time for single storey buildings. This appears to have developed in response to the tacit understanding that earthquake hazard did exist (even though it was not adequately quantified).

It should be noted that some buildings tagged Red in the earthquake zone (as having significant damage) may still be repairable following a detailed structural assessment. Red tagged buildings should be subject to a detailed inspection by a suitably qualified Professional Engineer prior to being demolished.

Failures in small buildings

The majority of buildings surveyed were single storey of unreinforced masonry or with confining small sized concrete members (confined masonry buildings). The confinement is in the form of reinforced concrete members of a standard type cast after masonry is constructed. The style is defined as generally with tie beams top and bottom of all walls (approx. 150 x 150 reinforced with 4 x 8mm diameter round bars) with columns cast inside brick walls (generally approx. 150 x 200 with 4 x 6mm dia. round bar). Footings are approx. 800mm to 1200mm deep of a pyramid shape of mortared rounded river stones.

It was clear that most of the collapsed minor buildings involved failure of un-reinforced masonry. While in-plain failures were recorded in many buildings, out-of-plane failures were more numerous and more severe. The housing near Periaman and Secincin that was collapsed was mostly in rural areas and amounted to approx. 2% – 3% of the buildings seen, while around 10% – 15% of the buildings remained standing with only some fallen walls. These houses were generally of unreinforced load-bearing masonry. The masonry was rendered standard brick or rounded river rocks or stones approx. 150 mm – 300 mm in size that were stacked and mortared in place. Many “river stone” walls were observed to have sustained damage with many fallen.

Where confined masonry had been observed to have been damaged (including collapses) there was a lack of the following:-

- adequate reinforcing bars at joints;
- anchorage of bars;
- leg length of hooks;
- spacing/diameter of ties and anchorage of ties.

With the joints poorly detailed, the confinement of the masonry walls would be ineffective, leading to poor performance in earthquake. Plain round bar (undeformed) was invariably observed (except in the most recent multistorey concrete structures) which further exacerbated concerns regarding reinforcement anchorage.

Larger multi-storey structures

For the larger concrete structures, the most common failures involved the development of plastic hinges at the tops and bottoms of ground floor columns. Reinforcement in most structures was observed to be plain round bar. Only in some newer structures was deformed reinforcement bar observed. Invariably, multi-storey concrete structures had infill walls of unreinforced masonry throughout the building constructed hard up against the concrete structure (no gaps). In some cases the infill unreinforced masonry saved the structure by acting as shear walls and absorbing most of the lateral deformation energy with resulting crushing and diagonal cracking of the infill.

It was not clear whether many of the structures were specifically designed for lateral forces. This may be the result of the lower design requirements of the pre-2002 Building Code (Indonesian Seismic Building Code SNI-1981). Unreinforced masonry walls (rendered brick) appeared to be the only lateral force resistant elements in most structures. That is, no reinforced concrete shear walls were observed.

Short columns had been created in many structures by the infill masonry not extending to the underside of the beams above and therefore not forming a proper shear wall. The columns in such locations would then form a 'soft storey', with concentration of most of the lateral deformation into the short column leading to failure in shear or by the formation of plastic hinges. In these locations, column ties would not be adequate for the shear deformation experienced. Shear failures were frequently observed in the potential plastic hinge zones at the tops of columns, indicating that the structure had little ductility capacity.

Bricks

The bricks used throughout the building industry around Padang are of orange/red clay with the majority appearing to be incompletely fired. Bricks were commonly able to be broken easily by stamping on them with the foot. In only one case out of a number of manual tests carried out on numerous sites, the brick could not be broken with the foot. The fired clay was often able to be crumbled with the fingers, and in some cases the centre of the bricks appeared un-fired with the centre able to be hollowed with the thumbnail.

Hollow Concrete Blocks

The hollow concrete blocks observed in a number of the school buildings inspected were approx. 90mm thick. They did not appear to be suitable for installing reinforcement and pouring of grout (the hollows being too small). In one location, a broken portion of one block was crumbled by hand indicating the blocks may be of low strength or of variable quality. Reinforced concrete block masonry was not observed in any buildings inspected during the survey.

Concrete

In many broken concrete members, the aggregate was observed to be of rounded river gravel of large size (ranging up to >40 mm). It was observed that reinforcing steel was being recovered from fallen structures by beating the concrete members with sledge hammers and hand hammers – suggesting that the concrete strength is low. Honeycombing of concrete members was also observed on many buildings due to incomplete compaction of concrete during pouring.

Specific Engineering Recommendations:

15. Reinforcement detailing—Reinforcement must be adequately anchored at joints by applying the following:

    Reinforcement must be adequately detailed, particularly at joints. The appropriate Structural Concrete Design Standard should be followed. Where a Structural Engineer is not involved in the design (e.g. for the standard confined masonry type construction) guidelines should be provided on development lengths and lap lengths for the range of bar sizes and types (plain round and deformed) commonly used. These should take into account the steel strength and concrete strength.

    Corner bars must be provided in all concrete joints to transfer forces from beams to columns.

Ties must be adequately anchored with hooks that turn 135 degrees (with appropriate leg length) and be spaced appropriately (e.g. min 150mm centres).

16. Bracing of roof structure—In many cases the roof trusses were not braced to one another or to the shear walls below. Guides on bracing of buildings and roof framing should be prepared and made available to all levels of the building industry (including building owners).

17. Tie the structure together—Connections between all elements of the building are important to ensure that load paths continue to function during earthquake shaking. The links provided by the concrete elements in the traditional confined masonry type construction provide for the tying together of the walls and structure. It is when these ties do not hold together through poor joint detailing (e.g. lack of corner bars) that failures were seen. Provision of load paths through sound design of joints and provision of connections to walls should be ensured in all buildings.

18. Gable walls, parapets and balcony barriers—Design of parapets and gable walls should be restricted to light framed materials (masonry should be banned for these elements) and provided with ties to the building structure of sufficient strength and durability to resist the lateral seismic forces.

19. Pounding—Gaps should be provided between separate buildings to allow for deflections during earthquakes without the buildings colliding.

20. Short columns—Columns with adjacent masonry walls that are not the full height of the column will be subject to higher lateral deformation and should be designed accordingly. Preferably, such short column/soft storey structural formations should not be used.

21. Deformed reinforcement—The use of deformed reinforcement bar should be encouraged. This would improve the strength of concrete members, improve the anchorage of the bars and lead to the use of higher quality steels.

22. Shear walls—The use of evenly distributed shear walls should be encouraged. Properly designed shear walls tied into the structure are of great value in resisting lateral earthquake actions. For larger concrete framed buildings, concrete shear walls designed for the lateral earthquake forces would be a better solution than infill masonry walls. Care should be taken to ensure that any infill masonry that is not intended to act as a shear wall is provided with enough clearance around its edges to avoid it interfering in the lateral behaviour of the structure (example: the short columns unwittingly caused by masonry, see Item 20 above).

23. Shop Fronts—Many shop fronts have no shear resistance at the front of the building. This can cause a soft storey and/or torsional type failure. A number of such failures were seen. Some damaged buildings were still in use where the deformation was of a dangerous nature. Shop fronts should be provided with some form of lateral resistance (e.g. short shear walls).

24. Column/beam concrete joint detailing—Joints observed had poor detailing of the steelwork, with resultant shear failures and plastic hinges forming in the columns. More attention should be paid to joint detailing with particular attention to shear ties, lap lengths and column continuity through floors. The use of strong column/weak beam design philosophy should be encouraged.

"The transverse reinforcement in columns was consistently observed to be too widely spaced and poorly detailed, which was particularly critical when column hinging occurred" – by transverse do you meant he reo in the beams or the ties?

25. Mis-match of floor levels—Where two buildings meet and the floor levels are different, loads from one building may be transferred into the mid-point of the next buildings columns leading to failure of the columns. This should be avoided by providing gaps to prevent transfer of loading (including pounding).

26. Fixed stairs—Concrete stairways create a stiff element in the building structure. This may result in damage to the stair or to the surrounding structure. Design should take these elements into consideration. These could be better utilised to resist lateral loads by incorporation of reinforced concrete shear walls and floor diaphragms.

Conclusion

It is clear from the level of damage observed during the survey and from the loss of life, that many buildings of West Sumatra will be damaged in the projected large earthquake expected to occur in coming decades. The current re-construction being undertaken is an important opportunity to carry out improvements in building practice and to thus increase the resilience of buildings.

To prepare Padang and other communities along the west coast of Sumatra for the expected large magnitude earthquake and tsunami, it is imperative that good engineering is supported by regulatory quality assurance processes. These recommendations are fundamental for reducing community risk and need to be swiftly integrated and implemented into the recovery and reconstruction process.

Draft Advice provided to World Bank, Oct 2009.

Initial Recommendations on West Sumatra Buildings

A major West Sumatra earthquake with a magnitude up to 8.5 is likely in either our lifetime or our children's lifetime. It will cause stronger shaking than the September 2009 earthquake and will possibly be followed by a major tsunami.

It is possible to use the current re-construction process to prepare for the next inevitable event. West Sumatra can and must "build back better" and it is paramount that recovery and re-construction is supported by an appropriate engineering and regulatory framework.

To improve the safety of the West Sumatra community the following recommendations are made to maximise building performance, assist recovery and reduce the impact on populations during the next earthquake.

Regulatory recommendations:

- The current building code needs to be reconsidered in light of the expected event – higher design requirements may be necessary for the general population of buildings and further increased seismic and tsunami criteria is required for post-disaster facilities (government buildings, schools, hospitals etc). Any review needs to be completed urgently in order to support building back better.

- A major Tsunami would likely follow the ~Mw 8.5 earthquake (within 20 or 30 minutes). Post disaster facilities should be designed for this hazard. Furthermore, any building of 3 storeys or more should have increased design measures to function as a tsunami refuge.

- Key facilities that have survived 30 Sept event relatively undamaged would fail in large numbers under the anticipated next event. They should be reviewed and strengthened as needed.

- Other engineered and non-engineered construction (commercial, residential) similarly needs to be reviewed for the expected event and strengthened as needed. Improved standards could be prepared for some typical construction types.

- More detailed assessment of apparently heavily damaged buildings will be required as some may only have limited structural damage and need not be demolished. Repair or strengthening may be required for the expected earthquake/tsunami

- Housing suffered greatly in this event, due to common building methods (un-reinforced masonry and reinforced concrete with masonry infill). At a minimum, confined masonry should be employed for all one story residential new construction. For two story and higher construction, more appropriate engineered design would be needed.

- Detailed hazard mapping is needed (site amplification, liquefaction, landslide, etc.) for use in local development planning by government.

Enforcement recommendations:

- A building code is of no use if it is not applied. The overall building construction and quality assurance process in West Sumatra needs to be assessed and modified to ensure buildings are designed and constructed to the required level. This will require education on appropriate construction techniques as well as a regime of building inspections during construction of engineered structures – both public and private.

- Building Permits should be required for all work to assist in quality control. An Advisory Team of Experts and Professionals would assist Provincial and Mayoral Offices to improve scrutiny of proposed designs.

- In many cases of poor performance reinforcement was not installed correctly or concrete was of poor quality. A mandated inspection regime is required to ensure buildings are constructed to the design.

- Training in fundamentals of reinforced concrete construction and seismic detailing should be provided throughout the professional and construction communities in West Sumatra (and Indonesia) to improve design and construction quality. Training of building workers and education of building owners will assist in the reform process.

Specific Engineering recommendations:

- Specific engineering design recommendations include amongst others:
    - Use of confined masonry instead of un-reinforced masonry and use of reinforced concrete with masonry infill designed as shear walls;
    - provision of gaps between buildings to reduce "pounding";
    - inclusion of shear walls on ground floors to reduce "soft storeys";
    - use of deformed reinforcement bars to maintain steel quality and improve reinforced concrete performance;
    - improved reinforced concrete joint detailing; and
    - provide countermeasures for liquefaction and other foundation problems.

To prepare Padang and other communities along the west coast of Sumatra for the expected large magnitude earthquake and tsunami, it is imperative that good engineering is supported by regulatory quality assurance processes. These recommendations are fundamental for reducing community risk and need to be swiftly integrated and implemented into the recovery and reconstruction process.

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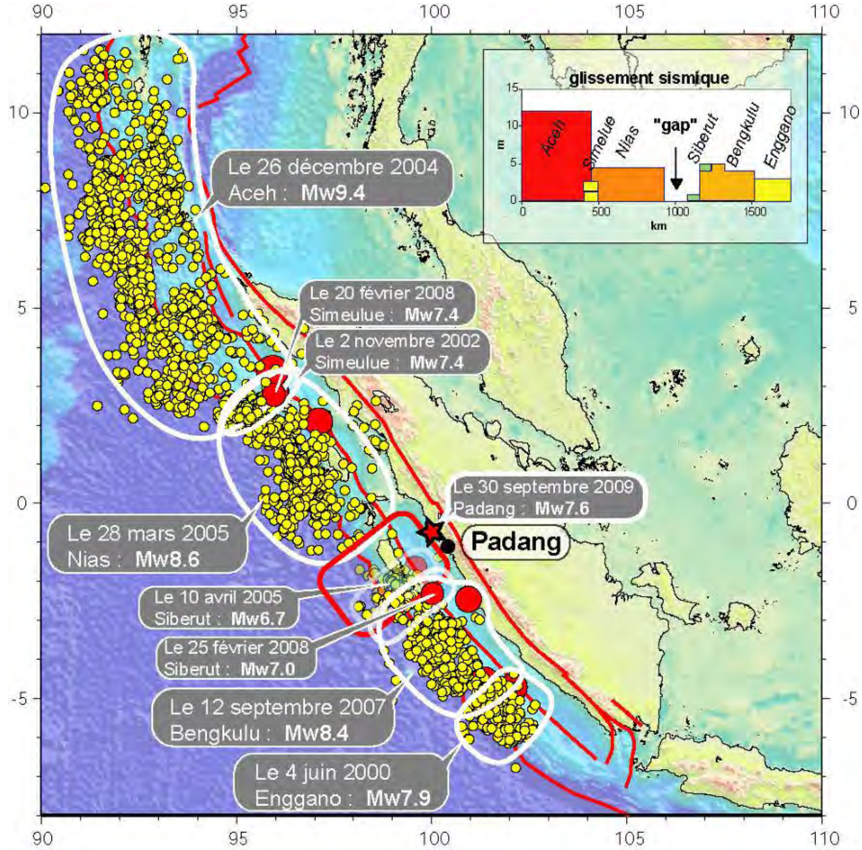

Figure 1 Recent earthquake activity near Padang (image from a web document, source unknown)

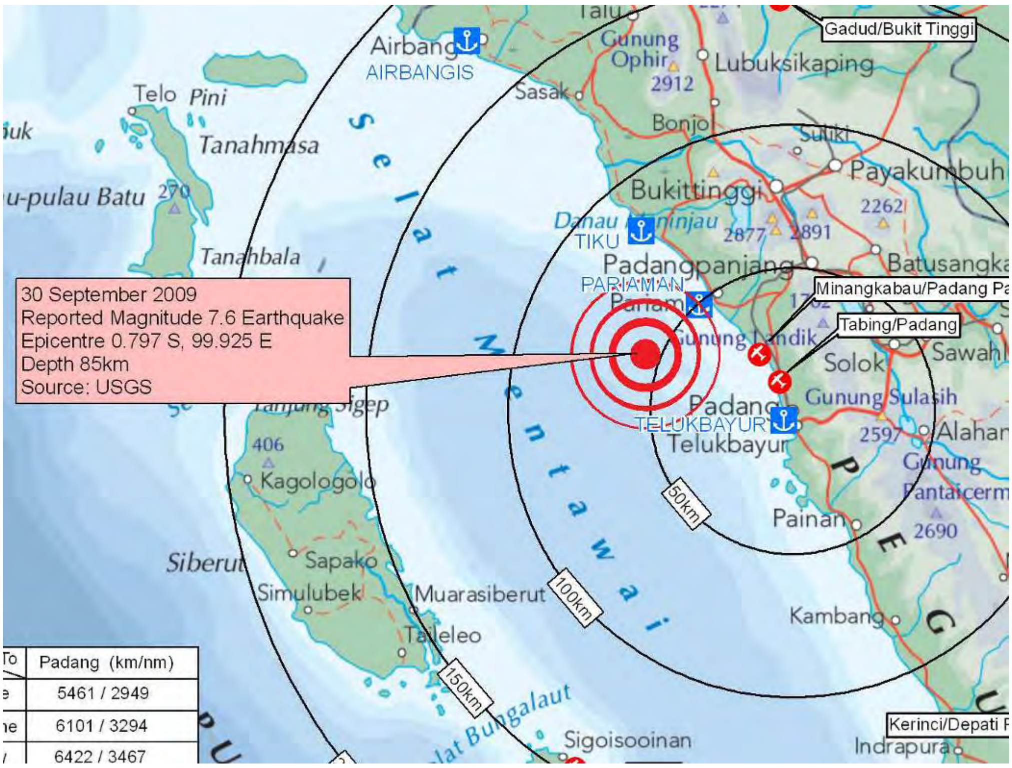

Figure 2 (detail of image from www.defence.gov.au)

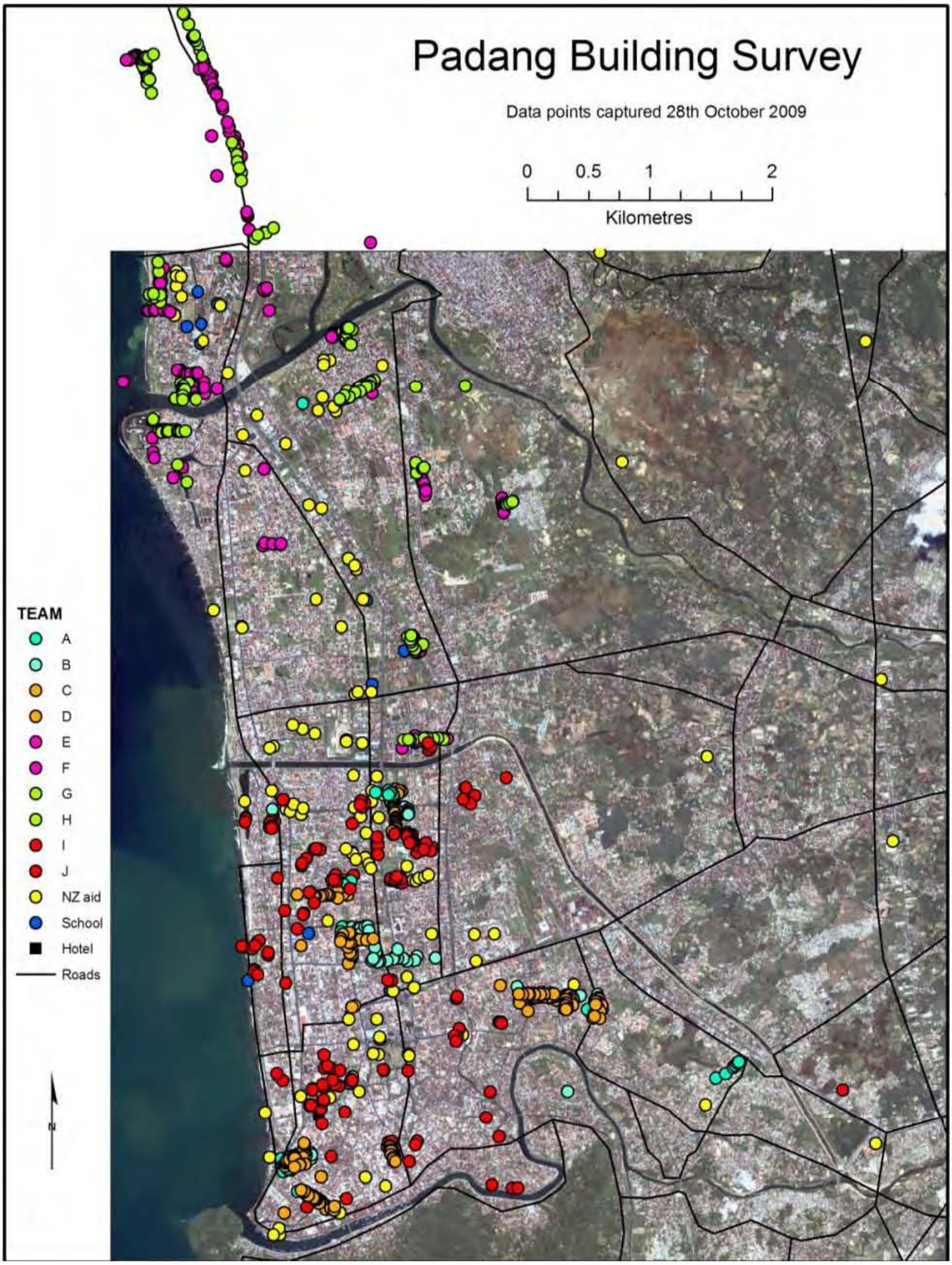

Figure 3 Data plot from survey data base

Figure 4 Poor reinforcement detailing

Figure 5 Poor reinforcement detailing

Figure 6 Soft bricks--Broken with fingers

Figure 7 Missing ties in column/joint

Figure 8 Demolition methods—recycling steel bars

Figure 9 Failed Gable Wall

Figure 10 Poor aggregates/concrete

Figure 11

Figure 12 This was a 6 storey hotel

Figure 13

Figure 14 Collapsed school (single storey)

Figure 15 Collapsed Medical Facility

Figure 16 School abandoned

Figure 17 School very near collapse

Figure 18

Figure 19 Soft Storey (commercial shop-front) Ground Floor Collapse

Figure 20

Figure 21 Another soft storey building near collapse

Figure 22 Settlement due to liquefaction (note sand forced up through cracks in concrete)

Figure 23 Sand brought to the surface due to liquefaction

Figure 24 Liquefaction caused heavier buildings to sink

Figure 25

Appendix A3

MASW Study

FINAL REPORT

An Enhanced Understanding of the Vulnerability of Buildings to Earthquake in Indonesia

Survey, data analysis and development of vulnerability models:

Peak Ground Acceleration Estimate based on MASW Survey and Existing Geotechnical Data for City of Padang and Pariaman

Prepared for:

Australian – Indonesia Facility for Disaster Reduction

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INSTITUT TEKNOLOGI BANDUNG

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CENTER FOR DISASTER MITIGATION

INSTITUT TEKNOLOGI BANDUNG

MAY 2010

LIST OF FIGURES

LIST OF TABLES

CONTENT

CHAPTER 1
INTRODUCTION

BACKGROUND

West Sumatra Earthquake

On 30 September 2009 a magnitude 7.6 earthquake strucks offshore the southern coast of West Sumatra. This event has had widespread impact and BNPB's reports indicate there were over 800 deaths and over 130,000 buildings totally destroyed or severely damaged in the Padang and Padang Pariaman District.

A preliminary survey of damage has been conducted by the Center for Disaster Mitigation-Institute of Technology Bandung (CDM-ITB) and found that there were a variety of buildings types that experienced different levels structural damage. In addition, there is indication that different sites could be subjected to different peak ground acceleration due to local ground condition within the city of Padang. A more extensive survey is needed, however, to acquire a statistical meaningful sample of how different building types performed during the earthquake under different ground shaking. In addition, further information is required to characterize site response and analysis of the earthquake source properties, and also to estimate the ground motion these buildings are likely to have experienced.

Importance of Ground Shaking in Vulnerability Information

Estimating how different types of buildings respond to different ground shaking is essential in predicting how much building damage might occur from potential future event. This information is needed for development of vulnerability model of different types of building constructions. The vulnerability model will correlate damage index or damage ratio of a particular building construction as a function to ground shaking. The ground shaking is usually represented by Modified Mercally Intensity (MMI) or Peak Ground (surface) Acceleration (PGA). Estimation of PGA due to the earthquake that caused corresponding damages of buildings is of primary importance. This report presents results of seismic survey and collection of geotechnical data in city of Padang and Pariaman to estimate spatial distribution of PGA within the city due to 30 September 2009 earthquake.

OBJECTIVES

Objectives of this work are to conduct estimate spatial peak ground acceleration (PGA) distribution due to 30 September 2009 earthquake. The spatial PGA distribution is conducted to cover the post disaster surveyed buildings in city of Padang and city of Pariaman, in the effort to provide PGA value associated with each surveyed building damages for vulnerability model development. Specific objectives of the work are:

- Conduct multi-channel analysis of surface wave (MASW) survey within the city of Padang and Pariaman.
- Conduct analysis of the 30 September 2009 earthquake source properties and estimation through ground motion attenuation to estimate the level of peak ground acceleration at reference baserock.
- Conduct site-response analyses though wave propagation analysis from base-rock to ground surface to estimate spatical PGA within the city of Padang and Pariaman.
- Provide information for development of vulnerability model for different building types.

CHAPTER 2
MULTI CHANNEL ANALYSIS OF SURFACE WAVES SURVEY

INTRODUCTION

The purpose of this MASW survey was to investigate the soil condition of some points at Padang city which underwent earthquake just recently. The field work was carried out during 23 December 2009 until 02 January 2010. The MASW survey was conducted at 30 points at Padang city and 3 points at Pariaman town. The following table presents the coordinates of measurement points:

Tabel 2.1. MASW Padang measurement points coordinates

Points	Lattitude	longitude
1	Haji camp	Haji camp
2	0^o 52' 59.29"	100^o 21' 1.13"
3	0^o 53' 23.9"	100^o 20' 39.5"
4	0^o 53' 44.9"	100^o 21' 12.2"
5	0^o 54' 11"	100^o 20' 50.2"
6	0^o 54' 26.3"	100^o 20' 41.7"
7	0^o 54' 13.4"	100^o 21' 35.7"
8	0^o 54' 14.7"	100^o 21' 52"
9	0^o 54' 18"	100^o 22' 6.2"
10	0^o 54' 37.2"	100^o 21' 53.9"
11	0^o 55' 5.8"	100^o 21' 13.2"
12	0^o 55' 27.6"	100^o 21' 24.5"
13	0^o 55' 15"	100^o 21' 52.8"
14	0^o 55' 40.7"	100^o 21' 49.7"
15	0^o 56' 9.5"	100^o 21' 46.1"
16	0^o 56' 5.1"	100^o 22' 31.5"
17	0.9391^o	100.36915^o
18	0.94052^o	100.35807^o
19	0.93965^o	100.36250^o
20	0.94323^o	100.37026^o
21	0.94796^o	100.37409^o
22	0.96373^o	100.3569^o
23	0.96007^o	100.35712^o
24	0.96326^o	100.37207^o

25	0.95859°	100.36852°
26	0.95795°	100.37979°
27	0.95492°	100.38563°
28	0.94776°	100.39307°
29	0.95496°	100.39745°
30	0.97417°	100.3826°

Tabel 2.2. MASW Pariaman measurement points coordinates

Points	Lattitude	longitude
1	0.62691°	100.16331°
2	0.56650°	100.27780°
3	0.59294°	100.28265°

Figure 2.1 and Figure 2.2 show the location map of MASW survey points.

