2007 West Sumatra Earthquake

Reconnaissance Report

miyamoto.

0A Acknowledgements

The following individuals and organizations assisted in the collection of data and information contained in this report.

Ir. Sjamsuir Burhan, MM – Kepala Dinas	Head of Ministry of Public Works, West Sumatra, Pemerintah Provinsi Sumatera Barat Dinas Tata Ruang dan Permukiman
Mr. Ade Edward	Technical Advisor to the Government of West Sumatra, Indonesian Association of Geologists
Mr. Andrew Gill	Taylor Devices, Inc.
Mr. Michael Harris	PT. Harkomindo, Commercial Director for Earthquake Structural and Protection Systems, Jakarta, Indonesia
Prof. Dradjat Hoedajanto	Associate Professor, Institute of Technology, Bandung, Indonesia
Ir. Dadan Krisnandar	Badan Pembianaan Konstruksi dan Sumber Daya Manusia, Jakarta, Indonesia
Professor Dr. Ir. Yulman Manaf	Rektor of Institute Technology, Padang, West Sumatra, Indonesia
Ir. Mochamad Natsir	Head of Planning Division, Agency for Construction Guidance and Human Resources Development, Ministry of Public Works, Jakarta, Indonesia
Ir. Iwan Nursyirwan	Director General, Agency for Construction Guidance and Human Resources Development, Ministry of Public Works, Jakarta, Indonesia
Professor Dr. H. Marlis Rahman	Vice Governor of West Sumatra, Indonesia
Ir. Taufik, MT	Sekretaris, Indonesian Society of Civil and Structural Engineers, Padang, West Sumatra, Indonesia
Ir. Hilda Osmiati	Chairperson, Solok Regency Council, West Sumatra, Indonesia
Ir. Sumaranto Widayatin	Senior Advisor to the Minister of Public Works on Inward Investment and Economic Affairs, Jakarta, Indonesia
Ir. Agoes Widjanarko	Director General, Ministry of Public Works, Directorate General for Human Settlements

00 Contents

01 Introduction

ON MARCH 6, 2007, A POWERFUL EARTHQUAKE HIT THE INDONESIAN ISLAND OF SUMATRA. IT RESULTED IN 70 FATALITIES, 500 INJURIES, AND SEVERE DAMAGE OR COLLAPSE OF NEARLY 15,000 BUILDINGS.

The total damage from the earthquake is estimated at over US$180 million, which is a large sum for this area. The quake had a moment magnitude of 6.4 and struck close to the city of Padang in the west part of the island, at 10:49 a.m. local time. The quake was preceded by two tremors, magnitude 4.8 and 4.9, which caused panic. As a result, people fled their homes and buildings, and this, in turn, reduced the number of casualties from the main shock. The main shock was followed by many aftershocks. The damage from the earthquake was substantial and included collapse of industrial buildings, mosques, homes, schools, and businesses.

As distressing as the human loss and economic consequences are, the effects could have been much worse. A large population inhabits the area alongside the Sumatra Fault. Cost-effective and reliable retrofit methods need to be developed to prepare this area for the next earthquake.

On March 17, an expert team led by K. Miyamoto of Miyamoto International and consisting of PT. Harkomindo, Professor Hoedajanto, and local experts and government officials, surveyed the impacted area and investigated the earthquake damage. Following the on-site investigations, the group formulated cost-effective and simple-to-implement retrofit strategies. The purpose of these strategies is to reduce future potential casualties and structural damage in this seismically active region. This report summarizes their findings.

Figure 1. Sumatra Earthquake of March 2007.

