BUILDING VULNERABILITY ASSESSMENT, PADANG EARTHQUAKE

Recommendations

3 December 2009
Padang Survey - Oct 2009

International Engineering Team

BUILDING VULNERABILITY ASSESSMENT, PADANG EARTHQUAKE RECOMMENDATIONS

EXECUTIVE SUMMARY

Following the earthquake of 30th Sept 2009, the Australian/Indonesian Facility for Disaster Reduction (AIFDR) supported the development of a team of experts from Indonesia, Australia, New Zealand and Singapore organized through Geoscience Australia and Institut Teknologi Bandung to carry out a survey of buildings across Padang. The survey set out 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 and the region from this event should be supported by the lessons learned from the 30th Sept 2009 earthquake.

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 with design codes, apparent 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.

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 for multi-storey construction
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 that basic design and construction improvements will be necessary if similar or worse impacts are to be avoided from the projected large earthquake and tsunami that is expected to occur in coming decades.

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.

BUILDING VULNERABILITY ASSESSMENT, PADANG EARTHQUAKE

RECOMMENDATIONS

Introduction

Following the earthquake of 30th Sept 2009, the Australian/Indonesian Facility for Disaster Reduction (AIFDR) supported the development of a team of experts from Indonesia, Australia, New Zealand and Singapore organized through Geoscience Australia and Institut Teknologi Bandung to carry out a survey of buildings across Padang. The survey set out 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 a ~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 including a large number of schools and medical facilities. 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 with design codes, apparent 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 associated 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 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 Periaman and Secincin) where the damage was reported to be most severe. Felt intensity in Padang has been identified for the 30 Sept 2009 earthquake to be VIII MMI at most. However, stronger intensity could be experienced under the expected larger earthquake.

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 – further 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. max. 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 stirrup reinforcement in columns was consistently observed to be too widely spaced and poorly detailed, which was particularly critical when column hinging occurred.

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 that basic design and construction improvements will be necessary if similar or worse impacts are to be avoided from the projected large earthquake and tsunami that is expected to occur in coming decades.

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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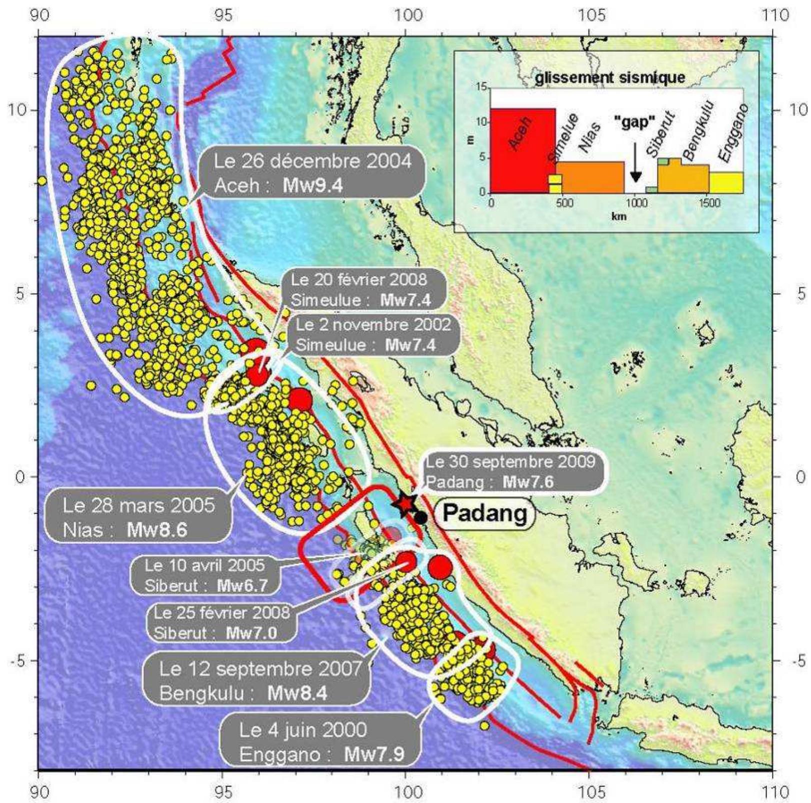

Figure 1 Recent earthquake activity near Padang (image from a web document, source unknown)