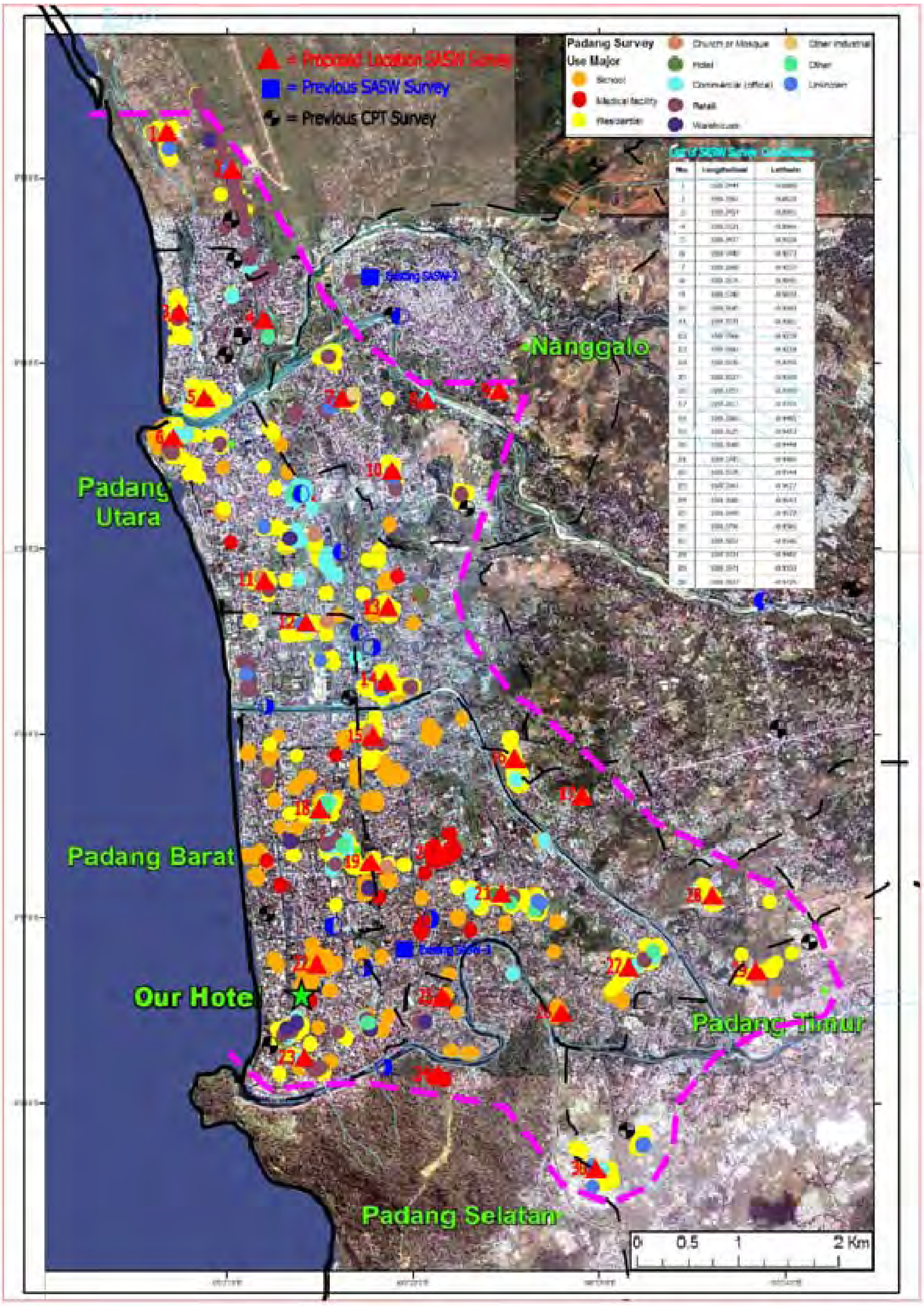

Figure 2.1. The location of MASW survey points for City of Padang
(MASW 1 ~ MASW 30)

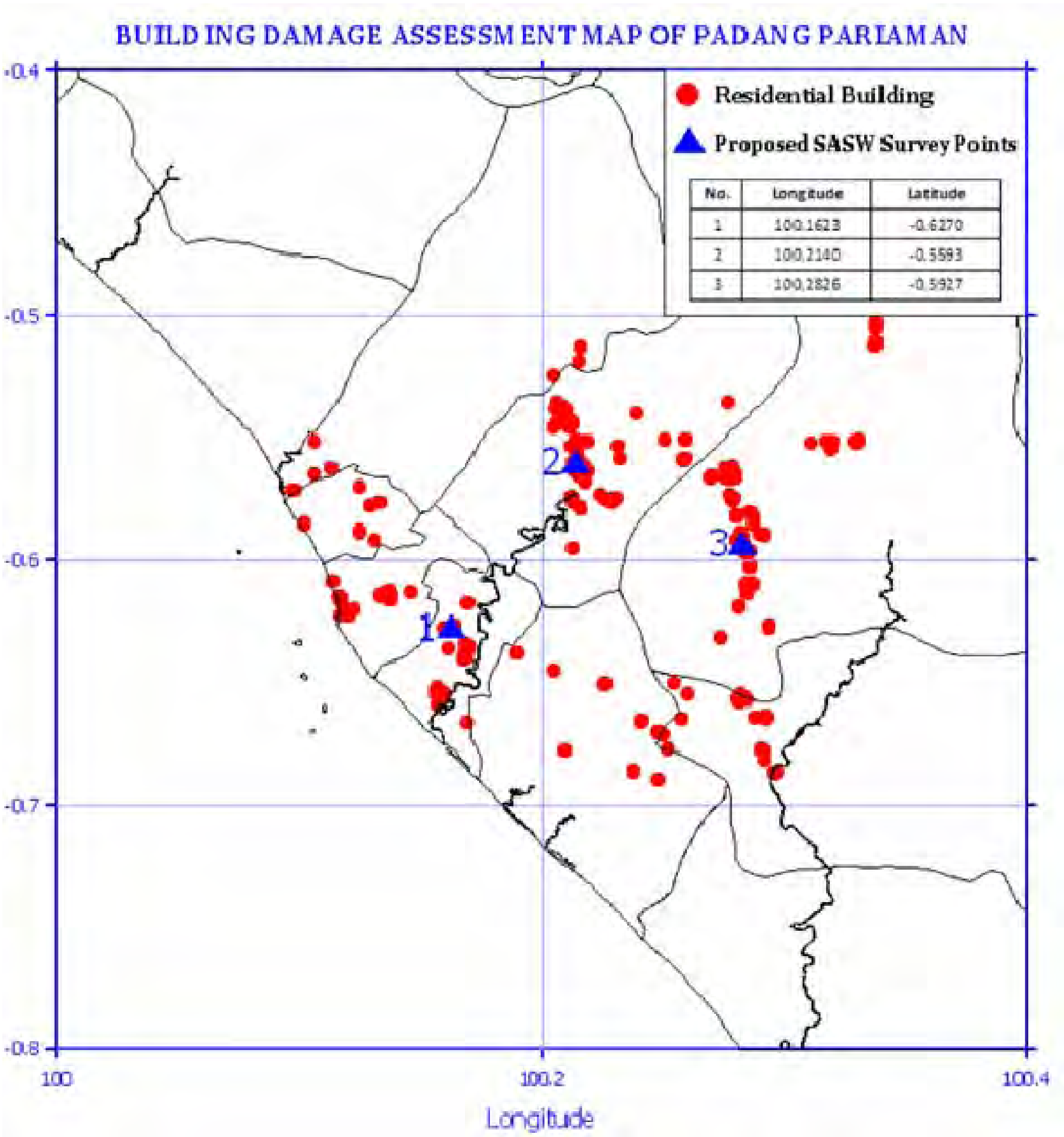

Figure 2.2. The location of MASW survey points for City of Padang Pariaman (MASW 1P ~ MASW 3P)

METHODOLOGY

The multichannel analysis of surface waves (MASW) method is one of the seismic survey methods evaluating the elastic condition (stiffness) of the ground for geotechnical engineering purposes. MASW first measures seismic surface waves generated from various types of seismic sources—such as sledge hammer—analyzes the propagation velocities of those surface waves, and then finally deduces shear-wave velocity (Vs) variations below the surveyed area that is most responsible for the analyzed propagation velocity pattern of surface waves. Shear-wave velocity (Vs) is one of the elastic constants and closely related to Young's modulus. Under most circumstances, Vs is a direct indicator of the ground strength (stiffness) and therefore commonly used to derive load-bearing capacity.

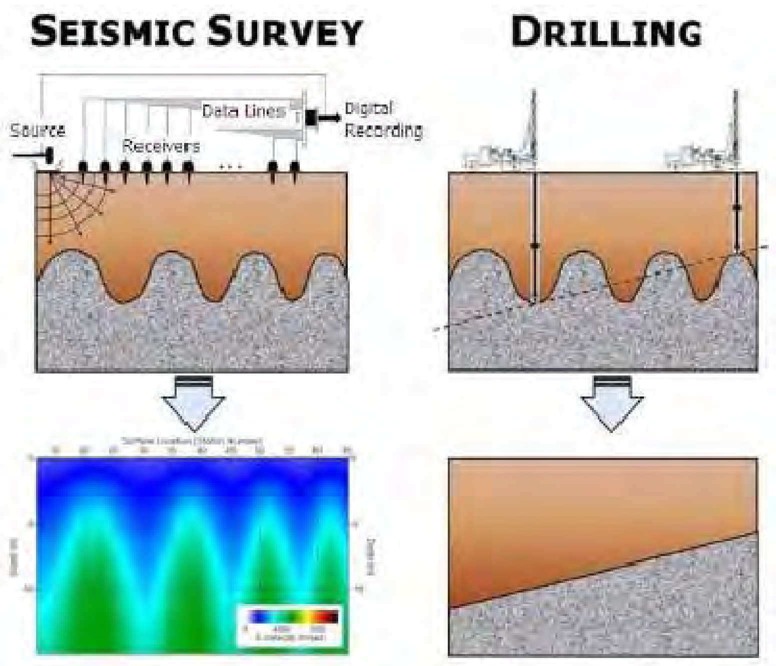

Figure 2.3. Comparison between the surface wave method and the drilling methods

Unlike the shear-wave survey method (seismic downhole and seismic crosshole) that tries to measure directly shear-wave velocities—which is notoriously difficult because of difficulties in maintaining favorable signal-to-noise ratio (S/N) during both data acquisition and processing stages—MASW is one of the easiest seismic methods that provides highly favorable and competent results. Data acquisition is significantly more tolerant in parameter selection than any other seismic methods because of the highest signal-to-noise ratio (S/N) easily achieved. This most favorable S/N is due to the fact that seismic surface waves are the strongest seismic waves generated that can travel much longer distance than body waves without suffering from noise contamination.

In comparison to a conventional drilling approach, it is fully implemented on the ground surface (non-invasive), covers the subsurface continuously in a manner similar to ground-penetrating radar (GPR), and provides more complete coverage.

Because of an increased ability to discriminate useful signal from harmful noise, the MASW method assures an increased resolution when extracting signal in the midst of noise that can be anything from natural or cultural activities (wind, thunder, traffic, etc.) to other types of inherent seismic waves generated simultaneously (higher-mode surface waves, body waves, bounced waves, etc.).

The common procedure for MASW surveys usually consists of three steps:

1. Data Acquisition---acquiring multichannel field records (commonly called shot gathers in conventional seismic exploration)

2. Dispersion Analysis---extracting dispersion curves (one from each record)

3. Inversion---back-calculating shear-wave velocity (Vs) variation with depth (called 1-D Vs profile) that gives theoretical dispersion curves closest to the extracted curves (one 1-D Vs profile from each curve).

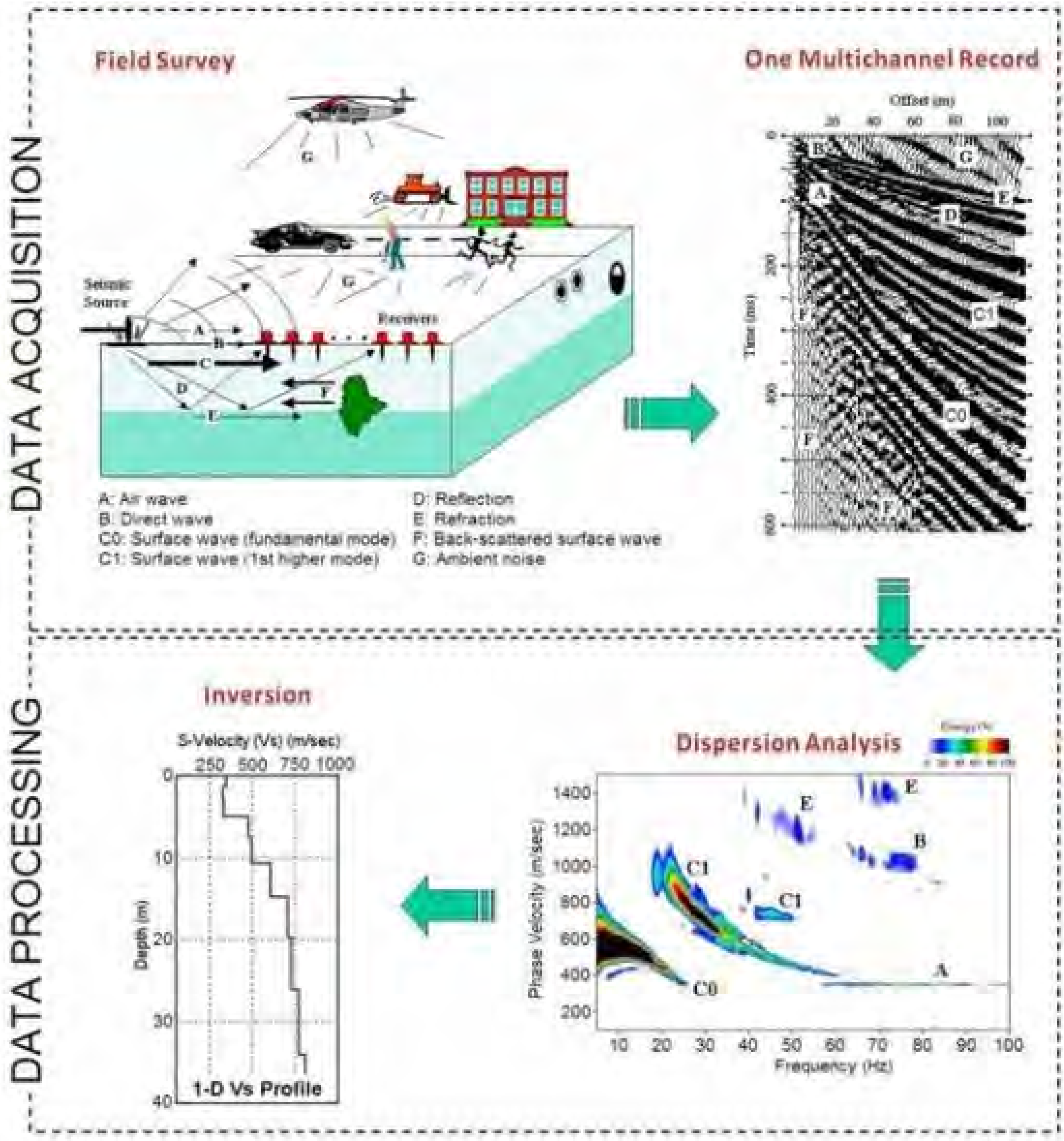

Figure 2.4. The overall procedure of Multi Channel Analysis of Surface Waves (MASW)

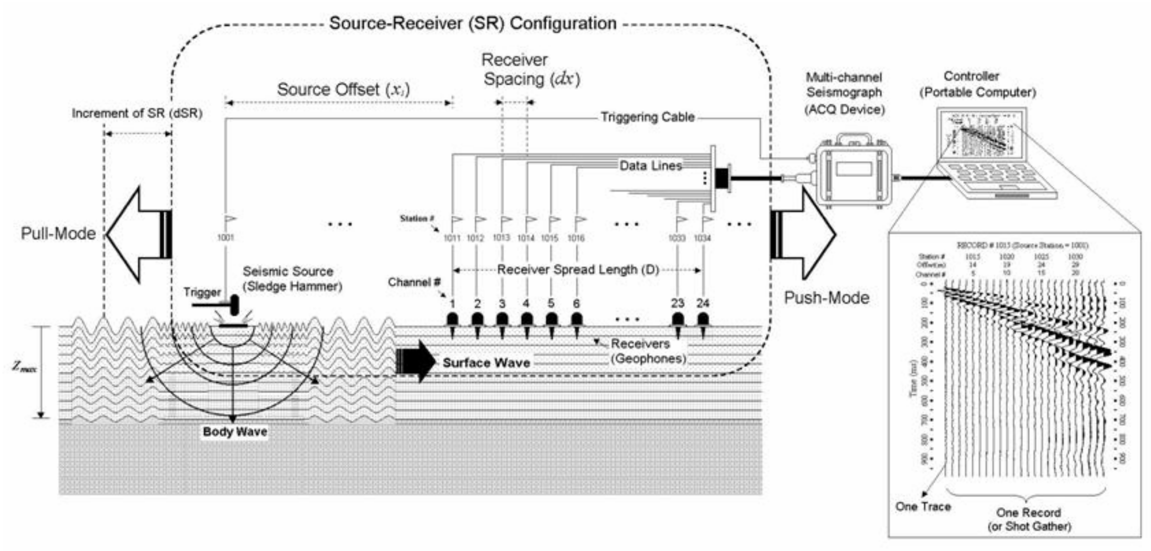

Figure 2.5. The Acquisition data procedure in the field

The field parameters that were used in the field i.e.:

a. The near offset (the distance between hammer blow to first geophone) was 18 m.

b. The number of all geophones are 12 geophones

c. The geophone spacing was 3 m

d. As the energy source, we employed a weight drop which weighs 60 kg.

e. The recording unit was 24 bit digital recorder (The seistronix RAS-24 recorder unit)

Goal of the field survey and subsequent data processing before inversion takes place is to establish the fundamental mode (M0) dispersion curve as accurately as possible, which has been one of the key issues with data acquisition and processing in the history of surface wave applications. Theoretical M0 curves are then calculated for different earth models by using a proper forward modeling scheme to be compared against the measured (experimental) curve. This inversion approach is based on the assumption that the measured dispersion curve represents the M0 curve only not influenced by any other modes of surface waves.

	Seistronix RAS-24 Seismic Recording system • 6, 12, or 24 channels per box • 24 bit A to D converter • Connect up to ten boxes in 2D or 3D configurations for up to 240 channels • Control the complete system with your notebook computer and Windows 95/98/XP • Built in extensive self test functions • Geophone Triaxial OYO

Figure 2.6. The seistronix RAS-24 recorder unit

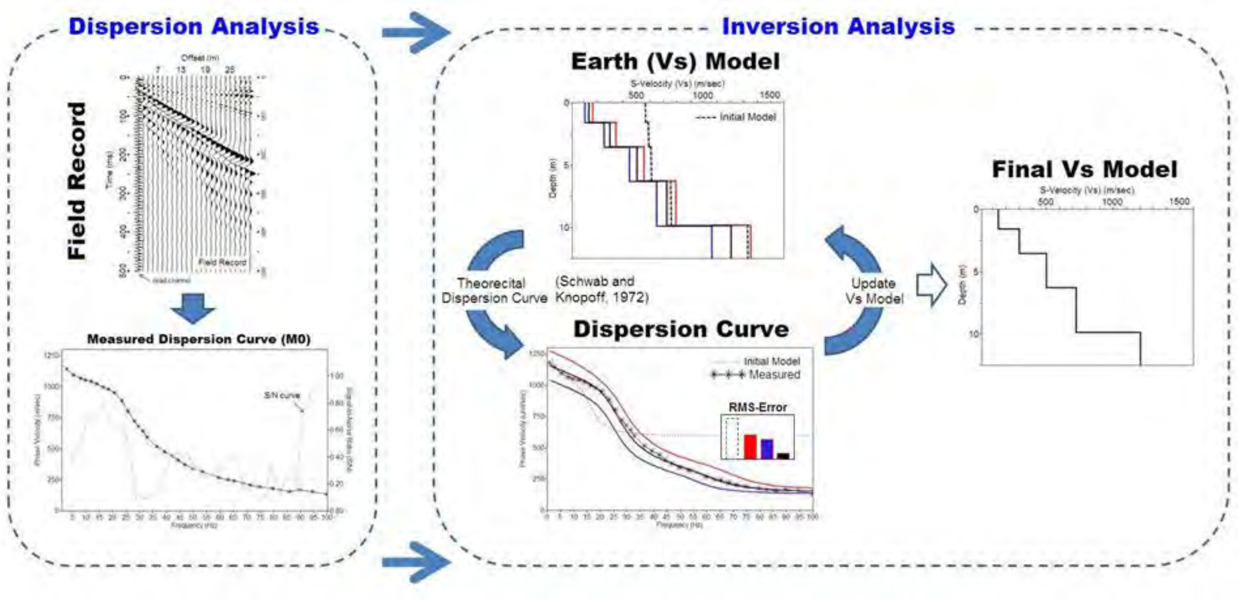

Figure 2.7. The inversion process to produce shear wave velocity profile

Key issue with this inversion approach has been the optimization technique to search for the most probable earth model among many other candidates as much efficiently as possible. The root-mean-square (R-M-S) error is usually used as an indicator of the closeness between the two dispersion curves (measured and theoretical), and the final solution is chosen as the 1D Vs pofile resulting in a preset (small) value of R-M-S error. Either a deterministic method such as the least-squares method or a random approach is taken for the optimization. The former type is usually faster than the latter type at the expense of the increased risk of finding a local, instead of global, minimum.

The complete MASW seismic survey result and documentation are presented in Appendix 1 and Appendix 2.

MASW SURVEY DATA ANALYSIS

Based on the 33 points of MASW tests in the City of Padang and Pariaman, generally the result shows that the first ground layer on the depth of 0-5 meter has the average Vs of 129.20 m/s, the second layer on the depth of 5-10 meter, tends to ossify with the average Vs of 172.27 m/s, and on the third layer on the depth of 10-30 meter has the average Vs of 210.915 m/s. Summary results of MASW survey shows the shear wave velocity profile (Vs) as depth function is shown in Figure 2.8 to Figure 2.14.

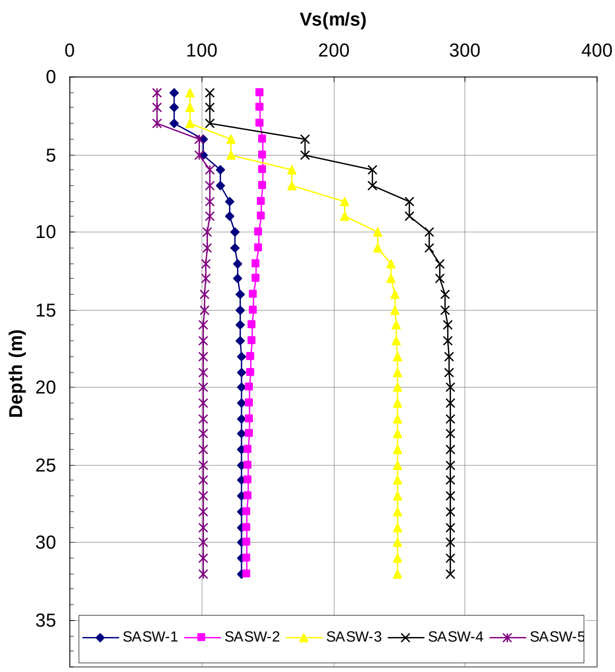

Figure 2.8. Shear wave velocity as function of depth of the MASW survey at point 01-05

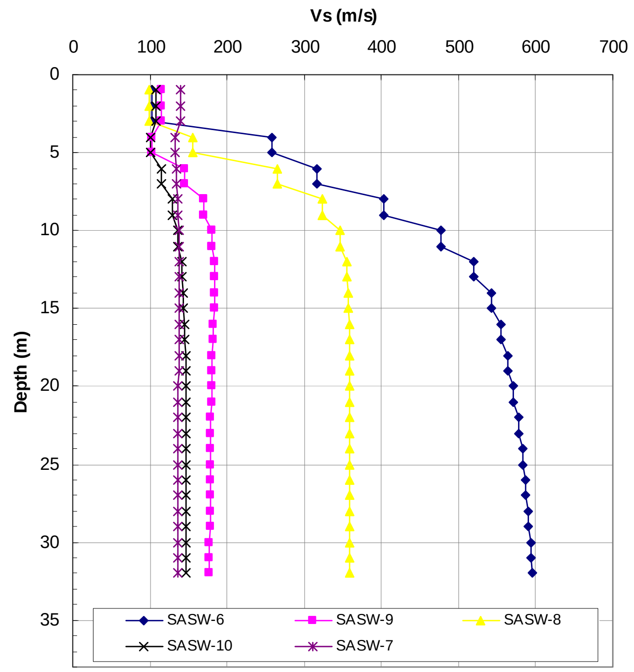

Figure 2.9. Shear wave velocity as function of depth of the MASW survey at point 06-10

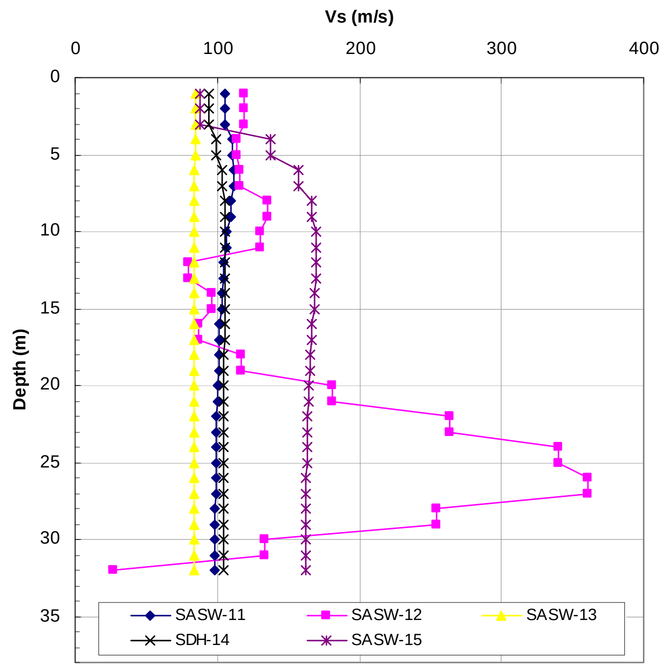

Figure 2.10. Shear wave velocity as function of depth of the MASW survey at point 11-15