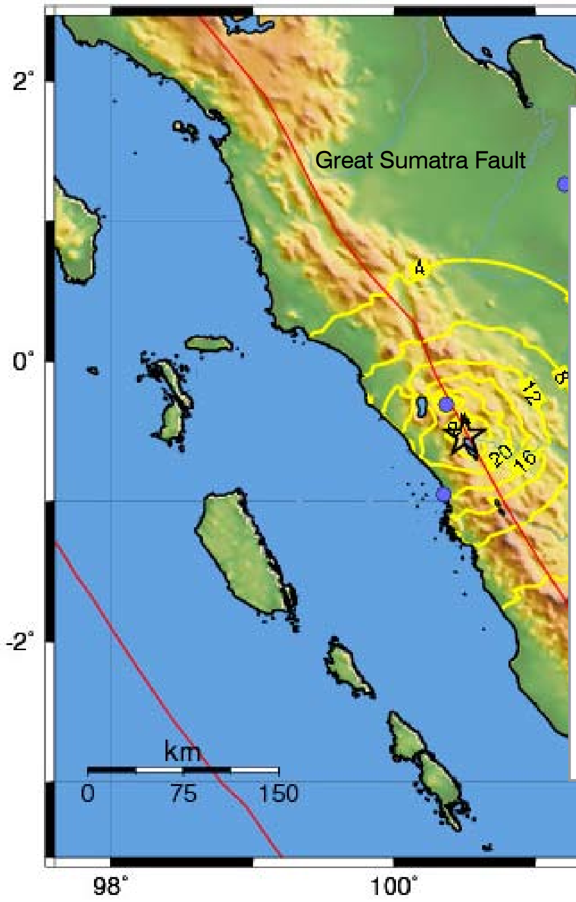
02 Earthquake Details

The main tremor had a magnitude of 6.4. Its epicentral depth is estimated at 30 kilometres. It occurred on March 6, 2007 at 10:49:41 a.m. local time, with an epicentre located at 0.536S, 100.498E, approximately 49 kilometres north-northeast of Padang, Sumatra, Indonesia.

Figure 2(inset) presents the earthquake as felt on the Modified Mercalli Intensity (MMI) scale. This quake is classified as a VI to VIII event on the MMI scale. This MMI corresponds to strong, shaking and moderately heavy damage.

As shown in Figure 3, the estimated peak ground acceleration (PGA) for this quake is approximately 30%g close to the site. The main tremor was preceded by several foreshocks and many aftershocks.

On March 6, 468 shocks measuring between 4.4 and 5.8 on the Richter scale were recorded. These shocks were followed by 355 shocks of magnitude 3.0 to 4.5 on the day after and by 114 shocks greater than magnitude 3.0 in the next two days.



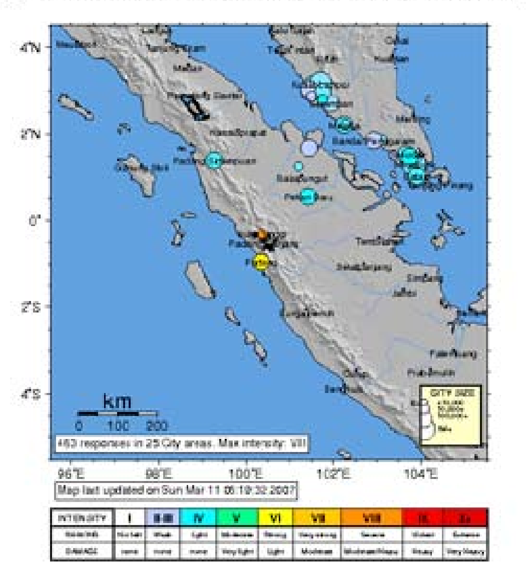


Figure 2. MMI for the main shock (from the United States Geological Survey).

Figure 3. Estimated PGA. %g (from the United States Geological Survey).

03 Seismicity of Indonesia

Indonesia, the world's largest archipelago, is prone to earthquakes due to its location on the so-called Pacific "Ring of Fire," an arc of volcanoes and fault lines encircling the Pacific Basin. Indonesia is located close to many major faults, and, as shown in Figure 4 many major tremors have hit the country.