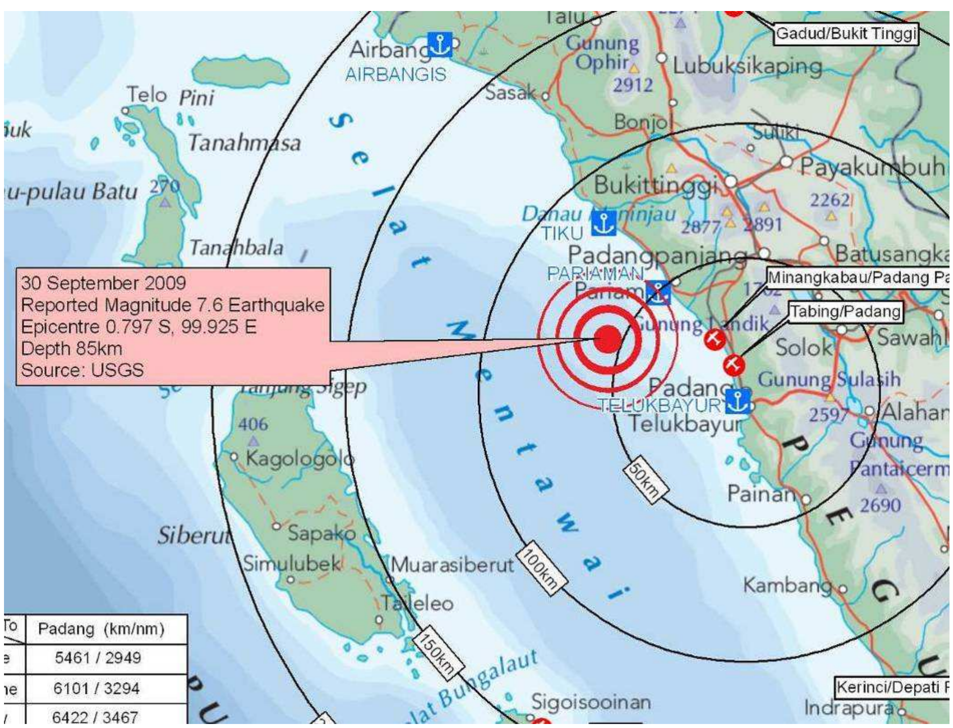

Figure 2 (detail of image from www.defence.gov.au)

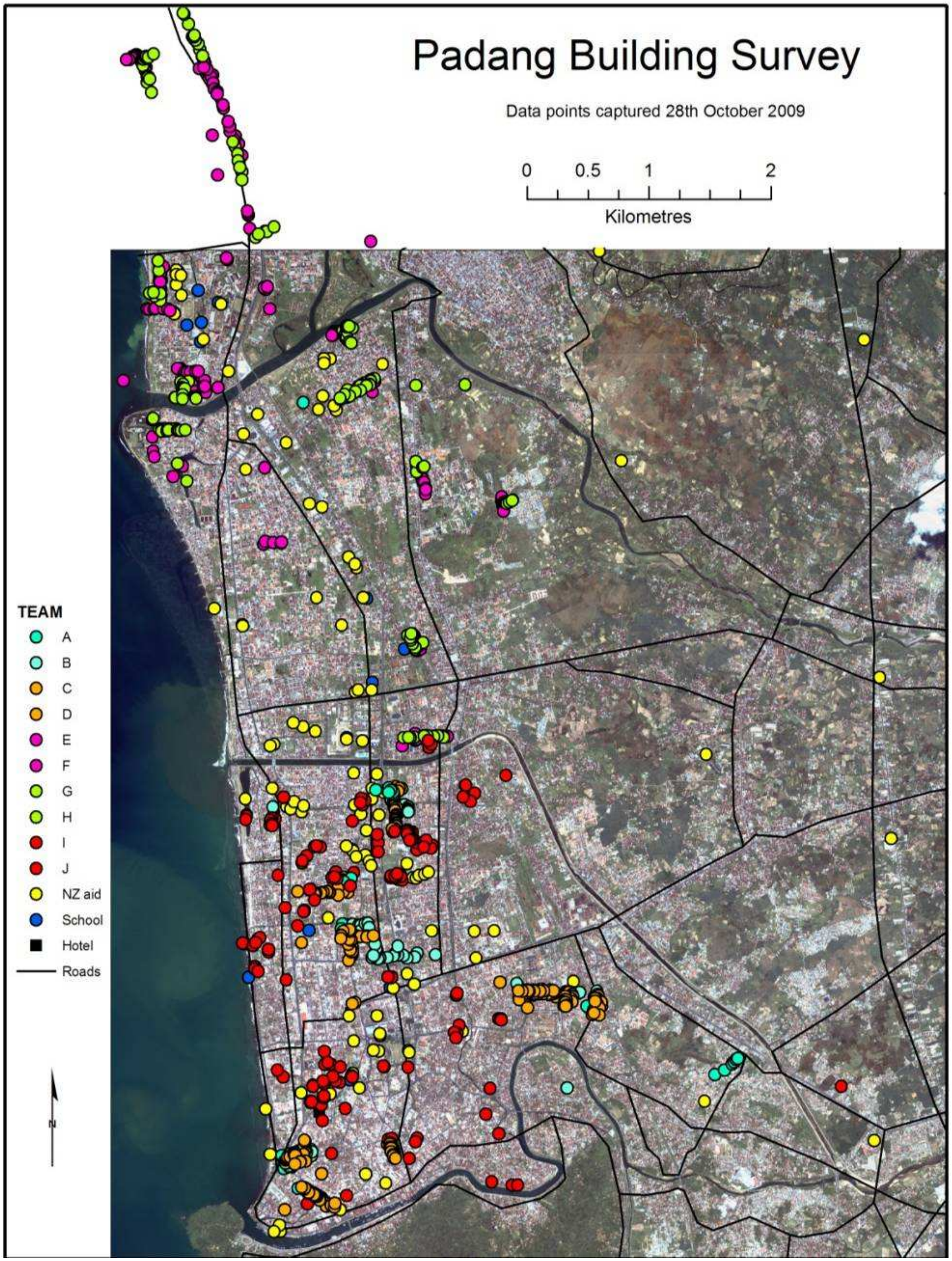

Figure 3 Data plot from survey data base

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 The 6 storey part of this hotel totally collapsed

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

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