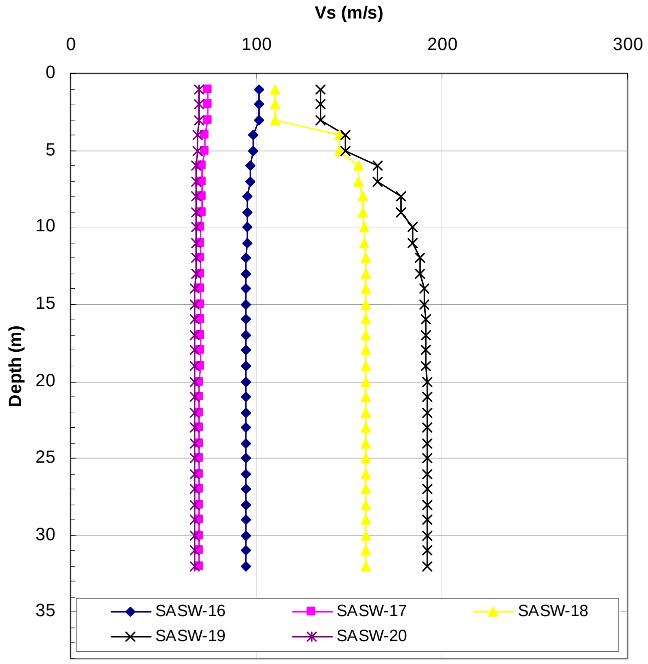

Figure 2.11. Shear wave velocity as function of depth of the MASW survey at point 16-20

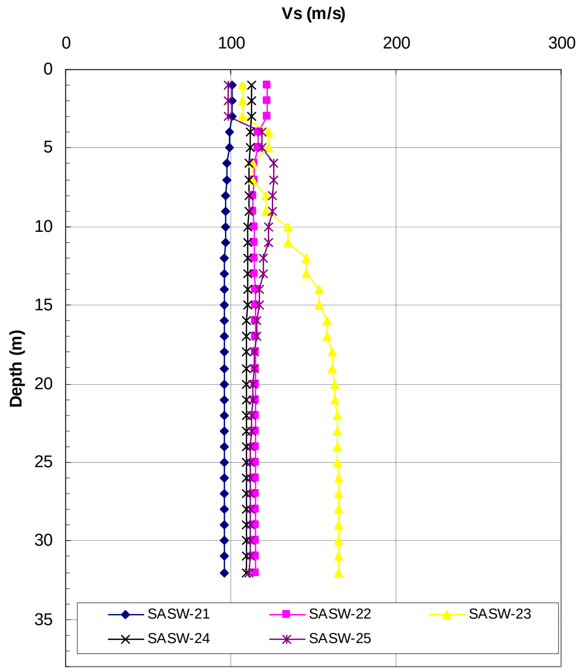

Figure 2.12. Shear wave velocity as function of depth of the MASW survey at point 21-25

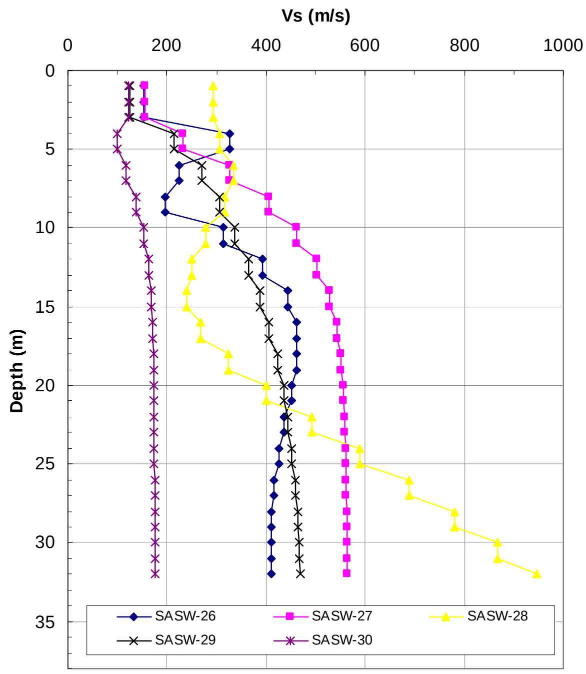

Figure 2.13. Shear wave velocity as function of depth of the MASW survey at point 26-30

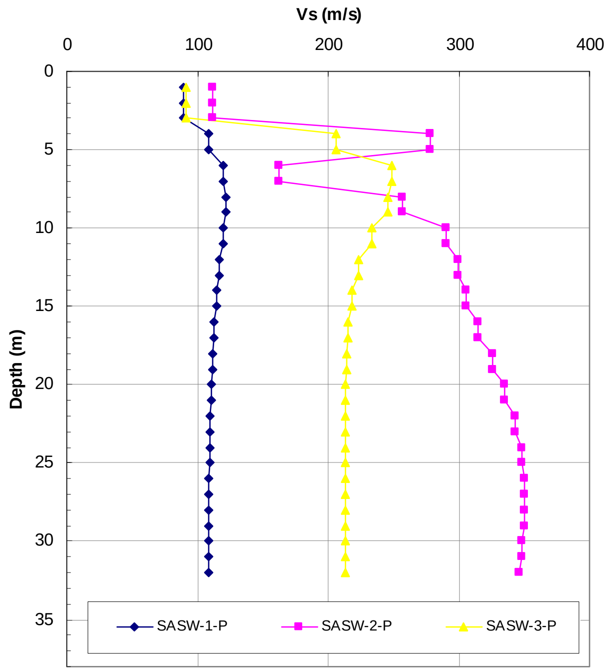

Figure 2.14. Shear wave velocity as function of depth of the MASW survey at point 1P-3P

Site classification analysis which is based on the MASW survey refers to the site classification criteria of SNI 1726-2002 is shown in the following tables.

Depth	SASW-1	di/Vsi	SASW-2	di/Vsi	SASW-3	di/Vsi	SASW-4	di/Vsi
1	79.444	0.01	144.11	0.01	91.538	0.01	105.99	0.01
2	79.444	0.01	144.11	0.01	91.538	0.01	105.99	0.01
3	79.444	0.01	144.11	0.01	91.538	0.01	105.99	0.01
4	100.89	0.01	146.63	0.01	121.85	0.01	177.95	0.01
5	100.89	0.01	146.63	0.01	121.85	0.01	177.95	0.01
6	114.01	0.01	146.66	0.01	168.06	0.01	229.68	0.00
7	114.01	0.01	146.66	0.01	168.06	0.01	229.68	0.00
8	121.49	0.01	145.14	0.01	208.31	0.00	257.77	0.00
9	121.49	0.01	145.14	0.01	208.31	0.00	257.77	0.00
10	125.6	0.01	143.13	0.01	233.98	0.00	272.47	0.00
11	125.6	0.01	143.13	0.01	233.98	0.00	272.47	0.00
12	127.79	0.01	141.21	0.01	243.62	0.00	280.22	0.00
13	127.79	0.01	141.21	0.01	243.62	0.00	280.22	0.00
14	128.97	0.01	139.58	0.01	246.77	0.00	284.33	0.00
15	128.97	0.01	139.58	0.01	246.77	0.00	284.33	0.00
16	129.62	0.01	138.26	0.01	247.94	0.00	286.51	0.00
17	129.62	0.01	138.26	0.01	247.94	0.00	286.51	0.00
18	129.99	0.01	137.24	0.01	248.43	0.00	287.69	0.00
19	129.99	0.01	137.24	0.01	248.43	0.00	287.69	0.00
20	130.19	0.01	136.46	0.01	248.64	0.00	288.32	0.00
21	130.19	0.01	136.46	0.01	248.64	0.00	288.32	0.00
22	130.31	0.01	135.86	0.01	248.74	0.00	288.67	0.00
23	130.31	0.01	135.86	0.01	248.74	0.00	288.67	0.00
24	130.38	0.01	135.41	0.01	248.79	0.00	288.85	0.00
25	130.38	0.01	135.41	0.01	248.79	0.00	288.85	0.00
26	130.42	0.01	135.07	0.01	248.81	0.00	288.95	0.00
27	130.42	0.01	135.07	0.01	248.81	0.00	288.95	0.00
28	130.44	0.01	134.82	0.01	248.82	0.00	289.00	0.00
29	130.44	0.01	134.82	0.01	248.82	0.00	289.00	0.00
30	130.45	0.01	134.63	0.01	248.82	0.00	289.03	0.00
31	130.45	0.01	134.63	0.01	248.82	0.00	289.03	0.00
32	130.46	0.01	134.49	0.01	248.82	0.00	289.05	0.00
32/Σdi/Vsi	**118.8697041**		**139.4591497**		**195.2126905**		**234.4927537**	
Soil Type	**SE**		**SE**		**SD**		**SD**	

Depth	SASW-5	di/Vsi	SASW-6	di/Vsi	SASW-7	di/Vsi	SASW-8	di/Vsi
1	66.004	0.02	102	0.01	140.53	0.01	98.328	0.01
2	66.004	0.02	102	0.01	140.53	0.01	98.328	0.01
3	66.004	0.02	102	0.01	140.53	0.01	98.328	0.01
4	98.602	0.01	257.65	0.00	133.22	0.01	155.61	0.01
5	98.602	0.01	257.65	0.00	133.22	0.01	155.61	0.01
6	106.21	0.01	315.78	0.00	134.07	0.01	264.61	0.00
7	106.21	0.01	315.78	0.00	134.07	0.01	264.61	0.00
8	106.03	0.01	403.9	0.00	136.69	0.01	323.48	0.00
9	106.03	0.01	403.9	0.00	136.69	0.01	323.48	0.00
10	104.39	0.01	478.03	0.00	138.13	0.01	346.98	0.00
11	104.39	0.01	478.03	0.00	138.13	0.01	346.98	0.00
12	103.05	0.01	520.53	0.00	138.46	0.01	355.2	0.00
13	103.05	0.01	520.53	0.00	138.46	0.01	355.2	0.00
14	102.21	0.01	542.88	0.00	138.18	0.01	357.66	0.00
15	102.21	0.01	542.88	0.00	138.18	0.01	357.66	0.00
16	101.75	0.01	554.33	0.00	137.71	0.01	358.36	0.00
17	101.75	0.01	554.33	0.00	137.71	0.01	358.36	0.00
18	101.52	0.01	564.24	0.00	137.25	0.01	358.55	0.00
19	101.52	0.01	564.24	0.00	137.25	0.01	358.55	0.00
20	101.41	0.01	571.81	0.00	136.86	0.01	358.59	0.00
21	101.41	0.01	571.81	0.00	136.86	0.01	358.59	0.00
22	101.36	0.01	578.00	0.00	136.57	0.01	358.60	0.00
23	101.36	0.01	578.00	0.00	136.57	0.01	358.60	0.00
24	101.33	0.01	583.27	0.00	136.36	0.01	358.61	0.00
25	101.33	0.01	583.27	0.00	136.36	0.01	358.61	0.00
26	101.32	0.01	587.47	0.00	136.21	0.01	358.61	0.00
27	101.32	0.01	587.47	0.00	136.21	0.01	358.61	0.00
28	101.31	0.01	590.80	0.00	136.10	0.01	358.61	0.00
29	101.31	0.01	590.80	0.00	136.10	0.01	358.61	0.00
30	101.31	0.01	593.4	0.00	136.03	0.01	358.61	0.00
31	101.31	0.01	593.4	0.00	136.03	0.01	358.61	0.00
32	101.31	0.01	595.42	0.00	135.98	0.01	358.61	0.00
32/Σdi/Vsi	**97.20427258**		**357.3480969**		**136.8910489**		**263.3724613**	
Soil Type	**SE**		**SD**		**SE**		**SD**	

Depth	SASW-9	di/Vsi	SASW-10	di/Vsi	SASW-11	di/Vsi	SASW-12	di/Vsi
1	115.05	0.01	107.38	0.01	105.73	0.01	118.55	0.01
2	115.05	0.01	107.38	0.01	105.73	0.01	118.55	0.01
3	115.05	0.01	107.38	0.01	105.73	0.01	118.55	0.01
4	102.99	0.01	101.49	0.01	110.86	0.01	113.23	0.01
5	102.99	0.01	101.49	0.01	110.86	0.01	113.23	0.01
6	145.33	0.01	115.63	0.01	111.38	0.01	116.27	0.01
7	145.33	0.01	115.63	0.01	111.38	0.01	116.27	0.01
8	170.51	0.01	128.24	0.01	109.39	0.01	135.16	0.01
9	170.51	0.01	128.24	0.01	109.39	0.01	135.16	0.01
10	180.85	0.01	136.37	0.01	106.94	0.01	130.62	0.01
11	180.85	0.01	136.37	0.01	106.94	0.01	130.62	0.01
12	183.65	0.01	141.21	0.01	104.78	0.01	79.133	0.01
13	183.65	0.01	141.21	0.01	104.78	0.01	79.133	0.01
14	183.41	0.01	143.94	0.01	103.06	0.01	95.828	0.01
15	183.41	0.01	143.94	0.01	103.06	0.01	95.828	0.01
16	182.07	0.01	145.44	0.01	101.77	0.01	86.802	0.01
17	182.07	0.01	145.44	0.01	101.77	0.01	86.802	0.01
18	180.69	0.01	146.24	0.01	100.8	0.01	117.13	0.01
19	180.69	0.01	146.24	0.01	100.8	0.01	117.13	0.01
20	179.61	0.01	146.66	0.01	100.09	0.01	180.58	0.01
21	179.61	0.01	146.66	0.01	100.09	0.01	180.58	0.01
22	178.79	0.01	146.87	0.01	99.55	0.01	263.23	0.00
23	178.79	0.01	146.87	0.01	99.55	0.01	263.23	0.00
24	178.25	0.01	146.98	0.01	99.16	0.01	339.66	0.00
25	178.25	0.01	146.98	0.01	99.16	0.01	339.66	0.00
26	177.92	0.01	147.04	0.01	98.87	0.01	360.29	0.00
27	177.92	0.01	147.04	0.01	98.87	0.01	360.29	0.00
28	177.70	0.01	147.07	0.01	98.65	0.01	254.41	0.00
29	177.70	0.01	147.07	0.01	98.65	0.01	254.41	0.00
30	177.57	0.01	147.08	0.01	98.493	0.01	133.08	0.01
31	177.57	0.01	147.08	0.01	98.493	0.01	133.08	0.01
32	177.49	0.01	147.09	0.01	98.371	0.01	26.409	0.04
32/Σdi/Vsi	**160.9427986**		**133.8086869**		**103.0406469**		**119.6672357**	
Soil Type	**SE**		**SE**		**SE**		**SE**	

Depth	SASW-13	di/Vsi	SDH-14	di/Vsi	SASW-15	di/Vsi	SASW-16	di/Vsi
1	84.461	0.01	94.549	0.01	87.55	0.01	101.78	0.01
2	84.461	0.01	94.549	0.01	87.55	0.01	101.78	0.01
3	84.461	0.01	94.549	0.01	87.55	0.01	101.78	0.01
4	84.269	0.01	98.954	0.01	137.06	0.01	98.647	0.01
5	84.269	0.01	98.954	0.01	137.06	0.01	98.647	0.01
6	84.099	0.01	103.19	0.01	157.33	0.01	96.597	0.01
7	84.099	0.01	103.19	0.01	157.33	0.01	96.597	0.01
8	84.005	0.01	105.07	0.01	166.9	0.01	95.513	0.01
9	84.005	0.01	105.07	0.01	166.9	0.01	95.513	0.01
10	83.962	0.01	105.5	0.01	169.92	0.01	94.954	0.01
11	83.962	0.01	105.5	0.01	169.92	0.01	94.954	0.01
12	83.943	0.01	105.38	0.01	169.6	0.01	94.663	0.01
13	83.943	0.01	105.38	0.01	169.6	0.01	94.663	0.01
14	83.935	0.01	105.14	0.01	168.13	0.01	94.514	0.01
15	83.935	0.01	105.14	0.01	168.13	0.01	94.514	0.01
16	83.932	0.01	104.94	0.01	166.53	0.01	94.436	0.01
17	83.932	0.01	104.94	0.01	166.53	0.01	94.436	0.01
18	83.93	0.01	104.79	0.01	165.19	0.01	94.396	0.01
19	83.93	0.01	104.79	0.01	165.19	0.01	94.396	0.01
20	83.93	0.01	104.7	0.01	164.21	0.01	94.375	0.01
21	83.93	0.01	104.7	0.01	164.21	0.01	94.375	0.01
22	83.93	0.01	104.64	0.01	163.52	0.01	94.36	0.01
23	83.93	0.01	104.64	0.01	163.52	0.01	94.36	0.01
24	83.93	0.01	104.61	0.01	163.06	0.01	94.36	0.01
25	83.93	0.01	104.61	0.01	163.06	0.01	94.36	0.01
26	83.93	0.01	104.59	0.01	162.77	0.01	94.36	0.01
27	83.93	0.01	104.59	0.01	162.77	0.01	94.36	0.01
28	83.93	0.01	104.58	0.01	162.58	0.01	94.35	0.01
29	83.93	0.01	104.58	0.01	162.58	0.01	94.35	0.01
30	83.929	0.01	104.58	0.01	162.47	0.01	94.353	0.01
31	83.929	0.01	104.58	0.01	162.47	0.01	94.353	0.01
32	83.929	0.01	104.57	0.01	162.4	0.01	94.352	0.01
32/Σdi/Vsi	**84.01879431**		**103.3164762**		**150.3325665**		**95.55600411**	
Soil Type	**SE**		**SE**		**SE**		**SE**	

Depth	SASW-17	di/Vsi	SASW-18	di/Vsi	SASW-19	di/Vsi	SASW-20	di/Vsi
1	73.898	0.01	110.56	0.01	134.47	0.01	69.205	0.01
2	73.898	0.01	110.56	0.01	134.47	0.01	69.205	0.01
3	73.898	0.01	110.56	0.01	134.47	0.01	69.205	0.01
4	72.324	0.01	145.04	0.01	147.93	0.01	68.398	0.01
5	72.324	0.01	145.04	0.01	147.93	0.01	68.398	0.01
6	71.187	0.01	155.16	0.01	165.54	0.01	67.829	0.01
7	71.187	0.01	155.16	0.01	165.54	0.01	67.829	0.01
8	70.482	0.01	157.81	0.01	177.69	0.01	67.532	0.01
9	70.482	0.01	157.81	0.01	177.69	0.01	67.532	0.01
10	70.087	0.01	158.51	0.01	184.64	0.01	67.392	0.01
11	70.087	0.01	158.51	0.01	184.64	0.01	67.392	0.01
12	69.878	0.01	158.71	0.01	188.34	0.01	67.329	0.01
13	69.878	0.01	158.71	0.01	188.34	0.01	67.329	0.01
14	69.771	0.01	158.77	0.01	190.24	0.01	67.301	0.01
15	69.771	0.01	158.77	0.01	190.24	0.01	67.301	0.01
16	69.717	0.01	158.79	0.01	191.21	0.01	67.288	0.01
17	69.717	0.01	158.79	0.01	191.21	0.01	67.288	0.01
18	69.689	0.01	158.79	0.01	191.69	0.01	67.283	0.01
19	69.689	0.01	158.79	0.01	191.69	0.01	67.283	0.01
20	69.676	0.01	158.79	0.01	191.93	0.01	67.281	0.01
21	69.676	0.01	158.79	0.01	191.93	0.01	67.281	0.01
22	69.67	0.01	158.79	0.01	192.04	0.01	67.28	0.01
23	69.67	0.01	158.79	0.01	192.04	0.01	67.28	0.01
24	69.67	0.01	158.80	0.01	192.10	0.01	67.28	0.01
25	69.67	0.01	158.80	0.01	192.10	0.01	67.28	0.01
26	69.66	0.01	158.80	0.01	192.13	0.01	67.28	0.01
27	69.66	0.01	158.80	0.01	192.13	0.01	67.28	0.01
28	69.66	0.01	158.80	0.01	192.15	0.01	67.28	0.01
29	69.66	0.01	158.80	0.01	192.15	0.01	67.28	0.01
30	69.663	0.01	158.8	0.01	192.15	0.01	67.279	0.01
31	69.663	0.01	158.8	0.01	192.15	0.01	67.279	0.01
32	69.662	0.01	158.8	0.01	192.16	0.01	67.279	0.01
32/Σdi/Vsi	**70.40184452**		**151.4009673**		**178.0735051**		**67.58706973**	
Soil Type	**SE**		**SE**		**SE**		**SE**	

Depth	SASW-21	di/Vsi	SASW-22	di/Vsi	SASW-23	di/Vsi	SASW-24	di/Vsi
1	100.68	0.01	122.22	0.01	107.06	0.01	112.25	0.01
2	100.68	0.01	122.22	0.01	107.06	0.01	112.25	0.01
3	100.68	0.01	122.22	0.01	107.06	0.01	112.25	0.01
4	99.056	0.01	116.63	0.01	122.91	0.01	111.75	0.01
5	99.056	0.01	116.63	0.01	122.91	0.01	111.75	0.01
6	97.825	0.01	114.08	0.01	113.33	0.01	111.13	0.01
7	97.825	0.01	114.08	0.01	113.33	0.01	111.13	0.01
8	97.047	0.01	113.71	0.01	121.58	0.01	110.63	0.01
9	97.047	0.01	113.71	0.01	121.58	0.01	110.63	0.01
10	96.57	0.01	114.01	0.01	134.49	0.01	110.29	0.01
11	96.57	0.01	114.01	0.01	134.49	0.01	110.29	0.01
12	96.283	0.01	114.4	0.01	145.56	0.01	110.06	0.01
13	96.283	0.01	114.4	0.01	145.56	0.01	110.06	0.01
14	96.112	0.01	114.72	0.01	153.43	0.01	109.91	0.01
15	96.112	0.01	114.72	0.01	153.43	0.01	109.91	0.01
16	96.012	0.01	114.93	0.01	158.5	0.01	109.82	0.01
17	96.012	0.01	114.93	0.01	158.5	0.01	109.82	0.01
18	95.953	0.01	115.06	0.01	161.57	0.01	109.77	0.01
19	95.953	0.01	115.06	0.01	161.57	0.01	109.77	0.01
20	95.919	0.01	115.14	0.01	163.34	0.01	109.73	0.01
21	95.919	0.01	115.14	0.01	163.34	0.01	109.73	0.01
22	95.90	0.01	115.19	0.01	164.36	0.01	109.71	0.01
23	95.90	0.01	115.19	0.01	164.36	0.01	109.71	0.01
24	95.89	0.01	115.21	0.01	164.91	0.01	109.70	0.01
25	95.89	0.01	115.21	0.01	164.91	0.01	109.70	0.01
26	95.88	0.01	115.23	0.01	165.20	0.01	109.69	0.01
27	95.88	0.01	115.23	0.01	165.20	0.01	109.69	0.01
28	95.88	0.01	115.24	0.01	165.35	0.01	109.69	0.01
29	95.88	0.01	115.24	0.01	165.35	0.01	109.69	0.01
30	95.875	0.01	115.24	0.01	165.42	0.01	109.69	0.01
31	95.875	0.01	115.24	0.01	165.42	0.01	109.69	0.01
32	95.873	0.01	115.24	0.01	165.46	0.01	109.69	0.01
32/Σdi/Vsi	**96.79924602**		**115.5678098**		**142.913646**		**110.292834**	
Soil Type	**SE**		**SE**		**SE**		**SE**	

Depth	SASW-25	di/Vsi	SASW-26	di/Vsi	SASW-27	di/Vsi	SASW-28	di/Vsi
1	98.437	0.01	152.47	0.01	154.5	0.01	292.79	0.00
2	98.437	0.01	152.47	0.01	154.5	0.01	292.79	0.00
3	98.437	0.01	152.47	0.01	154.5	0.01	292.79	0.00
4	119.1	0.01	327.14	0.00	231.46	0.00	307.23	0.00
5	119.1	0.01	327.14	0.00	231.46	0.00	307.23	0.00
6	125.86	0.01	224.54	0.00	327.61	0.00	333.62	0.00
7	125.86	0.01	224.54	0.00	327.61	0.00	333.62	0.00
8	125.43	0.01	196.02	0.01	405.02	0.00	316.06	0.00
9	125.43	0.01	196.02	0.01	405.02	0.00	316.06	0.00
10	122.65	0.01	312.97	0.00	462.24	0.00	278.57	0.00
11	122.65	0.01	312.97	0.00	462.24	0.00	278.57	0.00
12	119.65	0.01	393.56	0.00	502.01	0.00	248.98	0.00
13	119.65	0.01	393.56	0.00	502.01	0.00	248.98	0.00
14	117.22	0.01	443.03	0.00	527.63	0.00	239.63	0.00
15	117.22	0.01	443.03	0.00	527.63	0.00	239.63	0.00
16	115.38	0.01	462.96	0.00	543.08	0.00	268.89	0.00
17	115.38	0.01	462.96	0.00	543.08	0.00	268.89	0.00
18	114.07	0.01	462.9	0.00	552.01	0.00	324.28	0.00
19	114.07	0.01	462.9	0.00	552.01	0.00	324.28	0.00
20	113.17	0.01	451.71	0.00	557.08	0.00	399.55	0.00
21	113.17	0.01	451.71	0.00	557.08	0.00	399.55	0.00
22	112.55	0.01	436.98	0.00	559.93	0.00	492.50	0.00
23	112.55	0.01	436.98	0.00	559.93	0.00	492.50	0.00
24	112.12	0.01	425.19	0.00	561.53	0.00	590.20	0.00
25	112.12	0.01	425.19	0.00	561.53	0.00	590.20	0.00
26	111.83	0.01	416.13	0.00	562.42	0.00	687.98	0.00
27	111.83	0.01	416.13	0.00	562.42	0.00	687.98	0.00
28	111.63	0.01	411.16	0.00	562.90	0.00	779.70	0.00
29	111.63	0.01	411.16	0.00	562.90	0.00	779.70	0.00
30	111.5	0.01	410.02	0.00	563.16	0.00	867.13	0.00
31	111.5	0.01	410.02	0.00	563.16	0.00	867.13	0.00
32	111.41	0.01	411.49	0.00	563.31	0.00	946.45	0.00
32/Σdi/Vsi	**114.2653306**		**319.3177203**		**391.8320448**		**365.5755794**	
Soil Type	**SE**		**SD**		**SC**		**SC**	

Depth	SASW-29	di/Vsi	SASW-30	di/Vsi	SASW-1-P	di/Vsi	SASW-2-P	di/Vsi	SASW-3-P	di/Vsi
1	125.34	0.01	122.27	0.01	89.205	0.01	111.31	0.01	91.053	0.01
2	125.34	0.01	122.27	0.01	89.205	0.01	111.31	0.01	91.053	0.01
3	125.34	0.01	122.27	0.01	89.205	0.01	111.31	0.01	91.053	0.01
4	213.65	0.00	100.33	0.01	108.99	0.01	278.41	0.00	206.31	0.00
5	213.65	0.00	100.33	0.01	108.99	0.01	278.41	0.00	206.31	0.00
6	269.87	0.00	116.2	0.01	119.73	0.01	162.25	0.01	248.97	0.00
7	269.87	0.00	116.2	0.01	119.73	0.01	162.25	0.01	248.97	0.00
8	305.84	0.00	137.83	0.01	121.71	0.01	256.35	0.00	245.8	0.00
9	305.84	0.00	137.83	0.01	121.71	0.01	256.35	0.00	245.8	0.00
10	336.67	0.00	153.15	0.01	119.8	0.01	290.83	0.00	233.22	0.00
11	336.67	0.00	153.15	0.01	119.8	0.01	290.83	0.00	233.22	0.00
12	363.89	0.00	162.72	0.01	116.96	0.01	299.17	0.00	223.79	0.00
13	363.89	0.00	162.72	0.01	116.96	0.01	299.17	0.00	223.79	0.00
14	387.2	0.00	168.24	0.01	114.46	0.01	305.62	0.00	218.36	0.00
15	387.2	0.00	168.24	0.01	114.46	0.01	305.62	0.00	218.36	0.00
16	406.59	0.00	171.3	0.01	112.54	0.01	314.78	0.00	215.5	0.00
17	406.59	0.00	171.3	0.01	112.54	0.01	314.78	0.00	215.5	0.00
18	422.32	0.00	173	0.01	111.21	0.01	326.1	0.00	214.13	0.00
19	422.32	0.00	173	0.01	111.21	0.01	326.1	0.00	214.13	0.00
20	434.98	0.00	173.9	0.01	110.31	0.01	335.43	0.00	213.52	0.00
21	434.98	0.00	173.9	0.01	110.31	0.01	335.43	0.00	213.52	0.00
22	444.89	0.00	174.38	0.01	109.73	0.01	343.07	0.00	213.24	0.00
23	444.89	0.00	174.38	0.01	109.73	0.01	343.07	0.00	213.24	0.00
24	452.63	0.00	174.63	0.01	109.34	0.01	347.96	0.00	213.12	0.00
25	452.63	0.00	174.63	0.01	109.34	0.01	347.96	0.00	213.12	0.00
26	458.60	0.00	174.75	0.01	109.10	0.01	350.17	0.00	213.07	0.00
27	458.60	0.00	174.75	0.01	109.10	0.01	350.17	0.00	213.07	0.00
28	463.29	0.00	174.82	0.01	108.94	0.01	350.13	0.00	213.05	0.00
29	463.29	0.00	174.82	0.01	108.94	0.01	350.13	0.00	213.05	0.00
30	466.88	0.00	174.85	0.01	108.84	0.01	348.36	0.00	213.04	0.00
31	466.88	0.00	174.85	0.01	108.84	0.01	348.36	0.00	213.04	0.00
32	469.64	0.00	174.86	0.01	108.77	0.01	346.22	0.00	213.03	0.00
32/Σdi/Vsi	**313.3993008**		**151.5640911**		**109.9470035**		**257.1315204**		**193.8327175**	
Soil Type	**SD**		**SE**		**SE**		**SD**		**SD**	

Further, map which shows the site classification on each location based on the recent MASW's survey and previous geotechnical investigation are shown in Figure 2.15 and Figure 2.16. Figure 2.17 and Figure 2.18 show combined site classification map for city of Padang and Pariaman.