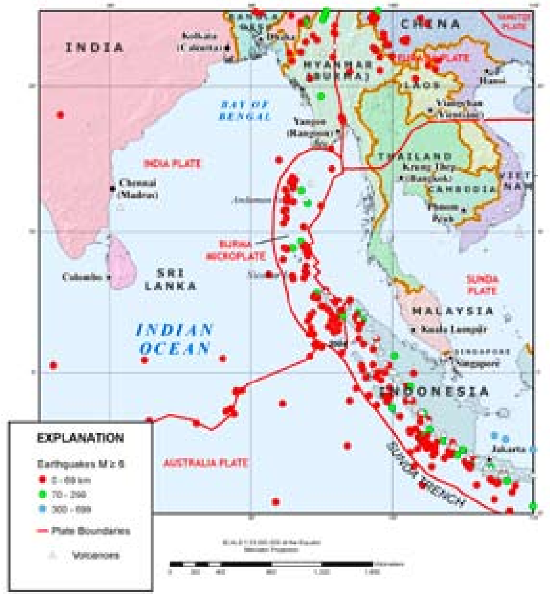
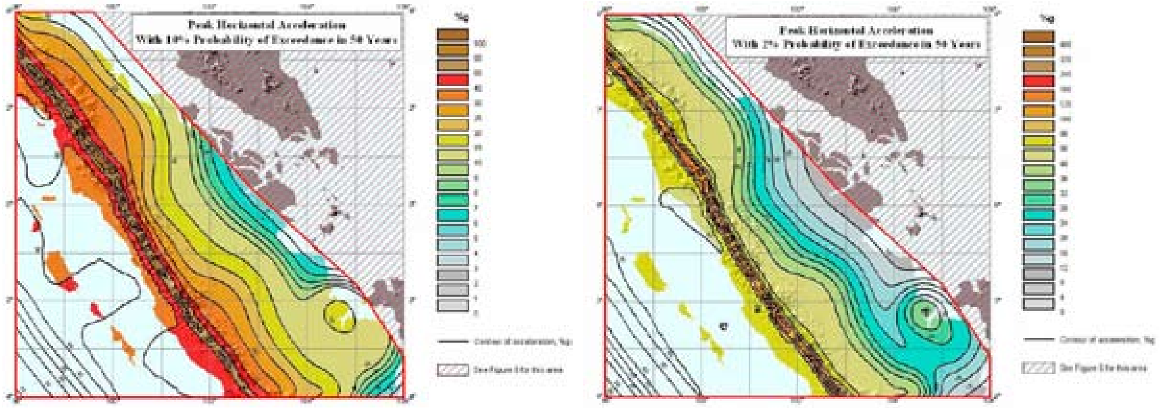


Figure 4. History of earthquakes in Indonesia (from the United States Geological Survey).

Figure 5 shows the 500- and 2,500-year return events and their expected peak ground accelerations for Indonesia. Note that at Sumatra, and near the site of the March 2007 earthquake, large accelerations are to be expected. In particular, for the 2,500-year event, the peak ground acceleration is well over 150% of gravity, and as such, it is expected that large earthquakes will occur and that these hazards will place large seismic demand on the structural systems.



a. 500-year event

b. 2500-year event

Figure 5. Earthquake hazard maps of Western Sumatra (from the Institute of Technology, Bandung, Indonesia).

Padang, in Sumatra, is one of several Indonesian cities where a tsunami warning system exists. In December 2004, a powerful magnitude 9.1 earthquake off Sumatra triggered a tsunami that killed more than 250,000 people in a dozen Indian Ocean countries, including more than 160,000 in Indonesia's Aceh province.

Date	Location	Magnitude	Fatalities
1917 01 02	Bali	N/A	1,500
1938 02 01	Banda Sea	8.5	
1976 06 25	Papua	7.1	5,000
1992 12 12	Flores Region	7.5	2,500
2000 06 04	Southern Sumatra	7.9	103
2002 10 10	Irian Jaya	7.6	8
2002 11 02	Northern Sumatra	7.5	3
2003 05 26	Halmahera	7.0	1
2004 01 28	Scram	6.7	37
2004 02 05	Irian Jaya	7.0	
2004 02 07	Irian Jaya	7.3	
2004 07 25	Southern Sumatra	7.3	
2004 11 11	Kepulauan Alor	7.5	34
2004 11 26	Papua	7.1	32
2004 12 26	Sumatra	9.1	283,106
2005 01 01	Off the W. Coast of N. Sumatra	6.6	
2005 02 19	Sulawesi	6.5	
2005 02 26	Simeulue	6.8	
2005 03 02	Banda Sea	7.1	
2005 03 28	Northern Sumatra	8.6	1,313
2005 04 10	Kepulauan Mentawai Region	6.7	
2005 05 14	Nias Region	6.7	
2005 05 19	Nias Region	6.9	
2005 07 05	Nias Region	6.7	
2005 11 19	Simeulue	6.5	
2006 01 27	Banda Sea	7.6	
2006 03 14	Seram	6.7	4
2006 05 16	Nias Region	6.8	
2006 05 26	Java	6.3	5,749
2006 07 17	South of Java	7.7	730
2007 01 21	Molucca Sea	7.5	4
2007 03 06	Sumatra	6.4	70

Table 1. List of Major Earthquakes in Indonesia, 1917 to 2007 Earthquake Details (from the United States Geological Survey).

04 Commercial and Residential Buildings

Most commercial, retail, and residential buildings at the earthquake site consist of three types of structures: (1) unreinforced masonry (URM) walls, with one withe, and concrete “bond” beams and columns; (2) wood framing, and (3) concrete moment frame structures with URM infills. There are very few industrial facilities in this area; therefore, there was no reportable major damage to industrial structures.

URM buildings performed poorly and sustained severe damage and collapse. Concrete bond beams and columns typically occur on the two ends and top of URM infill walls. These concrete members usually have a small cross-section and are lightly reinforced with longitudinal smooth bars. They have minimal transverse reinforcement, use poor joint detailing, and do not provide confinement to the infill URM. The URM walls do not have out-of-plane connections to roof or floor diaphragms. The wood-frame buildings fared relatively well because they are a lightweight building system. The major issue for wood construction was collapse induced by soft-story response of the first story. Reinforced concrete moment frame structures exhibited shear failure, spalling, and failure at the joints.

Nearly 44,000 structures sustained damage. The damage was considered medium and heavy for approximately 60% of these buildings. As a result, more than 135,000 people were displaced. It appears that 20% of the total residential structures have collapsed or have sustained significant damage.

Figure 8. These photographs show out-of-plane failure of URM walls. These URM buildings do not have adequate floor diaphragms, and URM walls are not positively connected to the perimeter bond beams and columns. As such, they are not restrained against out-of-plane failure.

Figure 6. This commercial/residential structure used URM framing. The lateral-story stiffness and strength were significantly less for the upper floors and resulted in a soft-story collapse of the first story.

Figure 7. The presence of URM infill dramatically alters the seismic response of concrete frames. The infills reduce the clear height of the columns from story height to the height between solid infills. This short-column effect prevents development of full flexural capacity and induces brittle shear failure.

Figure 9. The beam-to-column joints for the concrete moment frames do not use ductile detailing. The reinforcement steel does not extend sufficiently into the joint, nor does it have adequate development length. Furthermore, the joints are not confined and hence are susceptible to shear failure.

05 Religious Facilities

Indonesia is the world's most populated Muslim country. Mosques are common in Indonesia. Typical mosque structures use concrete framing consisting of tall, slender columns. URM infills are placed on one (back) side of the building. As such, these buildings experience torsional-translational coupled response.

More than 950 mosques were damaged in the earthquake. Approximately 65% of these buildings sustained medium or heavy damage. Had the quake occurred during prayer time, it would have resulted in substantial casualties.

Figure 10. This photograph shows typical mosque construction. Note the slender exterior concrete columns. This building was constructed in the mid-1990s.

Figure 11. These photographs show spalling of concrete from tall, slender column at the story level and shear failure of the interior URM wall. Note that walls are placed on the back side only, and thus the building is torsionally irregular.