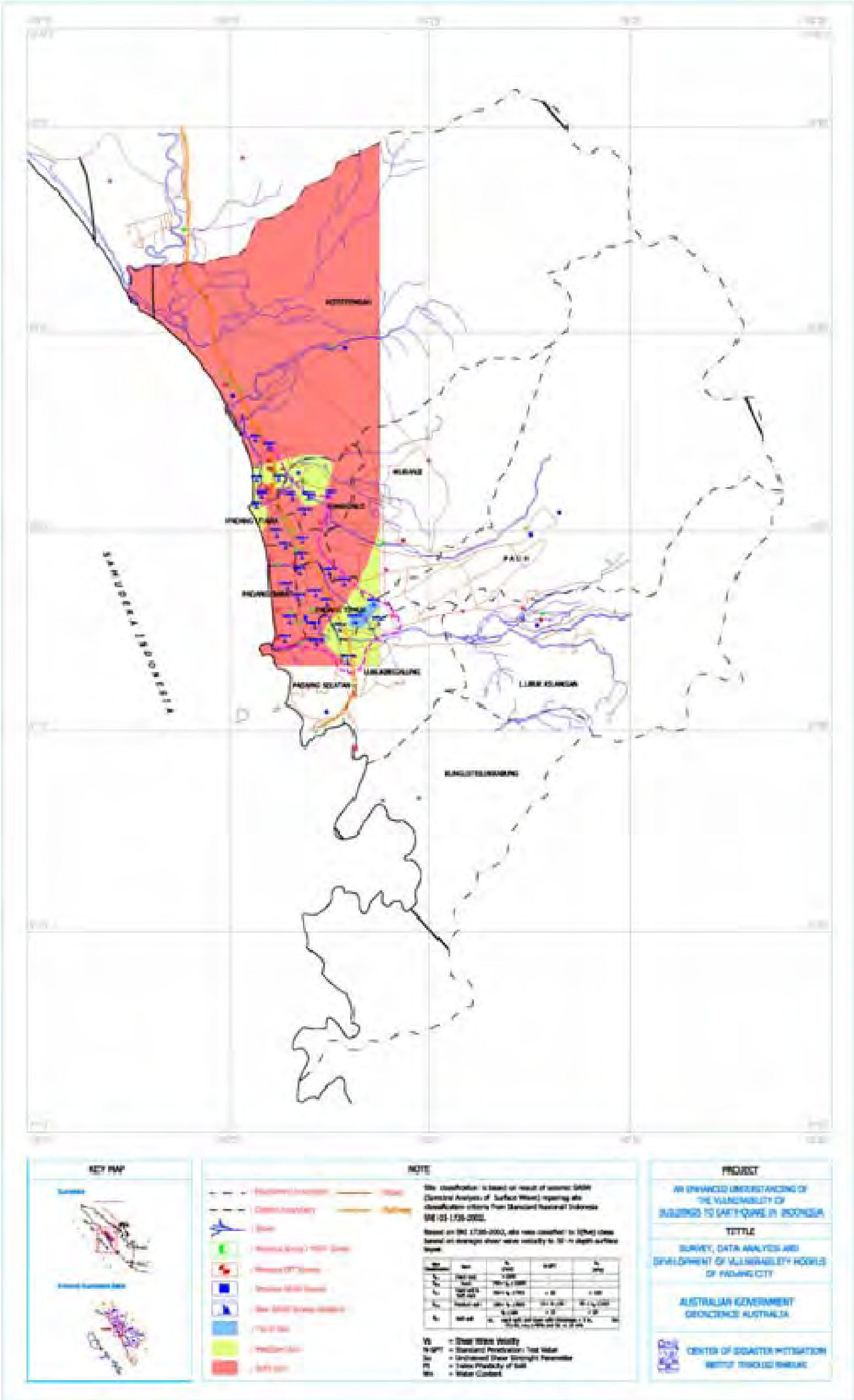

Figure 2.15. Site classification map for city of Padang based on the recent MASW's average shear wave velocity

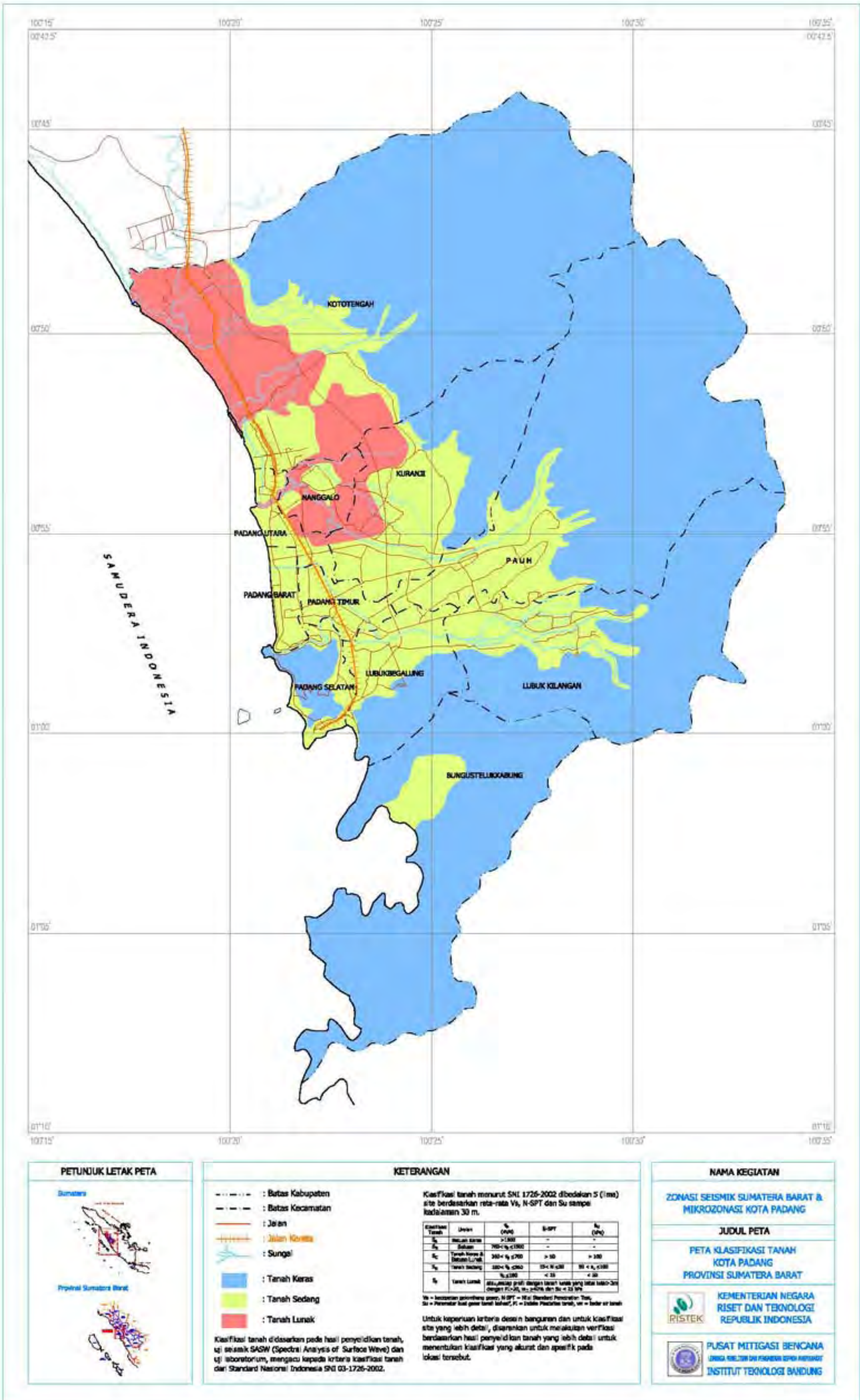

Figure 2.16. Site classification map for city of Padang based on the previous geotechnical investigation

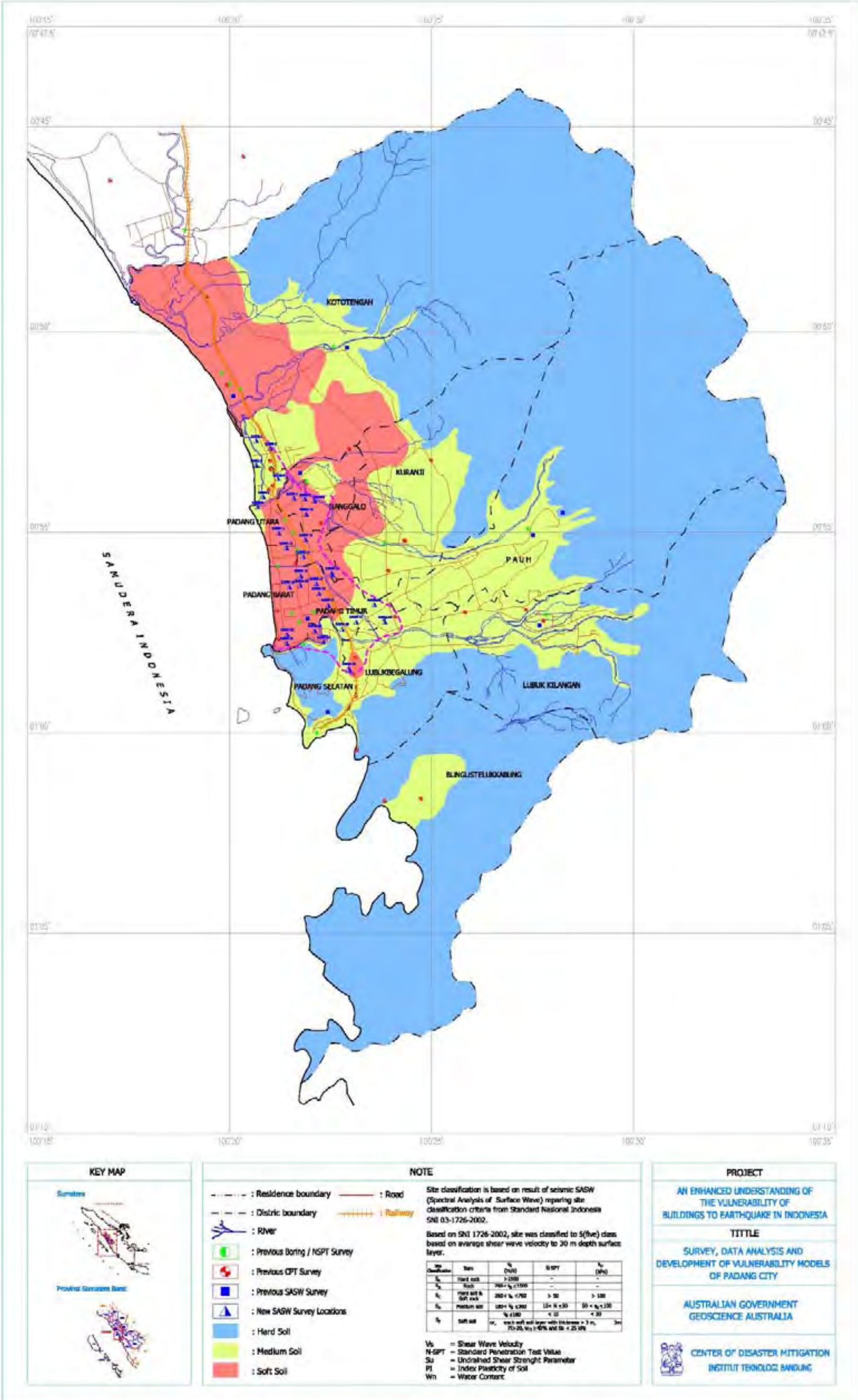

Figure 2.17. Combined Site classification map for city of Padang based on the recent MASW survey and previous geotechnical investigation

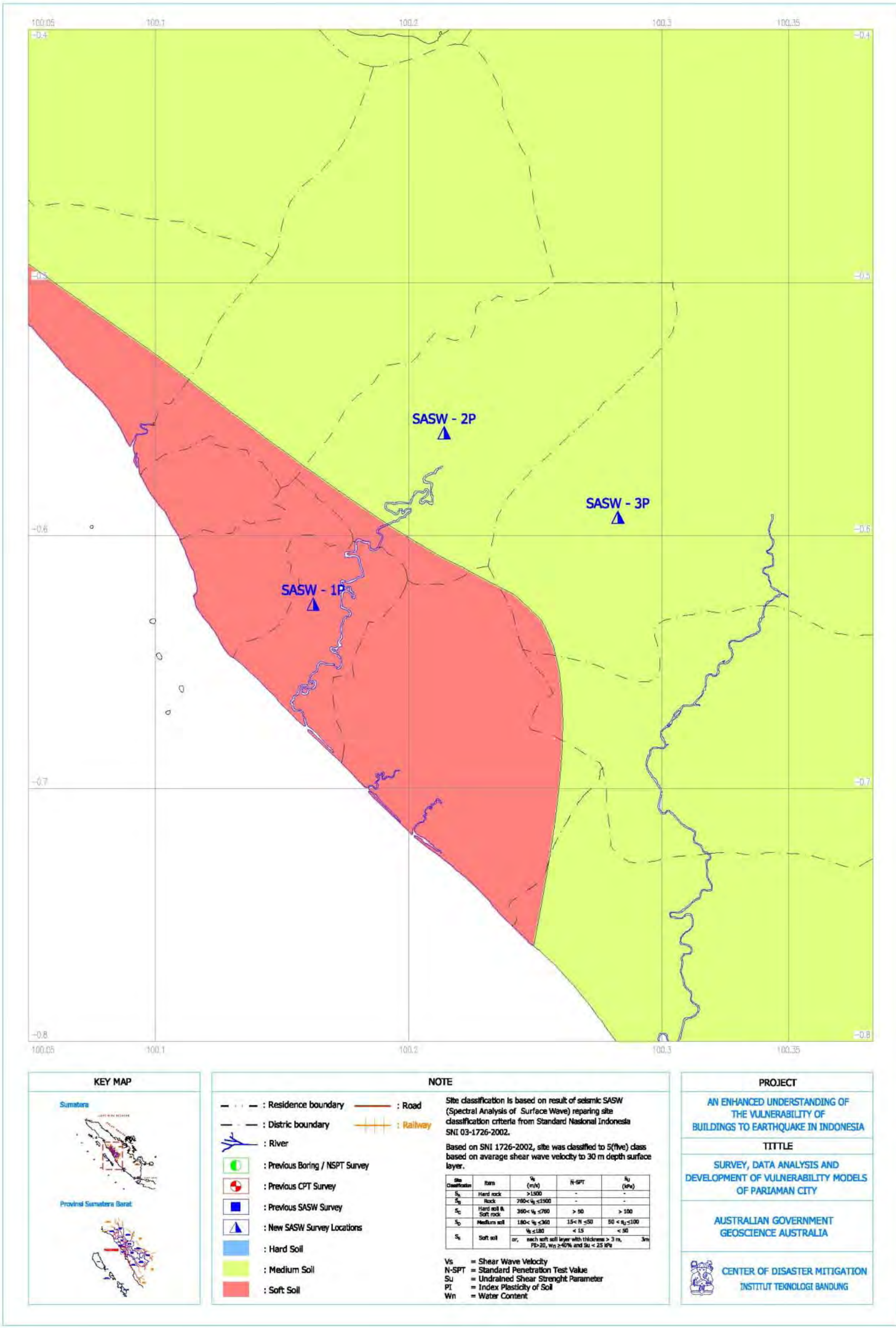

Figure 2.18. Combined Site classification map for city of Pariaman based on the recent MASW survey and previous geotechnical investigation

CHAPTER 3

ANALYSIS OF 30 SEPTEMBER 2009 PADANG EARTHQUAKE EVENT

INTRODUCTION

Prior to peak ground acceleration (PGA) estimate at ground surface, earthquake event analysis to estimate spatial distribution of PGA at reference baserock of West Sumatra Province (including Padang and Pariaman cities) was conducted. The analysis was conducted by performing attenuation of the 30 September 2009 earthquake. The analysis has been carried out by identifying the earthquake source characteristics.

The attenuation analysis was conducted to recommend level of peak ground acceleration (PGA) at reference base-rock using 3-D earthquake sources model with EZ-FRISK 7.32 Build 001 software. Attenuation functions by Young's Intraslab (1997) has been adopted to represent the subduction intra-slab earthquake source.

TECTONIC SETTING AND EARTHQUAKE HISTORY

The city of Padang and Pariaman are located in Province region of West Sumatra, which is part of Eurasian plate that moves slowly relative towards south-east with a slip-rate around 0.4cm/year. Relative movement in west part of this Province, where there is an interaction between Eurasin Plate and Hindia Oceanic Plate with relative northwards movement of approximately 7 cm/year (Minster and Jordan, 1978 in Yeats et al., 1997). This interaction creates subduction angle (oblique) and it had been estimated since lime period and still take place up to now. Besides subduction, second interaction of this plate also creates principal structures of Sumatra Fault, known as Sumatra Fault Zone (SFZ) and Mentawai Fault Zone. West region of Sumatra island is one of area which is located in an active plate boundary (active plate margin) in the world, and it could be expressed with height frequency of earthquakes in this region. Earthquakes spread in this region are not only come from the activity of Subduction Zone, but also from active fault system along side Sumatra Island.

With this tectonic setting, earthquake sources within West Sumatra region originate from ocean (subduction) and onland (SFZ segments). SFZ that passing the region of West Sumatra consist of 4 (four) segments, starting from south to north. These segments are Suliti (95 km in length) with slip rate of 11 mm/year, Sumani segment (60 km in length) with slip rate of also 11 mm/year, Sianok segment (95 km in length) with slip rate 11 mm/years, and Sumpur segment (35 km in length) with slip rate of 23 mm/year (Sieh and Natawidjaya, 2000). Except Sumpur segment, three other segments have been noted that generated some earthquake events. Many earthquakes had occurred along interface of the subduction zone and shallow crustal fault system of West Sumatra segment. Among other large earthquakes at least there were three destructive earthquakes have been noted with magnitude higher than 7 in the year 1926 (Mw 7.8, Located in Padang Panjang), 1943 (Mw 7.7, Located in Singkarak) and 2007 (Mw 7.9, located in South Coastal Area). Previous large earthquakes noted were those occurred in 1797 (estimated M=8.2) and 1833 (estimated M=8.7), both followed by tsunamis.

The West Sumatra Earthquake (Mw=7.6, depth 80km) has occurred on September 30, 2009 at 10:16:09 (UTC) or 17:16:09 (local time), epicenter 0.789°S, 99.961°E, about 45 km North-West of Padang City (Source: BMKG and USGS). The earthquake has caused more than 1100 casualties and more than 1000 injured. Total number of more than 100,000 unit houses need to be repaired and reconstructed. Many school buildings, hospitals, government buildings, and residential housings have experienced severe damages and some were collapse. Tomographical cross section of this subduction segment (Widiantoro, 2009) with distribution of previous instrumental earthquake data and hypocenter of the West Sumatra earthquake is shown in Figure 3.1.

SEISMIC SOURCE MODELING

The West Sumatra earthquake, September 30, 2009 is identified of type intra-slab based on GPS monitoring and distribution of after shocks (Natawidjaja, 2009; Meilano, 2009). Tomographical cross section of this subduction segment (Widiantoro, 2009) with distribution of previous instrumental earthquake data and hypocenter of the West Sumatra earthquake are shown in Figure 3.1.

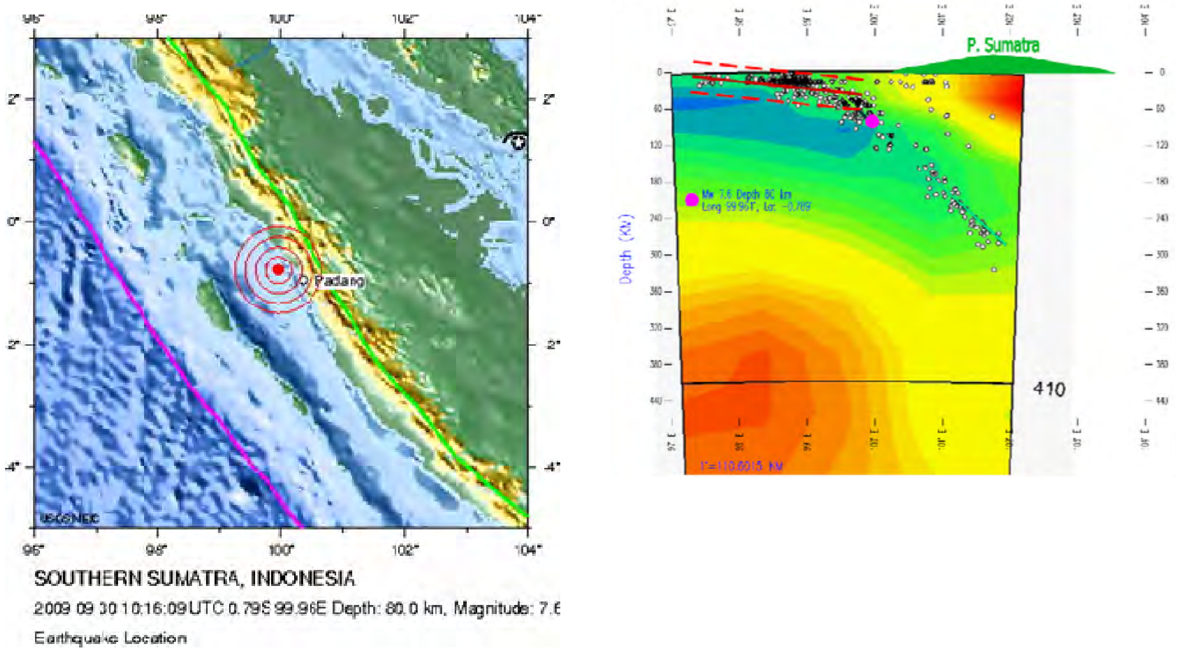

Figure 3.1. Epicenter and tomographical cross section of September 30, 2009 West Sumatra earthquake

EARTHQUAKE EVENT ANALYSIS

30 September 2009 earthquake event analysis was conducted using 3-D earthquake sources model with EZ-FRISK 7.32 Build 001 software. Result of spectral acceleration for site at at city of Padang from EZ-FRISK is shown in Figure 3.2. Attenuation function of Young's Intraslab has been adopted to represent the subduction intra-slab earthquake sources. To estimate spatial distribution of the ground shaking in terms of PGA at reference baserock, attenuation analysis has been conducted. Figure 3.3 shows attenuation curve of the analysis.