Figure 12. Collapse of a mosque is shown in these photographs. The URM walls on the extreme edges of the building collapsed due to the torsional motion.

06 Schools

The 2007 earthquake caused substantial damage to school buildings. These buildings use URM wall framing and thus experienced many of the same failures previously noted for residential structures. URM school buildings are the most vulnerable structures. These buildings must be retrofitted immediately, because many children's lives are in danger.

More than 700 school buildings were damaged, including more than 300 collapsed buildings. Of these, over 65% of damage was classified as either major or moderate. Foreshocks saved many students' lives. However, two teachers were killed.

Figure 13. The photograph shows unreinforced retaining wall failure of a school building. Note the diagonal shear cracks on the URM walls at the side of the building.

Figure 14. These photographs show out-of-plane collapse of URM walls. The walls were not adequately anchored to the foundation or roof diaphragm to restrain the URM walls. The Sumatra Fault is shown in the near distance. The roof diaphragm, perimeter concrete beam, and columns were weak.

Figure 15. The photographs show nonstructural damage to a school building. This building did not sustain any structural damage. However, the ceiling and soffit collapsed. Unless these elements are properly designed and anchored, they are life-safety hazards. For this school building, ceiling panels collapsed in the classrooms, and roof soffit panels dislodged.

07 Bridges

In this part of Indonesia, there are many bridges that cross the Great Sumatra Fault. Bridges are very important lifelines. After earthquakes, operational bridges are required for emergency access. A three-span concrete bridge close to the epicentre was near collapse after the March earthquake. Another two-lane steel bridge also close to the epicentre had slid off its bearings at the abutments.

Figure 16. The photographs show failure of piers for the concrete bridge. A heavy deck and bents contribute to high seismically induced force experienced by the bridge, which caused the brittle shear failure in one bent and rocking at another. This bridge is near collapse, and traffic has been redirected.

Figure 17. This photograph shows a steel truss bridge located in the earthquake-impacted area. Note that the superstructure did not sustain any damage. However, the bridge had an inadequate transverse shear key, and its abutment bearings had insufficient movement capacity. The steel members in this bridge appeared to be undamaged.

Figure 18. The photographs show failure of the substructure elements for the same steel truss bridge. The bridge is supported on bearings at the abutments, and it did not have an adequate transverse shear key. During the earthquake, the bridge slid off its bearings. The bearing pads did not have adequate width and/or restraint to allow or resist the seismic movement.

08 Lifelines

Immediately after the earthquake, the power was disconnected. Post-earthquake investigation showed that one of the bushings had tipped over. The bushing was not damaged. It was re-erected in the upright position, and electricity was restored within two days. The water and wastewater facilities were not damaged. The telephone lines were operational.

Figure 19. The local electric substation and its bushings are shown above. One bushing fell and caused a blackout for a few days.

09 Emergency Facilities

None of the hospitals were damaged severely during the earthquake. However, a fire station sustained significant damage. This one-story building had URM infill and concrete bond beam framing. Because of the damage, the firefighters had to erect tents for shelter.

Figure 20. A damaged local fire station building, with the cracked URM wall is shown in the top photograph, and temporary shelter for five firefighters is shown in the bottom photograph.

10 Ground Failure

The Great Sumatra Fault is a large fault with several modes of ground failure that were observed following the earthquake. There was liquefaction near the site, close to a lake. The epicentre of the fault was situated on sandy soil. Additionally, there were large areas of landslide and ground failure.

Figure 21. The extent of the Sumatra Fault is shown in this photograph. This is an inland slip fault and is 120 kilometres long with a subduction zone offshore. The earthquake caused a rupture along a 200-metre section, and there were three segments that slipped.

Figure 22. A large landslide caused by the earthquake is shown in this photograph. Note the roadway at the bottom of the landslide. This slide buried four houses.

Figure 23. As shown in these photographs, the earthquake also caused noticeable ground rupture both horizontally and vertically. Note the large section of slope instability next to the Great Sumatra Fault in the bottom photograph.