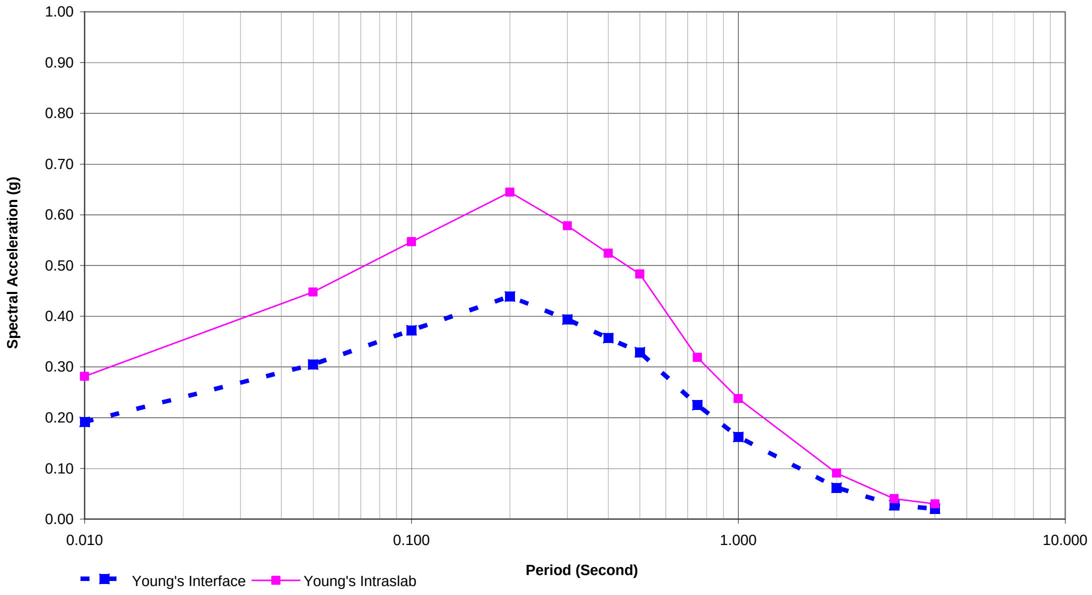

Figure 3.2. Deterministic baserock spectra result in Padang City developed using EZ-FRISK 7.32 Build 001

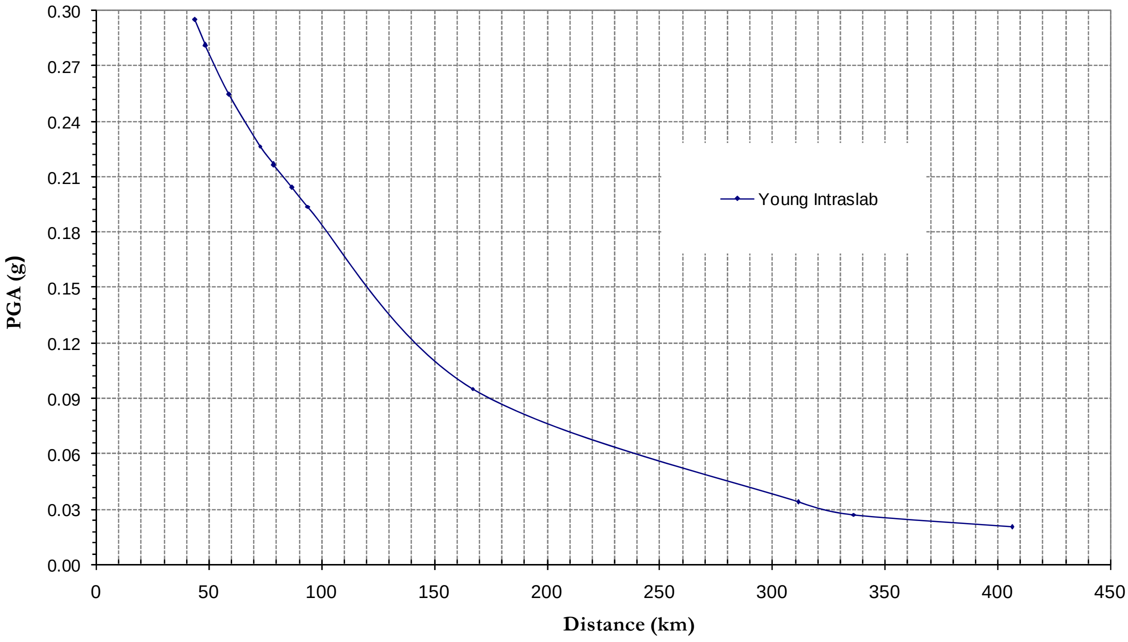

Figure 3.3. Attenuation curve of PGA (reference base-rock) of September 30, 2009 West Sumatra earthquake

Table 3.1 shows list of PGA (reference baserock) estimate at many cities in West and North Sumatra due to September 30, 2009 West Sumatra earthquake.

Tabel 3.1. List of PGA (reference base-rock) at many cities in West and North Sumatra due to September 30, 2009 West Sumatra earthquake

No.	Cities	Baserock PGA (g)
1	Medan	0.020
2	Padangsidempuan	0.096
3	Muarasigep	0.128
4	Muarasibeurut	0.105
5	Tuapejat	0.110
6	Sikakap	0.080
7	Airbangis	0.253
8	Labuhan	0.295
9	Pariaman	0.281
10	Padang	0.282
11	Painan	0.300
12	Kambang	0.237
13	Balaiselasa	0.202
14	Indrapura	0.159
15	Padangaro	0.161
16	Pulaupunjung	0.180
17	Solok	0.161
18	Muaro	0.204
19	Sawahlunto	0.216
20	Batusangkar	0.217
21	Padang Panjang	0.232
22	Bukittinggi	0.227
23	Lubukbasung	0.255
24	Payakumbuh	0.194
25	Kampus Unad Limau Manis	0.281
28	Sungaipenuh	0.116

Figure 3.4 shows spatial distribution of the estimated PBA. It is indicated that PBA at city of Padang is about 0.28g.

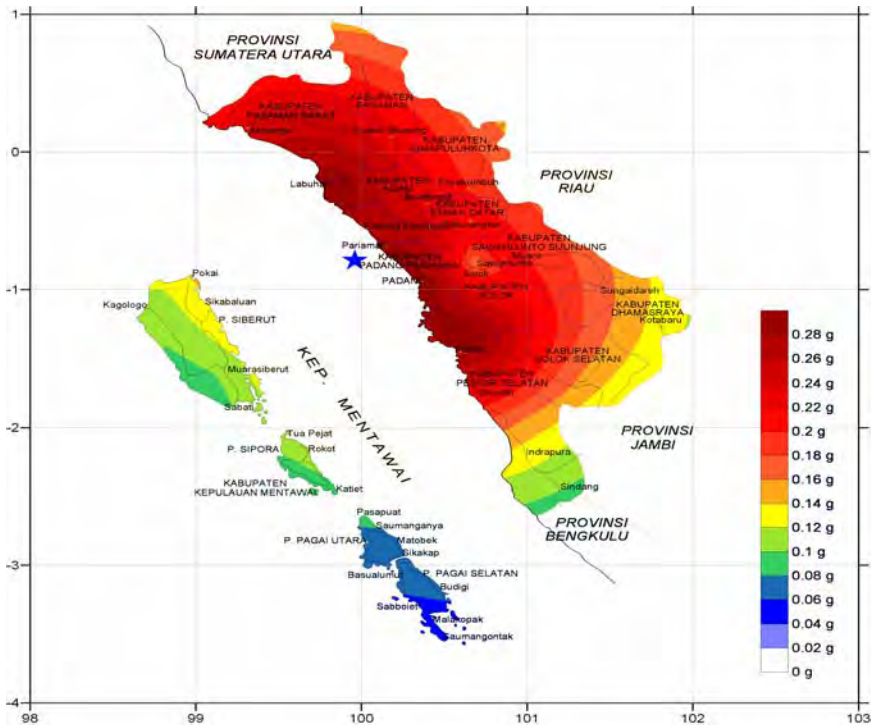

Figure 3.4 Estimated PGA (reference base-rock) spatial distribution using Young's Intraslab attenuation due to 30 September 2009 West Sumatra Earthquake

CHAPTER 4

SITE-RESPONSE ANALYSIS

INTRODUCTION

Spatial PGA at ground surface distribution (seismic microzonation mapping) of a city needs specific information on predicted earthquake ground motions at reference baserock and local ground condition in the form of shear wave velocity profile of each site to be analyzed. Site-response analysis (SRA) to estimate peak ground surface acceleration and response-spectra needs to be performed by considering predicted input motions and dynamic soil properties of the site. There is strong motion accelerometer installed in city of Padang by Indonesian Geophysical and Meteorological Agency (GMA). However, until this work was conducted, there is no strong-motion record data is obtained from GMA. Therefore, for site-response analysis in this study, simple method by scaling available strong motion records from other sites to spectral acceleration obtained from earthquake event analysis was conducted.

Strong motion records are commonly scaled to match target PGA or spectral values (at reference baserock) of the site of interest, by spectral-matching techniques. In this study, a spectral-matching technique proposed by Abrahamson that is adopted. The technique is built in the EZ-FRISK Computer Program Version 7.2 (Risk Engineering, Inc., 2004) is utilized. Then, time-domain wave propagation analyses from baserock to ground surface were conducted using NERA (nonlinear earthquake response analysis) computer program (Bardet and Tobita, 2001).

SEISMIC WAVE PROPAGATION ANALYSIS

Local site condition (site-class) covering the city of Padang is classified into 3 (three) classifications: Soft, Medium, and Hard. Each site-class is represented using a soil profile having a value of average shear wave velocity (Vs) in accordance with Indonesian Building Codes or International Building Codes (IBC2006). Seismic wave propagation analysis was conducted using NERA (nonlinear earthquake response analysis) computer program (Bardet and Tobita, 2001). This program applies time-domain approach of non-linear soil properties where its shear modulus decreases as a function of increasing strain, while damping increases as a function of increasing strain. The wave propagation analysis using NERA computer program indicated that the peak acceleration is not amplified significantly. In this case the peak acceleration of 0.38g at the base-rock is amplified to values that vary from 0.38 g to 0.42g at ground surface, depending upon the site class (for the hard soil the amplification factor become 1.0 and 1.1 for medium and soft soil). This relatively low amplification is considered due to soil non-linear characteristics under high peak acceleration. Variations of local ground conditions need to be identified through data collection and investigation for developing seismic microzonation map of the city.

Input Motion

In this analysis, four input motions are developed to identify the value of earthquake amplification on the ground sourface, and accomodate influence of near and far earthquake, amplitude, duration of earthquake, and the frequency contens. Input motion is then scaled appropriate with spectral accelerations estimated at the base. Strong motion records are scaled to match target spectral values of the site of interest using spectral-matching techniques. Several spectral matching and scaled input motions which are used for wave propagation analysis from the bese-rocks to the ground surface is shown in Figure 4.1 to Figure 4.6.

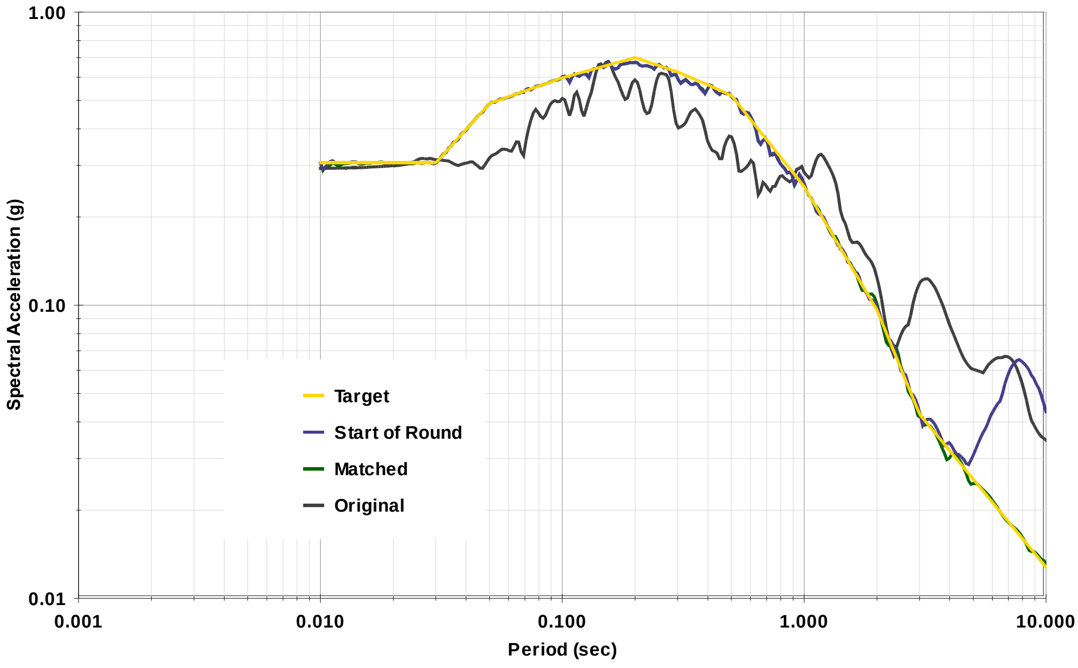

Figure 4.1. Spectral Matching, MASW23 (SE)

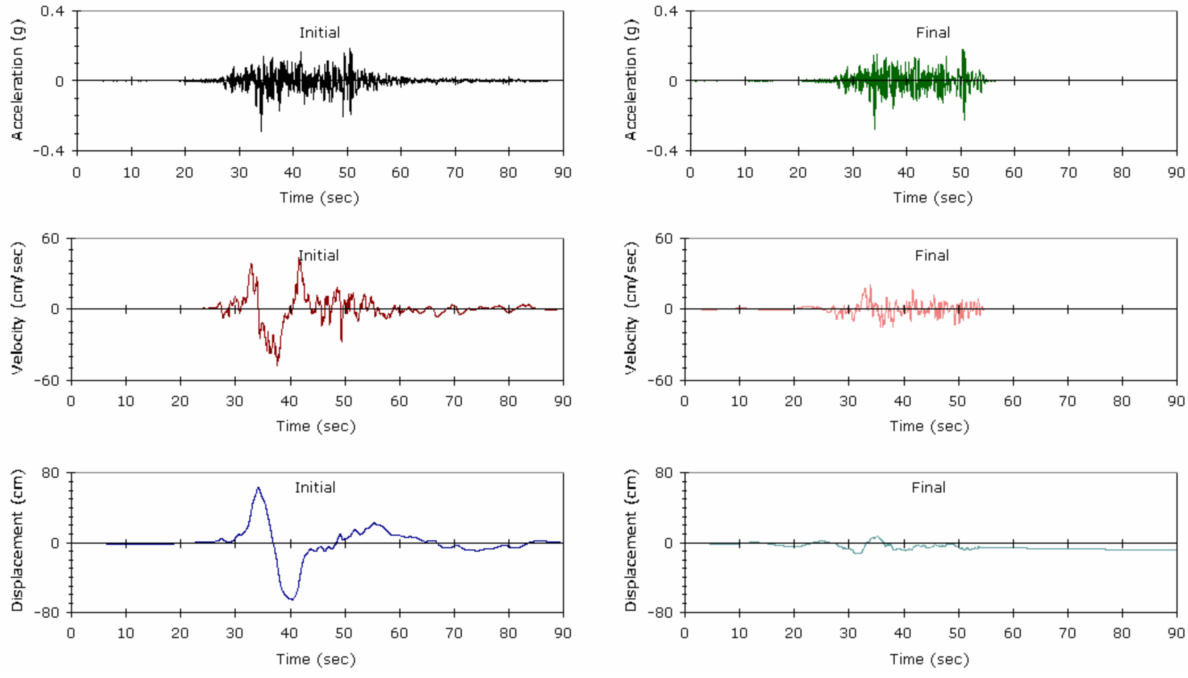

Figure 4.2. Scaled Input motion in corresponding to Spectral Matching, MASW23 (SE) (EZ-FRISK 7.32 Strong Motion Database)

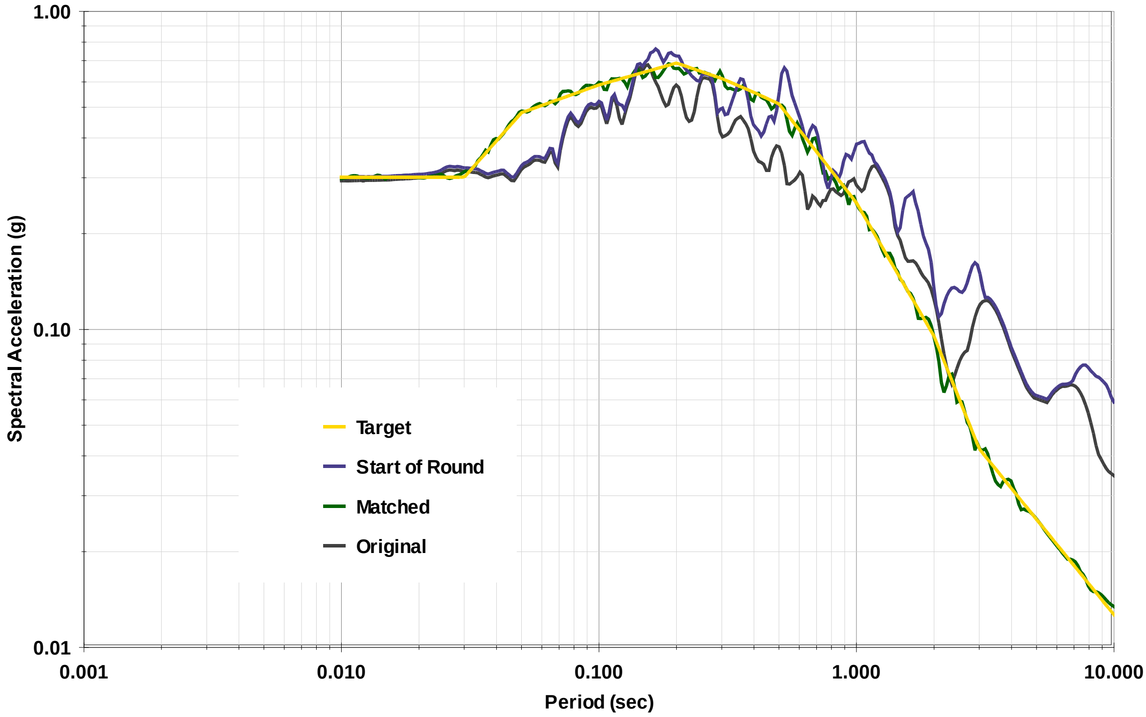

Figure 4.3. Spectral Matching, MASW26 (SD)

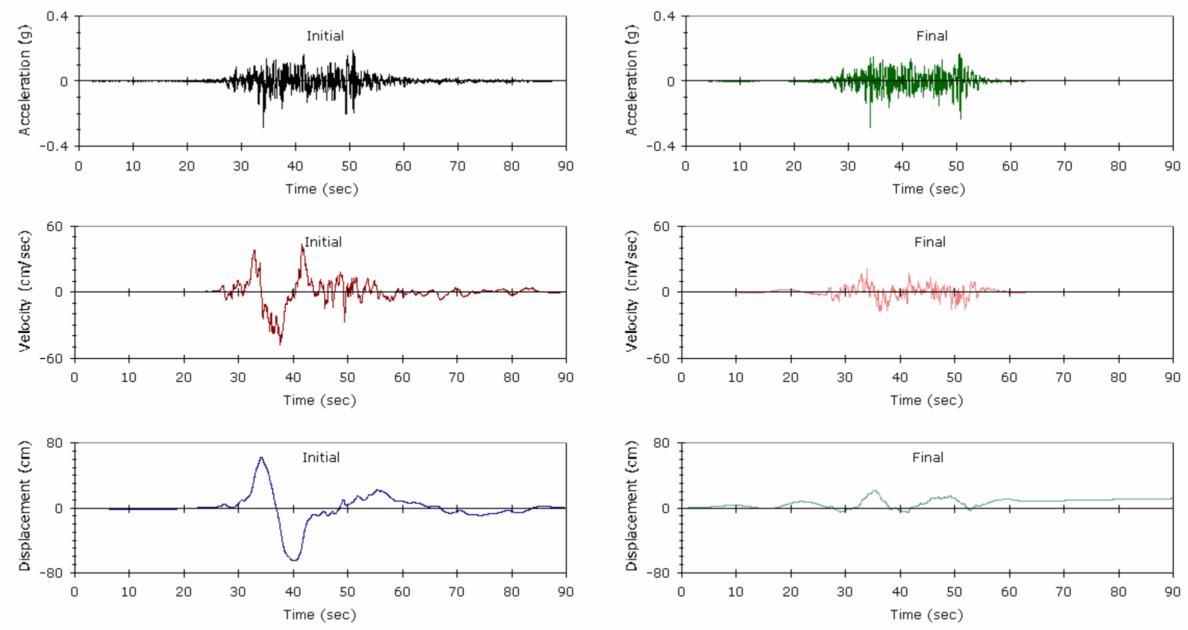

Figure 4.4. Scaled Input motion in corresponding to Spectral Matching, MASW26 (SD) (EZ-FRISK 7.32 Strong Motion Database)

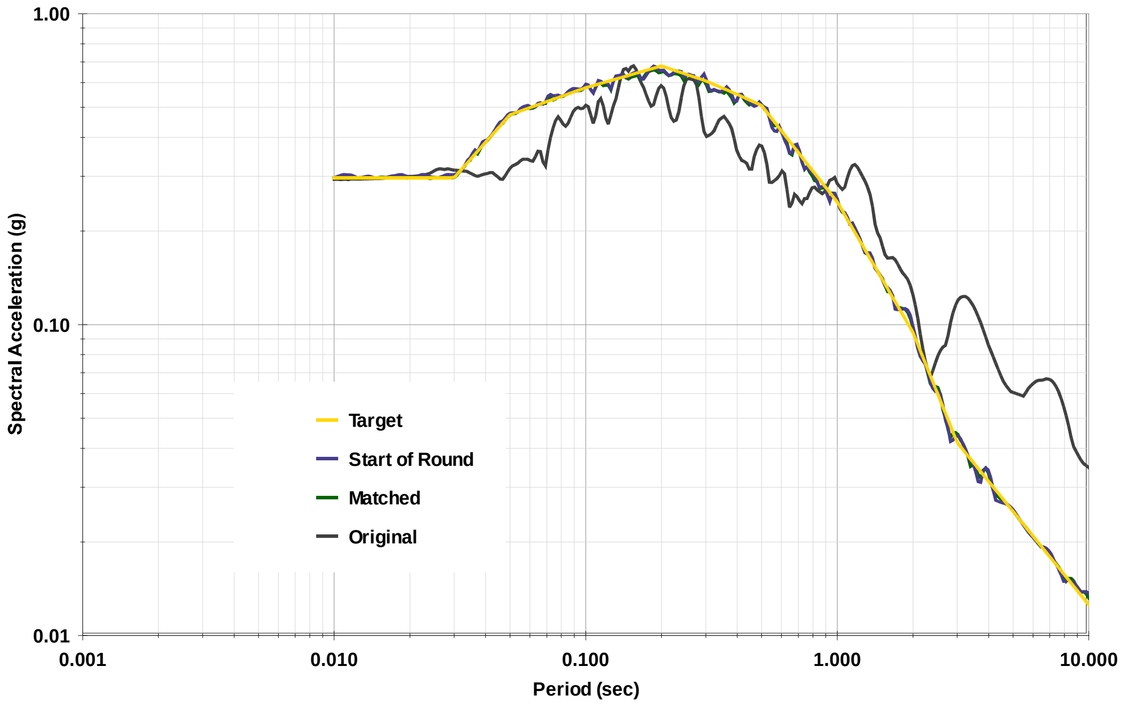

Figure 4.5. Spectral Matching, MASW28 (SC)

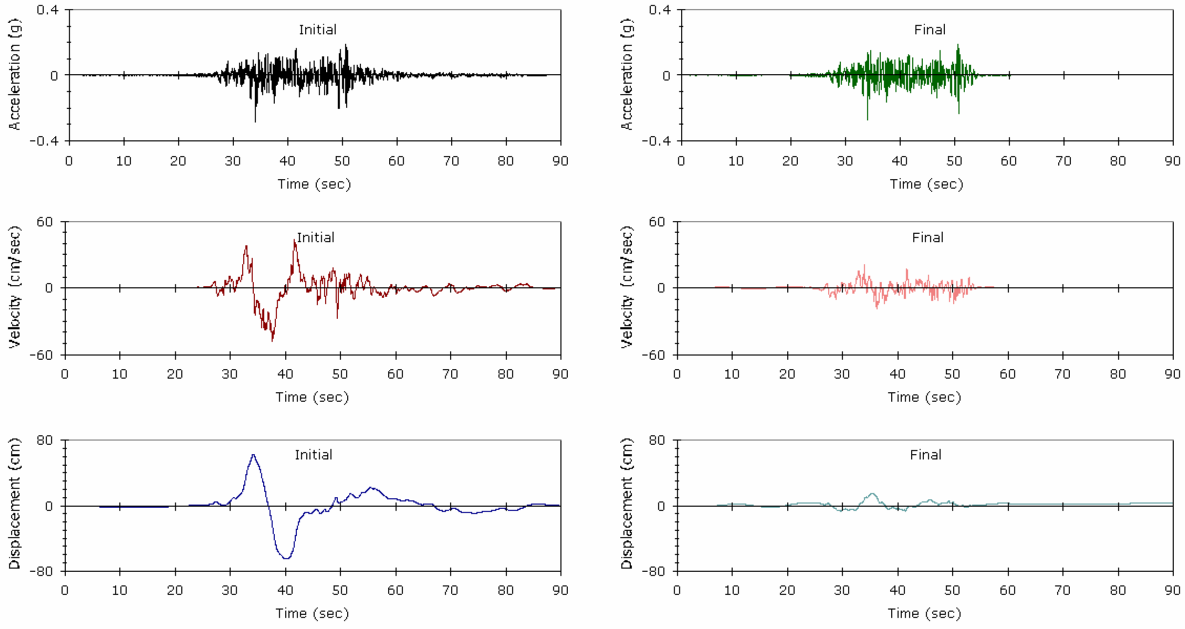

Figure 4.6. Scaled Input motion in corresponding to Spectral Matching, MASW28 (SC) (EZ-FRISK 7.32 Strong Motion Database)

Analysis Results

The value of maximum acceleration on the ground surface (Peak Ground Acceleration/PGA) is very affected by the value of earthquake acceleration in the baserock, the dynamic nature of ground (in these case Vs) and input motion which represents the duration and frequency contents. The variation of earthquake acceleration value on that ground layer during propagation from base rock to the ground surface is shown in Figure 4.7.