11 Emergency Response

Shortly after the earthquake, local authorities provided temporary shelters. The local agencies conducted a survey of the structures in the region. The buildings were green-, yellow-, and red-tagged to indicate, safe, damaged, and dangerous conditions, respectively.

TIDAK AMAN

TIDAK BOLEH DIPAKAI / DITEMPATI

Figure 24. A red-tagged building is shown in the top photograph, and seismographs at the local seismological station are shown in the bottom photograph.

Figure 25. The photographs show erected shelters and a temporary school by UNICEF and other agencies for displaced residents. Note that the permanent school building was completely destroyed; only debris remains.

12 Seismic Retrofits

Because this area experiences frequent large earthquakes and because many buildings are constructed near or on the fault line, it is imperative to develop rapid, reliable, and cost-effective seismic retrofit strategies for the typical buildings. Conceptual recommendations are outlined here.

12.1 URM AND REINFORCED CONCRETE (RC) BUILDINGS

For URM infills and concrete bond beams, it is recommended to strengthen the beam-to-column joints; see Figure 26. This will avert the brittle shear failure at the joints and will allow the concrete elements to provide some confinement to infills. Most importantly, they will carry the gravity loading and mitigate the building collapse.

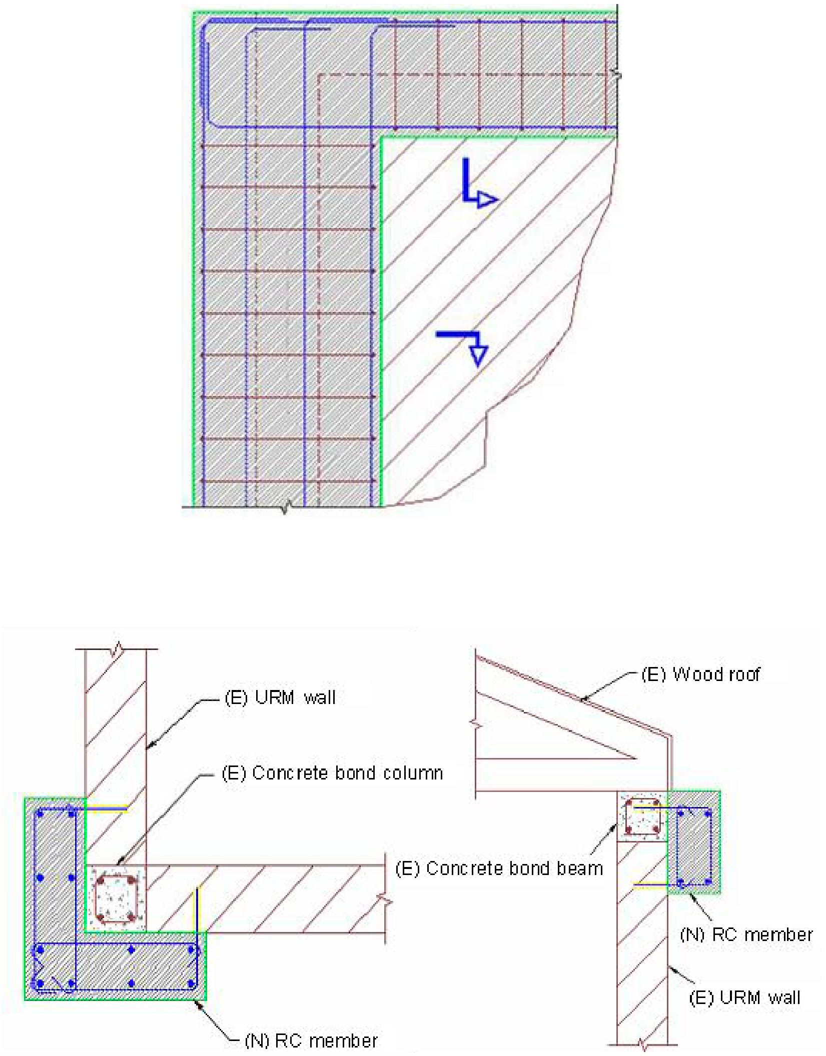


Figure 26. Proposed retrofit for the joints of concrete beam-column frames.