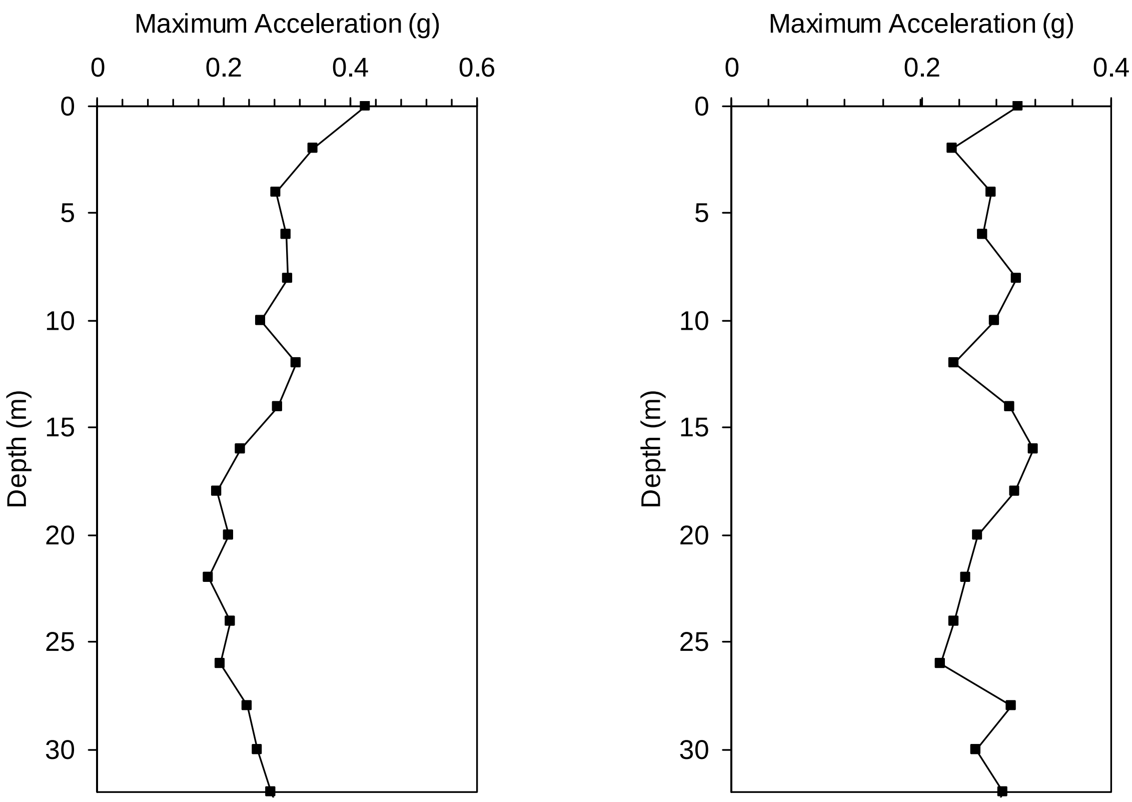

Figure 4.7. Variation of ground acceleration from base rock to the ground surface for soft and hard soil classification

Based on the result of seismic wave propagation analysis, which was carried out by considering the field condition on each locations in the sub district and the earthquake acceleration on the base rock, a microzonation map city of Padang and Pariaman are then developed which shows that the maximum value of seismic acceleration on the ground surface or Peak Ground Acceleration (PGA) as shown on Figure 4.8 and Figure 4.9.

For further development of vulnerability model of different building types, then a maximum value of seismic acceleration (PGA) at all the buildings surveyed is developed as shown in Appendix 3.

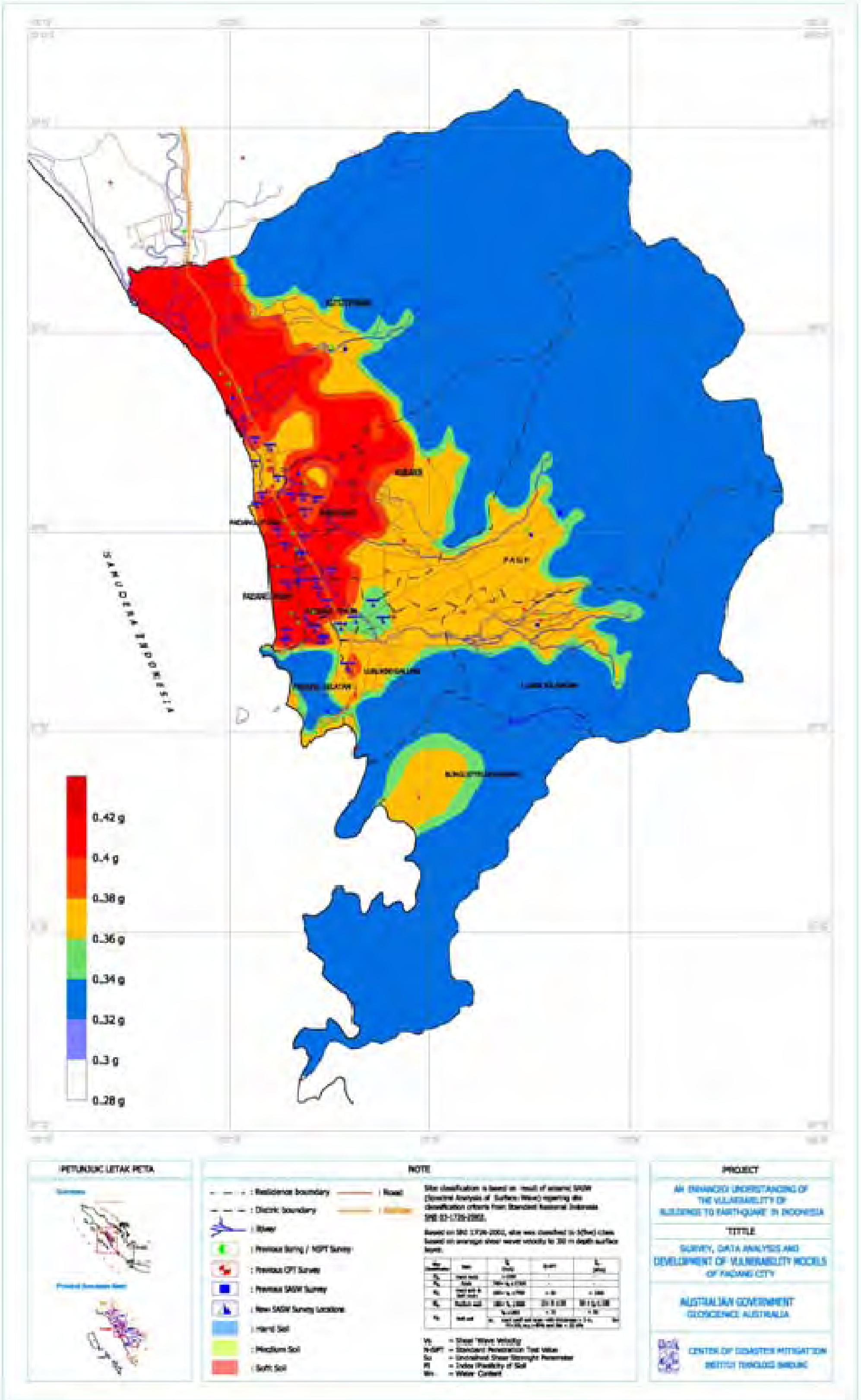

Figure 4.8. Peak Ground Acceleration (PGA) map for the city of Padang

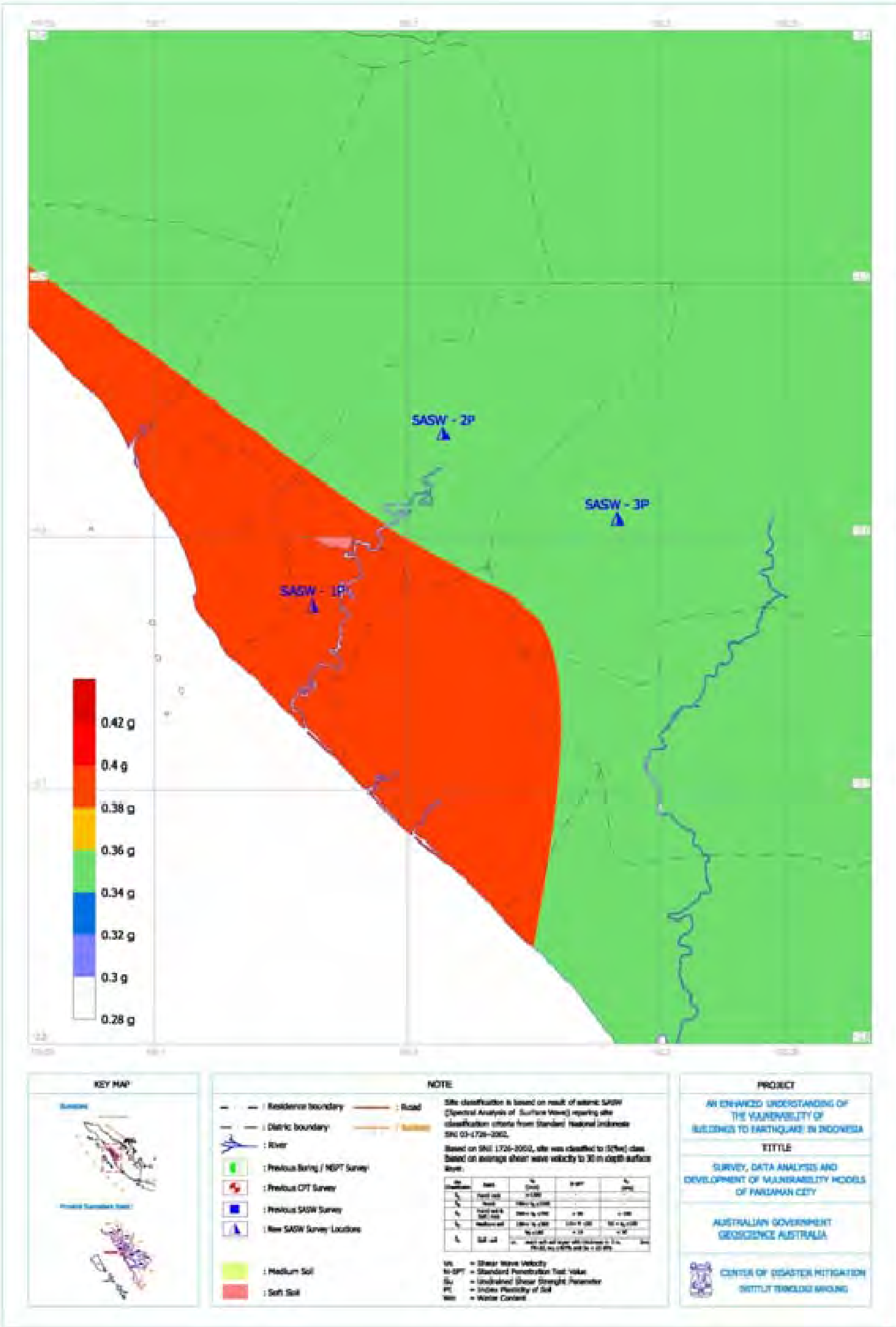

Figure 4.9. Peak Ground Acceleration (PGA) map for the city of Pariaman

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APPENDICES [Not included]

Appendix A4

Workshop Proceedings

Padang Earthquake Reconnaissance Workshop

28th and 29th April 2010

GEOSCIENCE AUSTRALIA

Contents

Summary

An AIFDR sponsored workshop was held at Geoscience Australia on the 28th and 29th April, 2010 to bring together many of the participants of the Padang Earthquake Reconnaissance Survey Team. The workshop reviewed Indonesian seismicity, the development of building regulations, historical building performance, the survey methodology, the survey outcomes, and the results of post survey analyses. It further considered the next steps for utilising the information to refine vulnerability knowledge and for disseminating the lessons learnt.

Introduction

On the 30th September 2009 a magnitude 7.6 earthquake struck West Sumatra in Indonesia. It caused widespread damage to buildings and the loss of an estimated 1,000 lives in the Padang and Padang Pariaman Districts. The Australia-Indonesia Facility for Disaster Reduction supported a team of Indonesian and international engineers and scientists to collect and analyse damage information needed for future disaster risk reduction in West Sumatra and for Indonesia more broadly. The activity was jointly led by the Centre for Disaster Mitigation at the Institute of Technology Bandung and Geoscience Australia in Canberra. The survey activity was successfully completed and the data sourced has been cleaned, processed and valuable vulnerability information has been derived.

The workshop brought together many of the key participants in the survey activity. It was an opportunity to put the damage observations made in the context of the nature of the local building stock and the regulations and building practices that have influenced their performance. The outcomes provide a valuable opportunity to refine a schema for categorising Indonesian buildings and to attribute an initial assessment of earthquake vulnerability to each building type.

Aims

The workshop aims were as follows:-

- to review the seismicity of Indonesia and the Padang region;
- to examine the evolution of building regulations in Indonesia and their application/enforcement regionally and with time;
- to review the historical performance of Indonesian structures subjected to strong earthquake ground motion;
- to review the nature of the Western Sumatran Earthquake and the post disaster survey activity that followed;
- to review the outcomes of this survey work, both from detailed building studies and as derived from population based surveys;
- to consider the post survey work aimed at determining the nature of local regolith and the severity of ground motion:
- to review the building stock categorisation schema developed for the survey and to augment this for future vulnerability model assignment and risk assessments;
- to develop a benchmark suite of earthquake vulnerability relationships
- to agree on the out-of-session process for populating the full building stock schema
- to discuss research opportunities for the development of improved earthquake vulnerability models for Indonesian buildings; and,
- to review the opportunities for carrying out more effective post-disaster surveys in Indonesia for all hazards based on the Padang survey experience.

Program

The workshop was held at Geoscience Australia on the 28th and 29th April, 2010. It consisted of four sessions over the two days with the following agenda.

Session One

Wednesday 9:00 am to 12:30 pm
(Chair:- Ken Dale)

PRELIMINARIES (Chair) 5mins

OFFICIAL WELCOME (Dr David Jepsen, Acting GL, Earth Monitoring Group) 5mins

INTRODUCTIONS (Chair) 10mins

INTRODUCTION AND WORKSHOP AIMS (Mark Edwards) 10mins

Indonesian Seismicity and Regulation Development

INDONESIAN SEISMICITY AND THE PADANG REGION (Wayan Sengara) 30mins

- Tectonic context
- Bedrock hazard nationally and in the Padang region
- Local regolith effects
- Associated tsunami hazard

General discussion facilitated by session chair

INDONESIAN BUILDING REGULATION DEVELOPMENT AND CONSTRUCTION PRACTICE (Made Suarjana) 30mins

- Evolution of standards (loadings and material)
- Implications for base shear resistance
- Typical construction practices
- Level of enforcement regionally and how this has changed with time

General discussion facilitated by session chair

HISTORICAL PERFORMANCE OF STRUCTURES IN INDONESIA (Made Suarjana) 30mins

- Review of severe historical earthquake events and their impacts.
- Learnings on earthquake vulnerability in the context of survey building stock schema

General discussion facilitated by session chair

Padang Earthquake and Survey Activity

THE 30 SEPT 2009 WESTERN SUMATRAN EARTHQUAKE (Dick Beetham) 20mins

- Event
- Rarity
- General footprint of severe ground motion

General discussion facilitated by session chair

OVERALL SURVEY OBJECTIVES AND APPROACH (Martin Wehner) 30mins

- Objectives
- Methodology
- Building stock categorisation

General discussion facilitated by session chair

DETAILED SURVEY (Richard Weller / Jason Ingham) 50mins

- Methodology
- Activity
- Outcomes
- Observations

General discussion facilitated by session chair

Session Two
Wednesday 1:30 pm to 5:00 pm
(Chair:- Jason Ingham)

POPULATION BASED SURVEY (Gerhard Horoschun) 30mins

- Methodology
- Activity
- Outcomes
- Observations

General discussion facilitated by session chair

Post Survey Analysis

INITIAL INTENSITY ASSESSMENT (Dick Beetham) 20mins

- Issues with survey attribution
- Cleaning of field assignments of MMI
- Intensity assignment approach
- Isoseismal map

General discussion facilitated by session chair

DETAILED GROUND MOTION STUDY (Wayan Sengara) 60mins

- Methodology
- MASW analysis to classify regolith
- Bedrock
- Local on regolith

General discussion facilitated by session chair

RESULTS FROM POPULATION BASED SURVEY (Martin Wehner / Dick Beetham) 50mins

- Damage data cleaning

- Reattribution of MMI intensities
- Reparation costing variability
- Nature of vulnerability relationships
- Validation data derived
- Results from social questions

General discussion facilitated by session chair

LEARNINGS ON SURVEY METHODOLOGIES USED IN PADANG (Chair) 30mins

General discussion facilitated by session chair

Session Three

Thursday 9:00 am to 12:30 pm
(Chair:- Richard Weller)

Building Stock Categorisation

REVIEW OF IMPACT ASSESSMENT PROCESS AND BUILDING SCHEMA (Mark Edwards) 30mins

- Earthquake impact and risk assessment process
- Feedback on applicability of building schema for multiple hazards
- Discussion on local hazard variation implications on vulnerability level.
- Review of industrial buildings coverage adequacy

General discussion facilitated by session chair

Preliminary Vulnerability Models

DAMAGE THRESHOLD FOR INDONESIAN STRUCTURES (Made Suarjana / Wayan Sengara) 30mins

- Identification of relative vulnerability of key building types.
- Assessment of damage thresholds as MMI intensity for building types
- Assessment (if possible) of more severe damage outcomes at high levels of shaking intensity.

General discussion facilitated by session chair

BENCHMARK EARTHQUAKE VULNERABILITY CURVE DEVELOPMENT (Mark Edwards) 100mins

- Identification of 8 building types selected from schema categories
- Review of vulnerability knowledge for each derived from Padang Earthquake and results for similar structures in other earthquake events
- Consensus on vulnerability curve

Heuristic process with audience input and facilitated by session chair

HEURISTIC OUT OF SESSION PROCESS (Mark Edwards) 30mins

- Discussion of process
- Review of tools

General discussion facilitated by session chair

Session Four

Thursday 1:30 pm to 5:00 pm
(Chair:- Wayan Sengara)

EARTHQUAKE VULNERABILITY RESEARCH OPPORTUNITIES (Made Suarjana / Wayan Sengara) 60mins

- Overview of structural vulnerability research in Indonesia
- Overview of ground motion modelling developments in Indonesia
- Selection of schema structure types for fundamental research
- Outline of research proposals to be developed out of session

General discussion facilitated by session chair

FUTURE USE OF PADANG DATA (Chair) 40mins

- Additional ground motion analysis
- Utilisation of other spectral values for damage association
- Publications

General discussion facilitated by session chair

Post Disaster Survey Activity

METHODOLOGIES (Neil Corby) 20mins

- Tools
- Strengths and weaknesses
- Appropriate methodologies

General discussion facilitated by session chair

FUTURE INDONESIAN POST DISASTER SURVEY ACTIVITY (Chair) 40mins

- Issues and challenges identifies from Padang activity
- Regional consensus on approach and data fields
- Training of participating academics and professionals
- Expansion to multi-hazard

General discussion facilitated by session chair

Next Steps

WORKSHOP SUMMARY AND NEXT STEPS (Chair) 50mins

- Summary of outcomes
- Out of session ranking processes
- Integration of respondent rankings to produce vulnerability model suite.
- Methodologies for post-disaster surveys
- Research opportunities
- Reporting of workshop outcomes
- Future workshop activity

General discussion facilitated by session chair

Workshop Close

Attendees

Assoc. Prof Wayan Sengara	Institute of Technology, Bandung, Indonesia
Dr Made Suarjana	Institute of Technology, Bandung, Indonesia
Assoc. Prof Jason Ingham	University of Auckland, NZ
Dick Beetham	GNS, NZ
Richard Weller	Cardno Consulting Engineers
Gerhard Horoschun	Australian Defence Force Academy, Canberra
Ken Dale	Geoscience Australia
Martin Wehner	Geoscience Australia
Neil Corby	Geoscience Australia
Mark Edwards	Geoscience Australia
Roger Charng	Geoscience Australia
Phil Cummins	Geoscience Australia (Day 1)

Session Reporting

The workshop discussion on the themes covered in the agenda was "seeded" by a targeted presentation. Presented in this section under the key subject areas is the essence of the lead presentation and the subsequent discussion.

INDONESIAN SEISMICITY AND REGULATION DEVELOPMENT

Indonesian Seismicity and the Padang Region

Padang lies in the second most severe seismic zone as defined by SNI-03-1726-2002. The standard defines response spectra for four site classifications ranging from hard rock to soft soil. Note that it is currently proposed that IBC-2006 be adopted for Indonesian New Building Codes. Current research involving Probabilistic Seismic Hazard Assessments (PSHA) and mapping has proposed a rezonation of Indonesia's seismic zones. There is a significant tsunami risk in Padang from a future subduction type earthquake.

The 2009 Western Sumatra earthquake produced approximately 0.25-0.3g in Padang at bedrock level. Soil amplification resulted in some spatial variation at foundation level across the region

The PSHA corresponding to 10% probability of exceedance (PE) in 50 years indicated that peak ground acceleration (PGA) of approximately 0.37g has potential to occur along coastal area of West Sumatra, while PGA for areas along the Sumatran Fault Zone (SFZ) could reach 0.5g-0.7g. This PGA is higher compared to the current Indonesian Building Codes of 2002.

De-aggregation analysis shows that the predicted PGA for the city of Padang is dominated by earthquakes originating from the Mentawai segment of the Subduction Megatrust, whereas for areas close to the SFZ, the predicted PGA will be dominated by shaking originated from SFZ earthquakes. A new Indonesian seismic zonation map is proposed to be either based on 10% PE in 50 years or 0.67 times (2% PE in 50 years) and two spectral values (at short and long period) will be adopted from PSHA outcomes.

Indonesian Building Regulation Development and Construction Practice

The history of Indonesian Seismic and Concrete Codes is summarised in Table 1. There is no formal Indonesian standard for masonry construction. However, there is a document named "Technical Guidelines for Seismic Resistant Homes and Buildings (2006)"

The requirements for a building permit vary from region to region. In many regions, the required documentation consists only of the structural drawings, and in other regions only the architectural drawings. In Jakarta, a design report covering the geotechnical, substructure and superstructure parts of the building is required in addition to the drawings. The design must be prepared by a licensed engineer and, for buildings over five storeys, it is reviewed by an expert panel. In Indonesia it is usual during the structural design of a building to ignore the effect of in-fill masonry walls and not to design non-structural elements.

Typical construction material strengths are as follows:-

- Concrete compressive strength: 15 – 20 MPa (concrete for high-rise buildings in Jakarta would be stronger);
- Clay brick compressive strength: 4 MPa;
- Mortar compressive strength: 8 MPa;
- Reinforcing steel yield strength: 240 MPa (plain bar) and 400 MPa (deformed bar).

Table 1: History of development of Indonesian Seismic and Concrete Codes

PERIOD	SEISMIC LOADINGS CODE	CONCRETE CODE
Pre 1970		PBI 1955[1] The Indonesian Reinforced Concrete Code (Peraturan Beton Bertulang Indonesia)
1970-1990	NI 18-1970[6] The Indonesian Loading Code	PBI 1971[2] The Indonesian Reinforced Concrete Code (Peraturan Beton Bertulang Indonesia)
1990-2000	PPTGIUG 1983[7] The Indonesian Seismic Code for Building Design (Peraturan Perencanaan Tahan Gempa Untuk Gedung)	SNI 1991 (Concrete)[3] The Indonesian Concrete Code (Tata Cara Perhitungan Struktur Beton untuk Bangunan Gedung SNI 03-2847-2002)
After 2000	SNI 2002 (Seismic)[8] The Indonesian Seismic Resistant design Standard for Building Structures (Tata Cara Perencanaan Ketahanan Gempa untuk Gedung – SNI-1726-2002) Technical Guidelines for Seismic Resistant Home and Building (2006)[5] (Pedoman Teknis Rumah dan Bangunan Gedung Tahan Gempa)	SNI 2002 (Concrete)[4] The Indonesian Concrete Code (Tata Cara Perhitungan Struktur beton untuk Bangunan Gedung SNI 03-2847-2002)

1. Very limited application and only applied to projects managed by the Public Works Department.
2. Based on FIP-CEB and ACI 318-70 codes. No detailing requirements for ductility.
3. Based on ACI 318-86 including modern seismic design concepts such as ductility.
4. Based on ACI 318M-99.
5. Provides drawings of minimum construction requirements.
6. Lateral load is specified as a function of building height. Structural analysis is linear elastic and structural design is based on allowable stress principals.
7. Included modern seismic design concepts such as structural ductility, collapse mechanisms and capacity design.
8. Based on “NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures” February 1998, UBC-97.

Historical Performance of Structures in Indonesia

Damage similar to that observed in Padang has been observed in previous earthquakes in Indonesia such as Tasikmalaya (2009), Yogyakarta (2006) and Aceh (2004). Types of damage often observed include:

- Poor performance of unreinforced masonry (URM) houses;
- Soft storey collapses;
- Torsion collapse due to building mass / building stiffness off-sets;
- Short column failures;
- Pounding between buildings;
- Collapse of masonry walls such as gable walls, infill walls in frames, internal partitions and walls damaged due to their greater relative stiffness attracting the bracing loads from surrounding concrete frames;
- Damage induced by poor reinforcement detailing;

- Stairs damaged by attracting bracing loads due to a lack of separation to primary structural frames;
- Damage to non-structural elements such as ceilings that were not constructed to resist earthquake actions;
- Damage to primary structure due to irregular structural layout such as columns off-set from beams; and,
- Failure of inadequately detailed beam – column joints;

There is a need for the damage observed during post-earthquake surveys to be related to the intensity of shaking so that building performance can be evaluated and compared between earthquakes.

PADANG EARTHQUAKE AND SURVEY ACTIVITY

The 30 September 2009 Western Sumatran Earthquake

A 7.6 magnitude earthquake occurred on 30 September 2009 within the subduction zone of the Indo-Australian and Euro-Asian plates. It was located 50 km west-northwest of Padang and at a depth 80 km below the surface. It resulted in relatively high ground shaking in Padang and up the coast to the north with felt intensities of VII (MMI) and higher reported. The earthquake caused lateral spreading, landslides and liquefaction.

Padang has been a focus of natural hazard scientists and disaster managers over the last five years. This is a result of increased evidence suggesting a high likelihood of an ~Mw 8.5 earthquake on the nearby subduction zone that could trigger a devastating tsunami. Significantly, the earthquake on the 30th September was not this ‘anticipated’ event.

The locked nature of the locally subducting plate means that a tsunamigenic earthquake still remains a significant threat to Padang and surrounding coastal areas. Recent assessment of earthquake risk along the plate boundary suggests it is possible that the earthquake on the 30th September has created additional stress on the subduction zone, *increasing* the probability of this tsunamigenic earthquake occurring in future decades.

The anticipated magnitude 8.5 event could generate a higher peak acceleration compared to that specified in the current (and previous) Indonesian Building Codes. The possibility of a ~Mw 7.5 earthquake on the Sumatra Fault Zone also exists. The time-frame for these events is well within the expected design life of any re-construction.

Should the ~Mw 8.5 earthquake occur, settlement of half a metre may occur along the coastline of West Sumatra (land behind the subduction zone). This should be included in any threat analysis from tsunami or ocean inundation flooding (e.g. risk from Sea Level Rise).

Overall Survey Objectives and Approach

The disaster survey had two objectives:

- Undertake a detailed survey of damage to public buildings such as schools and medical facilities that could inform recommendations regarding improvements that could be made to design and construction practices so that a repeat of the types of damage observed in Padang might be avoided.
- Undertake a population survey whereby damage to numerous buildings of all types and all damage levels was recorded to inform knowledge of the vulnerability of different types of buildings in the Padang region.

The survey was undertaken by ten field teams supported by a team of support staff. The detailed survey was undertaken by two teams consisting of experienced scientists and engineers from Indonesia, Australia, New Zealand and Singapore. The detailed survey teams surveyed approximately 400 buildings (300 schools and 100 medical facilities) which formed a subset of the approximately 4000 buildings surveyed for the population survey over a three week period. After the first week of surveying a draft report of recommendations was submitted to the World Bank and AIFDR.

The population survey was undertaken by eight teams consisting of a mix of three or four Indonesian undergraduate engineering students, postgraduate students and professional engineers together with experienced scientists and engineers from Indonesia, Australia, New Zealand and Singapore. The teams were supported by Indonesian translators and drivers.

The support staff provided liaison, logistical support and GIS services. They also recorded the survey information electronically on a daily basis.

Detailed Survey

The detailed survey teams conducted inspections of school and medical facility buildings. About 1 hour was spent surveying each building. Although the teams completed the population survey form at each building, their requirement to record a greater level of detail information regarding the earthquake damage led to the development of the detailed survey form. This form was targeted at the particular types of building structures used in Padang for school and medical facility buildings; commonly reinforced concrete frames with masonry infill and, to a lesser extent, confined masonry. The detailed survey teams were assisted by the provision of maps showing the location of the target buildings together with their GPS coordinates.

The following lessons were learnt during the detailed survey on the survey process itself:-

- The colour maps with locations of target buildings were very useful.
- It would be useful if the cameras could record the lat/long coordinates onto the photos.
- It is essential to record the building orientation. Supplied compasses were not very useful for this due to long stabilisation times.
- Integration of the two detail survey groups was difficult due to necessity of doing it by international mobile phones. Radios or local mobile phones would have been better.
- Photos were not taken as well as they may have been.
- The groups needed a dedicated person to liaise with school staff and pupils while the surveyors undertook the survey thus minimising the delay experienced by the survey group.
- Safety: uptake of PPE was not universal and tended to be discarded after a while. Problem with people entering damaged buildings without notifying a person on the outside where they were.
- There is a need for an identified communication route to a local authority for when the survey group notes buildings that are dangerously damaged and still in use.
- It was found that a single survey form is required across survey groups. It was further noted that the production of a universal survey form is understood to be within GEM’s remit.
- Difficulty in distinguishing between confined masonry and RC frame with infill masonry.
- Variety within URM and confined masonry categories needs to be captured on survey forms, e.g. river stone URM with pyramid URM footings is different to brick URM.
- Having the building irregularity codes on a separate sheet was difficult to use and the types identified were not tailored to Indonesian building types.

The following characteristics were noted during the detail survey as frequently contributing to earthquake damage:-

- Concrete appeared to be of very poor quality.
- Reinforcing steel appeared to be soft compared to NZ and Australian steels.

- Reinforcement detailing was universally poor.
- Repair work that was observed was not ‘building back better’.
- There was an absence of shear walls. Retrofit of such walls would go a long way towards improving performance in the next earthquake.
- Masonry gable walls often failed in face loading due to a lack of lateral restraint.
- Bricks were poorly fired.
- Brick masonry often had very thick mortar joints.

Population Based Survey

The eight detailed survey teams operated in two groups of four teams. The survey area within Padang was split into nine sectors that were divided between the two groups. Typically each group would spend two days surveying a sector in which representative streets would be chosen and every building on those streets would be surveyed by the teams. Towards the end of the survey period the detailed survey teams ventured outside the city area to survey buildings further afield to the east and south. This yielded data over a wider geographic range and terrain types.

The detailed survey utilised a standard paper form consisting of both sides of a single sheet of A4 paper. The design of the form was a difficult balance of capturing the maximum level of detail of information and the space available on the paper sheet. Position of surveyed buildings was recorded by means of a GPS device with the latitude and longitude manually recorded onto the paper form. Photos were taken with digital camera. Each team surveyed approximately 20 buildings during a day. Each day the support team transcribed the information from the paper forms into an electronic database and attached the photos to each record. Feedback from the support team was useful in detecting systematic errors that may have been creeping into recording of survey data.

Data regarding the inhabitants and their experiences during the earthquake were captured by interview where possible. The interview was also used to assign a MMI value to the building being surveyed.

The following lessons were learnt during the population survey:-

- It was noted that a good interpreter made a big difference to the performance of the groups.
- Access to many cars with drivers is essential for efficient surveying.
- The supplied GPS units were very slow in providing coordinates. Most groups relied on personal units or local university provided units after the first few days.
- It was noted that the first photo at a site should be of the front of the building and the second of an identifying address if there is one.

MASW SURVEY AND PGA ESTIMATE

Objectives

The objectives of this work are to estimate the spatial variation of peak ground acceleration (PGA) across the region due to 30 September 2009 earthquake. The spatial extent of the PGA attribution was to cover the post disaster surveyed buildings in city of Padang and city of Pariaman. Specific objectives of the work were:-

- Conduct a multi-channel analysis of surface wave (MASW) survey within the city of Padang and Pariaman.
- Conduct an analysis of the 30 September 2009 earthquake source properties and estimation through ground motion attenuation to estimate the level of peak ground acceleration at reference baserock.
- Conduct site-response analyses though wave propagation analysis from base-rock to ground surface to estimate spatial variation of PGA across the city of Padang and the town of Pariaman.

Teams

The earthquake ground motion analysis and MASW survey to estimate a spatial PGA for City of Padang and Pariaman has been conducted by the Center for Disaster Mitigation-Institute of Technology Bandung (CDM-ITB) team, with support from Universit of Andalas-Padang.

PGA Estimate

Firstly, a seismic attenuation analysis of the 30 September earthquake event was conducted. The analysis had been conducted by identifying the earthquake source characteristics and distance to sites of interest. In this process, deterministic seismic hazard analysis (DSHA) was conducted to estimate the spatial distribution of peak ground acceleration (PGA) at base-rock. The analysis was conducted using EZ-FRISK 7.32 software. Attenuation functions by Young's Intraslab (1997) has been adopted to represent the subduction earthquake sources.

Secondly, a site-response analysis (SRA) was carried out to estimate peak ground surface acceleration and response-spectra by considering predicted input motions and dynamic soil properties of the site. In the case of city of Padang and Pariaman, there is no strong motion data available yet, therefore the simplest and conventional method to generate input motions is performed by scaling available strong motion records from other sites. Strong motion records are commonly scaled to match target PBA of the site of interest spectral-matching techniques. In this study, spectral-matching techniques proposed by Abrahamson that is adopted and built in the EZ-FRISK Computer Program Version 7.2 is utilized. Then, time-domain wave propagation analyses from baserock to ground surface were conducted using the NERA (Non-linear Earthquake Response Analysis) computer program (Bardet and Tobita, 2001).

Results of Spatial PGA Distribution

Based on result of seismic wave propagation analysis, which was carried out by considering the Vs30 data for each location in the sub district and the estimated earthquake PGA at the base rock, a spatial PGA distribution map at the ground surface of city of Padang and Pariaman have been developed. The map for Padang is presented in Figure 1.

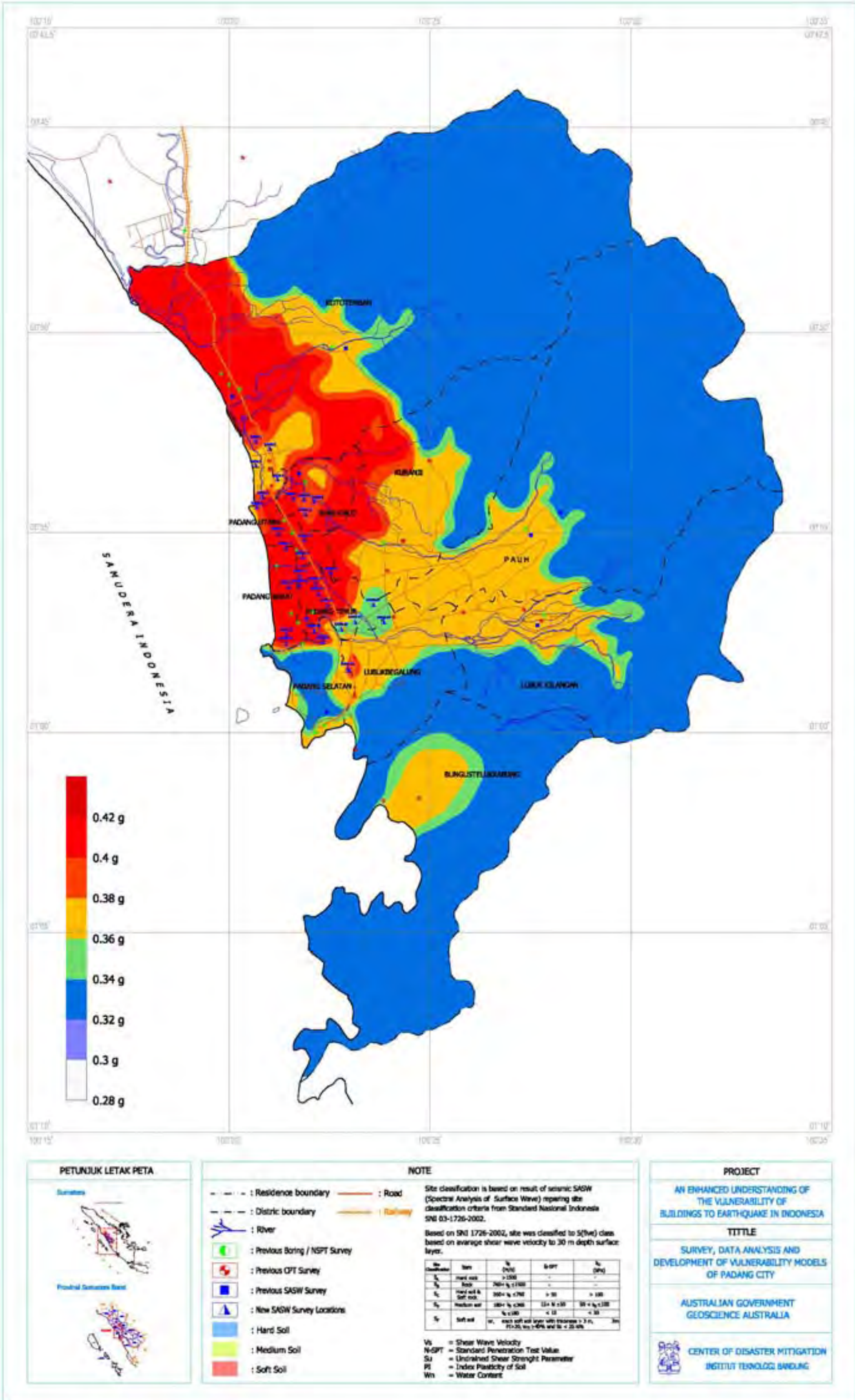

Figure 1. *Spatial distribution of ground surface PGA for city of Padang*

POST SURVEY ANALYSIS

Data cleaning

Validation of the data collected by the many field teams was a large task. The initial task was to check the recorded data at survey record level with reference to the corresponding photos. Importantly the MMI recorded during the field survey was reassessed as many had been biased by the damage to the surveyed building rather than looking more broadly at the neighbourhood outcomes. Additional survey entries were also obtained by translating approximately 400 survey records made by a New Zealand team, who were in Padang prior to the AIFDR sponsored survey, into the format of the population survey form.

Review of the population survey form

The workshop noted the following problems with the survey form used in Padang:

- Survey form did not address multi-use buildings well.
- Survey form did not address buildings with multiple structural systems (eg recording where a RC frame has a soft storey).
- Age could be difficult to determine and was often provided by interview.
- Pressed metal roof tiles may have been misclassified as heavy clay roof tiles.
- The MMI descriptions could be improved and be provided in Indonesian.
- There is a need for descriptions of different masonry types and of different levels of damage to masonry to aid surveyors. These could be provided by a data dictionary of example photos.

Reparation costing

More rigour was needed to the associate the damage index (defined as repair cost / replacement cost) to damage state number assigned in the field during the population survey. To provide this a quantity surveyor style costing of repairs to damaged buildings was undertaken for two types of buildings: a 3 storey reinforced concrete frame office building and a generic single storey confined masonry building. Detailed measurements were taken in the field of a representative 3-storey office building and representative dimensions were assigned for a single storey confined masonry building. Detailed descriptions of physical damage to each building were assigned to each element of the building fabric for each damage state together with the required work to effect repairs to a standard similar to that observed in Padang. The repairs for each damage state were costed using Padang repair rates supplied by the Institut Teknologi Bandung (ITB).

Note that some elements (e.g. deep foundations for the concrete framed building) were not costed for replacement resulting in the calculated damage index never reaching 1.0. For the residential buildings the damage index could exceed 1.0 because the demolition costs made up a significant component of full repair whereas the foundations were relatively cheaper. A smooth curve was fitted to the plotted values of damage index versus damage state number.

Vulnerability assessment

Vulnerability represents the average damage to a population of buildings of a given type as a function of hazard exposure magnitude. It is normally provided as a Damage Index for a population of structurally similar buildings. The hazard measure adopted was Modified Mercalli Intensity (MMI) which is a measure of the locally felt intensity of ground shaking. At the outset of the survey it was anticipated that a variation in MMI would be observed across the survey area. However, following refinement of the MMI intensities with reference to regolith, very little variation in MMI was observed with nearly all locations assessed as MMI 8 with a small portion (9%) assessed as MMI 7. The MMI intensities were further adjusted based on the PGA estimates derived form the MASW analysis. All local PGA values fell in the MMI range. Hence all surveyed points were grouped into a single set of results and vulnerability calculated for a single hazard magnitude that may be taken as MMI 8. The vulnerability results are given in Table 2.

Fragility represents the probability of a given building sustaining a predetermined level of damage for a given hazard magnitude. Fragilities were calculated for well represented building categories in the building schema. The fragility results are given in Table 3.

Table 2: *Average Damage Index for well represented building types in Padang at MMI 8*

SCHEMA DESCRIPTION	NUMBER OF SURVEYED BUILDINGSI	AVERAGE DI
URM / metal roof	365	0.35
URM / tile roof	27	0.48
Confined masonry residential / metal roof	1577	0.07
Confined masonry residential / tile roof	67	0.04
Timber frame residential	264	0.07
RC frame residential / metal roof	264	0.06
RC frame residential / tile roof	74	0.09
C1L pre 1981	206	0.07
C1L 1981 - 2002	226	0.07
C1L 2003+	151	0.06
C1M pre 1981	9	0.11
C1M 1981 - 2002	22	0.12
C1M 2003+	19	0.29
URML / URMM	138	0.31
W1 / W2	58	0.19
Timber frame with stucco infill	176	0.10

Salient results from the vulnerability and fragility data

The vulnerability and fragility data yield four results that are of particular importance.

Result 1.

While the sample size for taller reinforced concrete buildings, the data indicates that there has been little discernable improvement in the performance of buildings of this type with construction date. That is, more recently constructed buildings did not perform better than older buildings of the same type while the improvement of building regulations should point to a different result.

Result 2.

The data indicate that there is a distinct improvement in performance of confined masonry compared to unreinforced masonry (URM) buildings.

Result 3.

Unreinforced masonry buildings of any type perform poorly when subjected to earthquake actions.

Result 4.

The data indicate that a structural system with framing of any type will perform significantly better than unreinforced masonry buildings. This is an important result when considering reconstruction activities in Padang; new buildings should have a structural frame and URM type buildings should be avoided.

Table 3: *Fragilities for well represented building types in Padang at MMI 8.*

SCHEMA NO.	SCHEMA DESCRIPTION	NO OF BLDGS	PROBABILITY OF DAMAGE STATE				
			NONE	SLIGHT	MODERATE	EXTREME	COMPLETE
1	URM / metal roof	365	0.18	0.10	0.24	0.22	0.26
2	URM / tile roof	27	0.15	0.11	0.11	0.26	0.37
3	Confined masonry residential / metal roof	1577	0.58	0.08	0.28	0.05	0.02
4	Confined masonry residential / tile roof	67	0.76	0.00	0.21	0.01	0.01
5	Timber frame residential	264	0.71	0.09	0.12	0.05	0.03
11	RC frame residential / metal roof	264	0.58	0.13	0.21	0.03	0.05
12	RC frame residential / tile roof	74	0.46	0.15	0.26	0.04	0.09
15	C1L pre 1981	206	0.36	0.23	0.32	0.03	0.06
16	C1L 1981 - 2002	226	0.26	0.25	0.35	0.08	0.06
17	C1L 2003+	151	0.35	0.23	0.30	0.08	0.05
18	C1M pre 1981	9	0.11	0.00	0.44	0.44	0.00
19	C1M 1981 - 2002	22	0.09	0.14	0.59	0.05	0.14
20	C1M 2003+	19	0.11	0.05	0.37	0.21	0.26
42	URML / URMM	138	0.21	0.09	0.22	0.28	0.19
45	W1 / W2	58	0.40	0.14	0.19	0.17	0.10
51	Timber frame with stucco infill	176	0.38	0.16	0.34	0.07	0.05

Results from social questions

The survey included a set of questions aimed at determining the impacts of the earthquake on the inhabitants of Padang. Questions addressed the number and type of injuries, loss of services and temporary housing. This part of the survey form was only filled out when an interview with the inhabitants could be conducted. Approximately a quarter of surveyed sites recorded information about injuries and approximately a half of surveyed sites recorded information about loss of services. Other fields were more sparsely recorded and hence have not been analysed.

The expected number of injuries due to earthquake damage to buildings is often related to floor collapse. The results for the Padang survey of average number of injuries per building plotted against percentage floor collapse show no discernable correlation.

The expected number of injuries due to earthquake damage to buildings would be expected to increase with increasing building damage. The results for the Padang survey of average number of injuries per building potted against surveyed damage state number show an expected increase of injuries versus damage state except for the ‘complete collapse’ damage state. The unexpected result for Damage State 9 (complete collapse) may be due to a lack of inhabitants to interview at sites of completely collapsed buildings.

The survey results for loss of services displayed no correlation to type of building, building usage or severity of damage. These results imply that loss of services is due to failures within the supply chain rather than building specific factors.

BUILDING STOCK CATEGORISATION

The workshop discussed the Building Schema that had been used during the Padang survey. The specific observations were:

- Noted that the building schema needs more granularity to cover building types such as:
  - Different wall thickness URM, thick multiple leaf URM versus thin single or double leaf URM;
  - Different masonry types: brick versus river rock URM versus mud brick / mortar;
  - Different extents of masonry infill to concrete frame buildings;
  - Reorder the schema with URM at the top of both parts.
- Noted that it would be better to have the schema divided on the basis of height (rather than residential / non-residential usage) as single storey buildings have distinct construction types compared to taller buildings.
- Consider the possibility of using a tree structure to classify building types.
- Noted that there are no age related changes in house construction qualities or types.
- Noted that some building usages may have design requirements imposed on them, e.g. the department of education has specific requirements for school buildings.
- Noted that the schema appears to be suitable for multi-hazard work.

Based on the above comments the building stock schema was to be revised with out-of-session consultation with the workshop participants.

PRELIMINARY VULNERABILITY MODELS

Damage Threshold for Indonesian Structures

To utilise the available damage data from earlier Indonesian earthquakes in the development of vulnerability knowledge, it is necessary that such observations be related to the intensity of shaking felt. There is little data immediately available as previous survey reports were not compiled with the development of vulnerability knowledge as an objective. It is known that after the Yogyakarta earthquake a distinct difference in vulnerability of confined masonry structures was observed that corresponded to a difference in the quality of reinforcing to the confining concrete elements.

Earthquake Vulnerability Research Opportunities

The workshop discussed a wide range of potential future research that would advance the knowledge of the vulnerability of Indonesian building types to earthquake damage. Future experimental work should be designed to address design and construction deficiencies observed in the field and gaps in hazard knowledge. The topics discussed are summarised below:-

- Indonesian specific attenuation models development.
- Examination of the survey data from previous Indonesian earthquakes and compared to the data from the Padang survey.
- Utilisation of the opportunity to conduct full scale testing of damaged buildings in Padang prior to demolition.
- Research could be undertaken into retrofit options for existing building types (as opposed to new-build). This could be focussed on a particular building type, e.g. schools. This would involve:

- – Identification of typical construction types and details
- – Assessment (theoretical and experimental) of strength and ductility
- – Design of remedial details.
- Research on confinement strategies for existing URM.
- Acquisition of knowledge of the engineering properties of materials as constructed in Padang.
- Investigation of retrofit details for masonry gable walls and other face loaded masonry walls (e.g. internal partitions).
- Production of a design standard for masonry structures. The design guidelines could be tailored for different seismic zones.
- Investigate what can be done to introduce reinforced concrete block to construction in Indonesia.
- Numerical analysis of non-ductile RC frames to identify deficiencies followed by an experimental program to establish the magnitude of the deficiencies. May be able to utilise work done in other areas of the world with similar construction to understand legacy buildings, e.g. Turkey.

It was noted form the above that a strong research program will tend to cultivate a greater level of expertise in Indonesia as more engineers get exposed to the consequences of poor design and construction.

Future Utilisation of Padang Data

The workshop discussed future work that could be done using the survey data from Padang. The items suggested are listed below.

- Consider the use of ground motion measures other than base rock pga as indicators for MMI.
- Examine the effect of building orientation (remembering that vulnerability models are omni-directional).
- Examine different E/W and N/S ground motions.
- Examine the relevance of Padang vulnerability data to other areas of Indonesia. This may require surveys of building types in other areas to identify regional building peculiarities, e.g. the prevalence of metal roof tiles in Padang.
- De-aggregate URM categories.
- Record building specific damage from 30 September earthquake so that comparison can be made to damage to the same buildings from future earthquakes.
- Publish a combined journal paper.
- Run a workshop in Indonesia to present the results of the survey. Noted that this would need to be in Indonesian.

POST DISASTER SURVEY ACTIVITY

Methodologies

The workshop reviewed the data capture methodology used in Padang and noted what worked well and what didn’t. The following worked well:

- The forms were physically easy to fill out;
- The forms and other equipment continued to function in wet weather;
- Using a paper form was a reliable method that didn’t rely on power supply or software;
- The equipment was inexpensive to purchase and could be obtained quickly during the short mobilisation period prior to the survey;
- The paper form was easy to alter in the field.

The following weaknesses were noted:

- Transcription of the data from the paper forms to an electronic database was heavy handed and introduced errors;
- Hand writing of GPS coordinates from an electronic device introduced another source of error;
- There was a communication barrier at times with too few bilingual staff;

- The rotation of tasks within groups led to variability in the quality of recorded data;
- Charging sufficient batteries overnight between days of surveying was problematical.

The workshop discussed alternate technologies that could be used in the future including the Geoscience developed RICS system for rapidly capturing building inventory data. In particular is was observed that the local participants, including the students, showed a high level of information technical competency indicating that the utilisation of hand-held computer technology with pre-programmed survey templates would be a practical substitution for paper media.

Future Indonesian Post Disaster Survey Activity

A major problem encountered during the Padang survey was insufficient time for adequate training of survey staff in Padang. To overcome this for future surveys it is recommended that a workshop is held in Indonesia to train prospective surveyors so that future surveys will benefit from a pool of locally trained surveyors.

NEXT STEPS

The next phases of work after the workshop include undertaking the out-of-session heuristic ranking exercise to develop heuristic vulnerability curves for the revised Indonesian Building Schema, prepare the Reconnaissance Report for AIFDR, forward research proposals to AIFDR, forward recommendations for future workshops in Indonesia to AIFDR.

Vulnerability Model Development

HEURISTIC IN-SESSION PROCESS FOR BENCHMARK CURVES

The workshop attendees developed heuristic vulnerability curves for nine Indonesian building types. The curves are described by specifying four sets of MMI / Damage Index coordinates through which a vulnerability curve, expressed as a cumulative log normal distribution curve was fitted. The target values adopted are given in Table 4 with the MMI 8 value taken directly form the outcomes of the Padang earthquake survey data analysis. Curves were fitted to the target data using the GA developed *Eloss* software. The curves are defined as cumulative log-normal probability distribution curves defined by values for their median and beta as given in Table 5. Fragility curves were also derived from the vulnerability curves as cumulative log-normal probability distribution curves defined by values for their median and beta as given in Table 6.

Table 4: *MMI / Damage Index values to define benchmark heuristic vulnerability curves developed during the workshop.*

BUILDING TYPE	MMI	DAMAGE INDEX
URM with metal roof	6.0	0.0
	7.25	0.10
	8.0	0.35
	9.5	1.0
RC low rise frame with masonry in-fill walls	6.75	0.0
	8.0	0.07
	8.75	0.35
	11	1.0
Confined masonry	6.5	0.0
	8.0	0.07
	9.0	0.6
	11.0	1.0
RC medium rise frame with masonry in-fill walls	6.75	0.0
	8.0	0.18
	8.5	0.6
	10.0	1.0
Timber frame with stucco in-fill	6.0	0.0
	8.0	0.10
	9.5	0.60
	11.0	1.0
URM with river rock walls	5.5	0.0
	6.5	0.1
	8.0	0.7
	9.0	1.0
HAZUS C2H	6.5	0.0
	8.0	0.1
	10.0	0.6
	12.0	1.0
Timber frame residential	7.0	0.0
	8.0	0.07
	11.0	0.6
	12.0	1.0
Timber frame with masonry in-fill	6.0	0.0
	8.0	0.19
	9.0	0.6
	11.0	1.0

Table 5: *Median and variance (beta) values derived from the definition of benchmark vulnerability curves as cumulative log-normal probability distributions.*

BUILDING TYPE	MEDIAN (MMI)	BETA (MMI)
URM with metal roof	8.3	0.10
RC low rise frame with masonry in-fill walls	9.0	0.08
Confined masonry	8.9	0.07
RC medium rise frame with masonry in-fill walls	8.4	0.05
Timber frame with stucco in-fill	9.2	0.11
URM with river rock walls	7.5	0.11
HAZUS C2H	9.7	0.15
Timber frame residential	10.5	0.15
Timber frame with masonry in-fill	8.8	0.11

Table 7.4: *Median and beta values for the fragility curves derived for the benchmark vulnerability curves and defined as cumulative log-normal probability distributions. The fragility curves are consistent with the vulnerability curves defined in Table 5. Damage indices for damage levels taken as: Slight Damage = 2 to 10% loss, Moderate Damage = 11 to 50%, Extensive Damage = 50 to 99% and Complete Damage = 100%.*

BUILDING TYPE	SLIGHT		MODERATE		EXTENSIVE		COMPLETE	
	MEDIAN	BETA	MEDIAN	BETA	MEDIAN	BETA	MEDIAN	BETA
URM with metal roof	7.3	0.07	7.8	0.07	8.2	0.08	8.9	0.08
RC low rise frame with masonry in-fill walls	8.3	0.06	8.7	0.08	9.1	0.08	9.6	0.09
Confined masonry	7.8	0.04	8.2	0.05	8.7	0.06	9.2	0.06
RC medium rise frame with masonry in-fill walls	8.0	0.04	8.2	0.05	8.4	0.05	8.8	0.06
Timber frame with stucco in-fill	7.5	0.08	8.2	0.08	9.4	0.10	9.9	0.11
URM with river rock walls	7.5	0.08	8.2	0.08	9.4	0.10	9.9	0.11
HAZUS C2H	7.5	0.08	8.2	0.08	9.4	0.10	9.9	0.11
Timber frame residential	8.0	0.07	9.6	0.09	10.7	0.11	11.7	0.10
Timber frame with masonry in-fill	7.5	0.11	8.2	0.11	8.7	0.10	9.5	0.09

REVISED SCHEMA THROUGH OUT-OF-SESSION PROCESS

The Building Schema was revised to address the concerns raised and recommendations made during the workshop discussion. The revised building stock categorisation schema is shown in Figure 2 with primary division between engineered and non-engineered structures, between building height categories, and between Jakarta and the rest of the country as to regulatory enforcement. Within those categories the new schema has significantly more granularity than the old schema. Some workshop attendees felt that even further granularity should be provided for engineered reinforced concrete and steel framed buildings. However, it was also noted that the level of granularity needs to reflect the level of definition that can be captured both in the national exposure assignment work and also the ability to differentiate building types during post-disaster activity. Significantly the format of the new schema lends itself to extension should it be deemed necessary in the future to add categories.

Indonesian Building Stock Categorisation **Version IV**

Non-Engineered Buildings 1 storey (NEL)					
Structural system	Sub-type	Roof Type			
		1. Sheet metal, metal tile or synthetic	2. Heavy tile	3. Concrete slab	4. Thatch / leaves
1. URM	1.1 Mud brick	NEL 1.1.1	NEL 1.1.2	NA	NEL 1.1.4
	1.2 River stone	NEL 1.2.1	NEL 1.2.2	NA	NEL 1.2.4
	1.3 Thick fired brick	NEL 1.3.1	NEL 1.3.2	NEL 1.3.3	NEL 1.2.4
	1.4 Thin fired brick	NEL 1.4.1	NEL 1.4.2	NEL 1.4.3	NEL 1.4.4
2. Reinforced masonry	2.1 Confined masonry	NEL 2.1.1	NEL 2.1.2	NEL 2.1.3	NEL 2.1.4
	2.2 Reinforced block	NEL 2.2.1	NEL 2.2.2	NEL 2.2.3	NEL 2.2.4
3. Timber frame	3.1 Light clad	NEL 3.1.1	NEL 3.1.2	NA	NEL 3.1.4
	3.2 Stucco infill	NEL 3.2.1	NEL 3.2.2	NA	NEL 3.2.4
	3.3 Masonry infill	NEL 3.3.1	NEL 3.3.2	NA	NEL 3.3.4
4. Reinforced concrete frame	4.1 Masonry infill	NEL 4.1.1	NEL 4.1.2	NEL 4.1.3	NEL 4.1.4
	4.2 Other cladding	NEL 4.2.1	NEL 4.2.2	NEL 4.2.3	NEL 4.2.4

Non-Engineered Buildings 2 to 4 storeys (NEH)					
Structural system	Sub-type	Roof Type			
		1. Sheet metal, metal tile or synthetic	2. Heavy tile	3. Concrete slab	4. Thatch / leaves
1. URM	1.1 Mud brick	NEH 1.1.1	NEH 1.1.2	NA	NEH 1.1.4
	1.2 River stone	NEH 1.2.1	NEH 1.2.2	NA	NEH 1.2.4
	1.3 Thick fired brick	NEH 1.3.1	NEH 1.3.2	NEH 1.3.3	NEH 1.2.4
	1.4 Thin fired brick	NEH 1.4.1	NEH 1.4.2	NEH 1.4.3	NEH 1.4.4
2. Reinforced masonry	2.1 Confined masonry	NEH 2.1.1	NEH 2.1.2	NEH 2.1.3	NEH 2.1.4
	2.2 Reinforced block	NEH 2.2.1	NEH 2.2.2	NEH 2.2.3	NEH 2.2.4
3. Timber frame	3.1 Light clad	NEH 3.1.1	NEH 3.1.2	NA	NEH 3.1.4
	3.2 Stucco infill	NEH 3.2.1	NEH 3.2.2	NA	NEH 3.2.4
	3.3 Masonry infill	NEH 3.3.1	NEH 3.3.2	NA	NEH 3.3.4
4. Reinforced concrete frame	4.1 Masonry infill	NEH 4.1.1	NEH 4.1.2	NEH 4.1.3	NEL 4.1.4
	4.2 Other cladding	NEH 4.2.1	NEH 4.2.2	NEH 4.2.3	NEL 4.2.4

Engineered buildings – Capital City (>4 storeys) (EC)					
Structural system	Height / storeys	Facade type and separation	Age bracket		
			1. Pre 1981	2. 1981-2002	3. 2003+
1. Reinforced Concrete Moment Frame	1.1 5-8	1.1.1 URM	EC 1.1.1.1	EC 1.1.1.2	EC1.1.1.3
		1.1.2 Non-URM or separated URM	EC 1.1.2.1	EC 1.1.2.2	EC1.1.2.3
	1.2 9-25	1.2.1 URM	EC 1.2.1.1	EC 1.2.1.2	EC 1.2.1.3
		1.2.2 Non-URM or separated URM	EC 1.2.2.1	EC 1.2.2.2	EC 1.2.2.3
2. Reinforced Concrete Shear Wall	2.1 5-8	2.1.1 URM	EC 2.1.1.1	EC 2.1.1.2	EC 2.1.1.3
		2.1.2 Non-URM or separated URM	EC 2.1.2.1	EC 2.1.2.2	EC 2.1.2.3
	2.2. 9-25	2.2.1 URM	EC 2.2.1.1	EC 2.2.1.2	EC 2.2.1.3
		2.2.2 Non-URM or separated URM	EC 2.2.2.1	EC 2.2.2.2	EC 2.2.2.3
	2.3 25+	2.3.1 URM	EC 2.3.1.1	EC 2.3.1.2	EC 2.3.1.3
		2.3.2 Non-URM or separated URM	EC 2.3.2.1	EC2.3.2.2	EC 2.3.2.3
3. Steel moment frame	3.1 1-2	3.1.1 Any	EC 3.1.1.1	EC 3.1.1.2	EC 3.1.1.3
	3.2 3+	3.2.1 Any	EC 3.2.1.1	EC 3.2.1.2	EC 3.2.1.3
4. Steel braced frame	4.1 1-2	4.1.1 Any	EC 4.1.1.1	EC 4.1.1.2	EC 4.1.1.3
	4.2 3+	4.2.1 Any	EC 4.2.1.1	EC 4.2.1.2	EC 4.2.1.3

Engineered buildings – Regional (>4 storeys) (ER)					
Structural system	Height / storeys	Facade type and separation	Age bracket		
			1. Pre 1981	2. 1981-2002	3. 2003+
1. Reinforced Concrete Moment Frame	1.1 5-8	1.1.1 URM	ER 1.1.1.1	ER 1.1.1.2	ER1.1.1.3
		1.1.2 Non-URM or separated URM	ER 1.1.2.1	ER 1.1.2.2	ER1.1.2.3
	1.2 9-25	1.2.1 URM	ER 1.2.1.1	ER 1.2.1.2	ER 1.2.1.3
		1.2.2 Non-URM or separated URM	ER 1.2.2.1	ER 1.2.2.2	ER 1.2.2.3
2. Reinforced Concrete Shear Wall	2.1 5-8	2.1.1 URM	ER 2.1.1.1	ER 2.1.1.2	ER 2.1.1.3
		2.1.2 Non-URM or separated URM	ER 2.1.2.1	ER 2.1.2.2	ER 2.1.2.3
	2.2. 9-25	2.2.1 URM	ER 2.2.1.1	ER 2.2.1.2	ER 2.2.1.3
		2.2.2 Non-URM or separated URM	ER 2.2.2.1	ER 2.2.2.2	ER 2.2.2.3
	2.3 25+	2.3.1 URM	ER 2.3.1.1	ER 2.3.1.2	ER 2.3.1.3
		2.3.2 Non-URM or separated URM	ER 2.3.2.1	ER2.3.2.2	ER 2.3.2.3
3. Steel moment frame	3.1 1-2	3.1.1 Any	ER 3.1.1.1	ER 3.1.1.2	ER 3.1.1.3
	3.2 3+	3.2.1 Any	ER 3.2.1.1	ER 3.2.1.2	ER 3.2.1.3
4. Steel braced frame	4.1 1-2	4.1.1 Any	ER 4.1.1.1	ER 4.1.1.2	ER 4.1.1.3
	4.2 3+	4.2.1 Any	ER 4.2.1.1	ER 4.2.1.2	ER 4.2.1.3

Figure 2. *Building schema revised through out-of-session consensus*

HEURISTIC OUT-OF-SESSION PROCESS FOR NATIONAL SUITE

The benchmark curves populate only a small portion of the total building categorisation schema. Consequently the process for populating the full revised schema with reference to the benchmark curves derived was demonstrated and discussed. The primary tool is an Excel spreadsheet with the benchmark curves pre-loaded. Each workshop attendee agreed to assign a median and beta value to each of the other categories which would place the building type vulnerability in the correct relative position on the vulnerability curve graph.

Once all workshop attendees had returned their assignment then each of the respondent assessments would be weighted and combined to produce a fully populated national suite of earthquake vulnerability curves. With the finalisation of the revised building stock schema this out of session process was underway at the time of reporting. As the benchmark curves are refined the national suite will be adjusted in a relative fashion.

Issues & Recommendations

The workshop made the following recommendations:-

- That the AIFDR facilitate a workshop to be convened in Indonesia to communicate the results of the Padang reconnaissance to the Indonesian engineering community;
- That the AIFDR facilitate a workshop be held in Indonesia to train Indonesian engineers in post-earthquake survey techniques. The scarcity of trained staff was perceived as an impediment to efficient and productive future surveys;
- It appears that there is a scarcity of earthquake resistant design expertise within the Indonesian engineering profession. For example, it is understood that earthquake design is only taught as an elective subject that many students do not take. This could be addressed by AIFDR sponsoring the promotion of earthquake engineering in schools of engineering and through their sponsorship of post-graduate courses in earthquake design.
- That AIFDR consider sponsoring research covering the suggested topics noted under Earthquake Vulnerability Research Opportunities; and,
- The ‘Build Back Better’ campaign must address the widespread construction deficiencies noted in the World Bank report.

Acknowledgements

The post-disaster reconnaissance in Padang was funded by the AIFDR facility in Jakarta.

Appendix A5

Survey Information Metadata

SPATIAL METADATA –Padang building survey

Tools used for survey data capture

Filename: Padang_srv.shp

Type of object: Feature Class (ESRI Shapefile)
Number of records: 2896

Horizontal coordinate system
Geographic coordinate system name: GCS_WGS_1984

Geographic Coordinate System
Geographic Coordinate Units: Decimal degrees

Geodetic Model
Horizontal Datum Name: D_WGS_1984
Ellipsoid Name: WGS_1984
Semi-major Axis: 6378137.000000
Denominator of Flattening Ratio: 298.257224

Bounding coordinates
Horizontal
In decimal degrees

West: 100.081410
East: 100.646820
North: -0.380370
South: -1.204280

Attributes

FID

Alias: FID
Data type: OID
Width: 4
Precision: 0
Scale: 0
Definition: Internal feature number
Definition Source: ESRI

Shape

Alias: Shape
Data type: Geometry
Width: 0
Precision: 0
Scale: 0
Definition: Feature geometry.
Definition Source: ESRI

UFI

Alias: UFI
Data type: Number
Width: 16

Definition: *Unique field identifier relating to the point captured in the field*

DATE_

Alias: DATE_
Data type: Date
Width: 8

Definition: *Actually date point was captured in the field*

TEAM

Alias: TEAM
Data type: String
Width: 254

Definition: *Team letter for field data capture purposes*

SEQ_NO

Alias: SEQ_NO
Data type: Number
Width: 10

Definition: *Unique sequence number for each team which begins at 01 each new day of field surveying*

ADDRESS

Alias: ADDRESS
Data type: String
Width: 254

Definition: *Address at the point of capture, if known*

LAT

Alias: LAT
Data type: Float
Width: 19
Number of decimals: 11

Definition: *Latitude of point captured, this has a +/- 10m horizontal accuracy and may vary during the time of day*

L0NG

Alias: L0NG
Data type: Float
Width: 19
Number of decimals: 11

Definition: *Longitude of point captured, this has a +/- 10m horizontal accuracy and may vary during the time of day*

POWERPOINT

Alias: POWERPOINT
Data type: String
Width: 254

Definition: *All images taken of surveyed point, this can be hyperlinked to point for viewing*

USE_MAJOR

Alias: USE_MAJOR
Data type: String
Width: 254

Definition: *Main building usage*

USE_MINOR
Alias: USE_MINOR
Data type: String
Width: 254

Definition: *Secondary building usage*

STRUCTURE
Alias: STRUCTURE
Data type: String
Width: 254

Definition: *Structural information of the building surveyed*

WALL_TYPE

Alias: WALL_TYPE
Data type: String
Width: 254

Definition: *Wall type/material of building*

ROOF_TYPE
Alias: ROOF_TYPE
Data type: String
Width: 254

Definition: *Roof material of surveyed building – see attached documentation for more detail*

FLOOR
Alias: FLOOR
Data type: String
Width: 254

Definition: *Floor type of surveyed building*

STOREY
Alias: STOREY
Data type: Number
Width: 10

Definition: *Number of storeys of surveyed building*

AGE

Alias: AGE
Data type: String
Width: 254

Definition: *Estimated age of surveyed building, either from interviewed information or educated guess*

LENGTH

Alias: LENGTH
Data type: Number
Width: 10

Definition: *Estimated surveyed building length*

WIDTH

Alias: WIDTH
Data type: Number
Width: 10

Definition: *Estimated surveyed building width*

IRR_CODE

Alias: IRR_CODE
Data type: String
Width: 254

Definition: *Building irregularity code*

BEARING

Alias: BEARING
Data type: Number
Width: 10

Definition: *Long axis bearing of building*

PLAN

Alias: PLAN
Data type: String
Width: 254

Definition: *Plan shape code – see attached documentation for more detail*

SITE

Alias: SITE

Data type: String

Width: 254

Definition: *Site morphology of surveyed building, which could include hill top, steep slope, mild slope and flat*

MMI

Alias: MMI

Data type: Number

Width: 10

Definition: *Modified Mercalli index – see attached documentation for more detai*

SEIS_SEP

Alias: SEIS_SEP

Data type: String

Width: 254

Definition: *Seismically separated building*

SCHEMA

Alias: SCHEMA

Data type: Number

Width: 10

Definition: *Schema version number – data collection form revision number*

BLD_TYP

Alias: BLD_TYP

Data type: String

Width: 254

Definition: *Building type number – Indonesian building stock categorisation number*

NOTES

Alias: NOTES

Data type: String

Width: 254

Definition: *Free field for comments made about the surveyed building*

INSPECT

Alias: INSPECT

Data type: String

Width: 254

Definition: *Inspection accuracy; outside, partial or complete*

URM

Alias: URM

Data type: String

Width: 254

Definition: *Unreinforced masonry damage index; number ranging from 0 (negligible) to 9 (destruction)*

CONF_MAS

Alias: CONF_MAS

Data type: Number

Width: 10

Definition: *Confined masonry damage index; number ranging from 0 (negligible) to 9 (destruction)*

BAMB_TIMB

Alias: BAMB_TIMB

Data type: String

Width: 254

Definition: *Bamboo or Timber damage index; number ranging from 0 (negligible) to 9 (destruction)*

RC_FRAME

Alias: RC_FRAME

Data type: String

Width: 254

Definition: *Reinforced concrete frame damage index; number ranging from 0 (negligible) to 9 (destruction)*

STEEL_FR

Alias: STEEL_FR

Data type: String

Width: 254

Definition: *Steel frame damage index; number ranging from 0 (negligible) to 9 (destruction)*

GEOTECH
Alias: GEOTECH
Data type: Number
Width: 10

Definition: *Steel frame damage index; number ranging from 0 (negligible) to 9 (destruction)*

GEOTECH_2
Alias: GEOTECH_2
Data type: String
Width: 254

Definition: *Steel frame damage index; number ranging from 0 (negligible) to 9 (destruction)*

GEOTECH_3
Alias: GEOTECH_3
Data type: String
Width: 254

Definition: *Steel frame damage index; number ranging from 0 (negligible) to 9 (destruction)*

INHABIT_D
Alias: INHABIT_D
Data type: Number
Width: 10

Definition: *Number of persons in the surveyed building during the day time*

INHABIT_N
Alias: INHABIT_N
Data type: Number
Width: 10

Definition: *Number of persons in the surveyed building during the night time*

EVAC_DUR
Alias: EVAC_DUR
Data type: String
Width: 254

Definition: *Did any persons evacuate the building during the earthquake*

EVAC_AFT
Alias: EVAC_AFT
Data type: String
Width: 254

Definition: *Did any persons evacuate the building after the earthquake*

EQ_PLAN
Alias: EQ_PLAN
Data type: String
Width: 254

Definition: *Do the people living in the surveyed building have an evacuation plan*

BLD_OCC
Alias: BLD_OCC
Data type: Number
Width: 10

Definition: *How many days the building was unoccupied after the earthquake*

TMP_ACCOM
Alias: TMP_ACCOM
Data type: String
Width: 254

Definition: *where did the displaced persons move to for temporary accommodation*

DIS_ACCOM
Alias: DIS_ACCOM
Data type: Number
Width: 10

Definition: *Distance to the temporary accommodation from the surveyed building*

INJURY
Alias: INJURY
Data type: Number
Width: 10

Definition: *Persons injured during earthquake event*

INJUR_TYP
Alias: INJUR_TYP
Data type: String
Width: 254

Definition: *Type of injury sustained during the earthqauke*

FLR_COLL
Alias: FLR_COLL
Data type: Number
Width: 10

Definition: *Percentage of floor collapse*

UT_WATER
Alias: UT_WATER
Data type: Number
Width: 10

Definition: *Number of days water was unavailable after the event*

UT_POWER
Alias: UT_POWER
Data type: Number
Width: 10

Definition: *Number of days power was unavailable after the event*

UT_GAS
Alias: UT_GAS
Data type: String
Width: 254

Definition: *Number of days gas was unavailable after the event*

UT_TELECO
Alias: UT_TELECO
Data type: String
Width: 254

Definition: *Number of days telephone service was unavailable after the event*

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Appendix A6

Earthquake Damage State Descriptors

HAZUS Derived Building Damage State Descriptions

The severity of building damage is divided and categorised in HAZUS by four damage thresholds; slight, moderate, extensive and complete. The damage severities between these thresholds are defined by descriptions of typical physical damage and for which a typical reparation cost is attributed to restore the structure to a given standard. Presented below is a suite of damage state thresholds for a selection of five building types common in Indonesia. The descriptions have been developed based on HAZUS descriptors and supplemented by Indonesian post-disaster observations. The HAZUS structural and non-structural damage descriptors have been combined where applicable.

Unreinforced Masonry

DAMAGE STATE	DESCRIPTION
Slight	Diagonal, stair-step hairline cracks on masonry wall surfaces. Larger cracks present around window and door openings of walls with a large proportion of open area. Movements of lintels and cracks at the base of parapets.
Moderate	Most wall surfaces exhibit diagonal cracks. Some of the walls exhibit larger diagonal cracks. Masonry walls may have visible separations from floor and roof diaphragms. Significant cracking of parapets. Some masonry may fall from walls or parapets.
Extensive	In buildings with relatively large areas of wall opening most walls have suffered extensive cracking. Some parapets and gable end walls have fallen. Beams and trusses may have moved relative to their supports.
Complete	Structure has collapsed or is in imminent damage of collapse due to in-plane or out-of-plane failure of the walls. Typically 15% of the total floor area has collapsed.

Low Rise Light Wood Frame

DAMAGE STATE	DESCRIPTION
Slight	Small cracks to internal linings (where appropriate) at corners of doors and window openings. Small cracks to wall ceiling connections. Small crack in masonry chimneys and masonry veneer.
Moderate	Large cracks to internal linings (where appropriate) at corners of doors and window openings. Small diagonal cracks across bracing walls. Large cracks in masonry chimneys and toppling of some of the more vulnerable.
Extensive	Large diagonal cracks across bracing wall panels. Permanent lateral movement of floors and roof. Toppling of most chimneys. Cracks in foundations and slippage of structure above across foundations. Partial collapse of soft storey configurations.
Complete	Structure may have large permanent lateral displacements. Some may have collapsed or are in danger of imminent collapse (overall 3% collapsed floor area in population). Large foundations cracks and some structures have slipped off their foundations.

Low to Medium Rise Reinforced Concrete Frame/ Shear Wall

DAMAGE STATE	DESCRIPTION
Slight	**Frames:-** Flexural or shear type hairline cracks in some beams and columns near joints and within joints. **Walls:-** Diagonal hairline cracks on most concrete shear wall surfaces. Minor concrete spalling at few locations. **Non Structural:-** Few cracks in partitions at wall intersections and at ceiling level. A few ceiling tiles have moved or fallen. Exterior wall panels may need realignment.
Moderate	**Frames:-** Most beams and columns exhibit hairline cracks. In ductile frames some of the frame elements have reached their yield capacity indicated by large flexural cracks and some concrete spalling. Non ductile frames may exhibit larger shear cracks and spalling. **Walls:-** Most shear wall surfaces exhibit diagonal cracks. Some shear walls have exceeded yield capacity indicated by larger diagonal cracks and concrete spalling at wall ends. **Non Structural:-** Larger cracks in partitions at wall intersections and at ceiling level requiring repair. Falling of ceiling tiles more extensive with some damage to supporting "T" bar system. Light diffusers have fallen with some light fittings. More extensive damage to exterior wall panels and connections.
Extensive	**Frames:-** Some of the frame elements have reached their ultimate capacity indicated in ductile frames by large flexural cracks, spalled concrete and buckled main reinforcement. Non ductile frame elements have suffered shear failures and or bond failures at splices, broken ties and buckled main reinforcement in columns with possible partial collapse. **Walls:-** Most concrete shear walls have exceeded their yield capacities. Some walls have exceeded their ultimate capacities indicated by larger through-the-wall diagonal cracks, spalling around cracks and visibly buckled wall reinforcement. **Non Structural:-** Most partitions are cracked and many need replacement. Ceiling "T" bar system exhibits extensive buckling and with many light fittings fall. Extensive damage to exterior wall panels and most connections require inspection.
Complete	**Frames:-** Structure has collapsed or is in imminent danger of collapse due to brittle failure f non-ductile frame elements or loss of frame stability. Approximately 13% of low-rise and 10% of medium-rise structure floor area has collapsed. **Walls:-** Structure has collapsed or is in imminent danger of collapse due to failure of most shear walls and failure of some critical beans or columns **Non Structural:-** Most partitions need replacement. Ceiling requires complete replacement. Most exterior wall panels damaged with some panels fall. Extensive damage to glazing.

Concrete Frame With Unreinforced Masonry Infill Walls

DAMAGE STATE	DESCRIPTION
Slight	**Structure and Infill:-** Diagonal (sometime horizontal) hairline cracks on most infill wall. Crack at frame-infill interfaces. **Non Structural:-** Few cracks in partitions at wall intersections and at ceiling level. A few ceiling tiles have moved or fallen. Exterior wall panels may need realignment.
Moderate	**Structure and Infill:-** Most infill wall surfaces exhibit larger diagonal or horizontal cracks. Some walls exhibit crushing in brick around beam column connections. Diagonal cracks may be observed in concrete beams and columns. **Non Structural:-** Larger cracks in partitions at wall intersections and at ceiling level requiring repair. Falling of ceiling tiles more extensive with some damage to supporting "T" bar system. Light diffusers have fallen with some light fittings. More extensive damage to exterior wall panels and connections.
Extensive	**Structure and Infill:-** Most infill walls exhibit large cracks. Some bricks may dislodge and fall. Some walls may bulge out-of-plane. A few walls may fall partially or fully. A few concrete columns or beams may fail in shear resulting in partial collapse. Structure may exhibit permanent lateral deformation. **Non Structural:-** Most partitions are cracked and many need replacement. Ceiling "T" bar system exhibits extensive buckling and with many light fittings fall. Extensive damage to exterior wall panels and most connections require inspection
Complete	**Structure and Infill:-** Structure has collapsed or is on imminent danger of collapse due to a combination of total failure of the infill walls and non-ductile failure of the concrete beams and columns. About 15% of low rise and 13% of medium rise floor area is expected to be collapsed. **Non Structural:-** Most partitions need replacement. Ceiling requires complete replacement. Most exterior wall panels damaged with some panels fall. Extensive damage to glazing

Steel Moment Frame

DAMAGE STATE	DESCRIPTION
Slight	Minor deformations in connections or hairline cracks in a few welds. Minor brace deformation.
Moderate	Some steel members have yielded exhibiting observable permanent rotations at connections. A few welded connections may exhibit major cracks through welds or a few bolted connections may exhibit broken bolts or enlarged bolt holes. Some yielding of braces.
Extensive	Most steel members have exceeded their yield capacity resulting in significant permanent lateral deformation of the structure. Some of the structural members or connections may have exceeded their ultimate capacity exhibited by major permanent member rotations at connections, buckled flanges and failed connections. Some anchor bolts stretched. Partial collapse of portions of the structure may have occurred due to failed critical elements or connections.
Complete	A significant proportion of the structural elements have exceeded their ultimate capacities or some critical structural elements or connections have failed resulting in dangerous permanent lateral displacement, partial collapse or collapse of the building.