12.2 BUILDINGS WITH SOFT-STORY VULNERABILITY

To alleviate soft-story and torsional response of mosques and other commercial buildings, either braces or dampers can be added to the first floor of the building; See Figure 27.

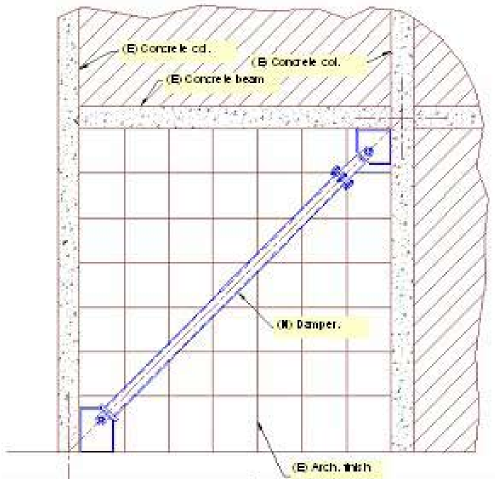


Figure 27. Damper used to mitigate soft-story response.

12.3 BRIDGES

For bridges that are supported at the abutments on inadequate bearing pads, seismic isolation pads provide an attractive replacement alternative. This isolation system will serve to reduce the inertial forces transferred to the substructure. Additionally, a well-designed system with adequate transverse shear keys would prevent the type of failures observed during this earthquake.

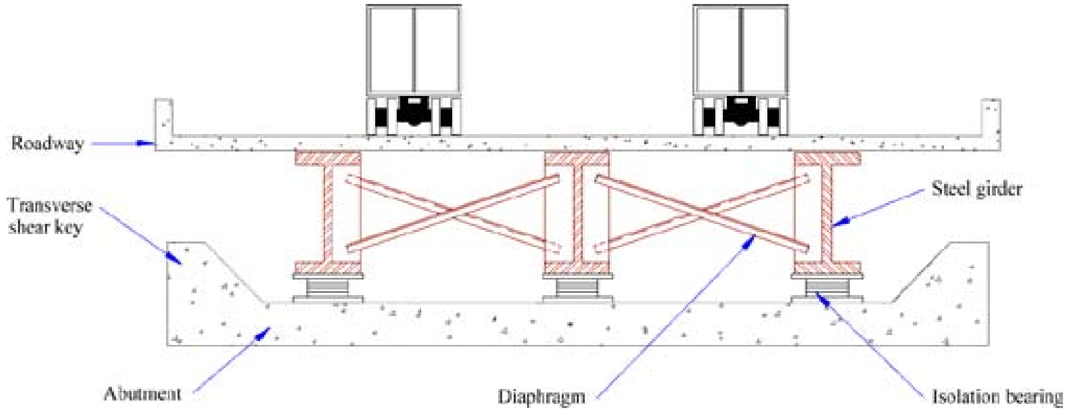


Figure 28. Schematic of a typical steel bridge with isolation bearings.

13 Conclusions and Recommendations

Post-earthquake reconnaissance of the West Sumatra region found widespread damage to residential buildings, schools, mosques, bridges, and industrial buildings.

Damage was anticipated after two magnitude 4.8 and 4.9 events, which were quickly followed by the main event of magnitude 6.4 some two hours later. The extent of the damage, however, was quickly identified as being excessive for this intensity of earthquake, with many destroyed or heavily damaged buildings.

Sadly, 70 people lost their lives, and more than 500 were injured. The misery was compounded by the total destruction of more than 700 schools, 950 damaged mosques (65% of them heavily damaged), and nearly 15,000 severely damaged or collapsed buildings. More than 135,000 people were left homeless. The total damage is estimated at over US$180 million.

This event was a “near miss.” If the magnitude 6.4 quake had hit first, mid-morning, then all the schools would not have been evacuated, and a collapse could easily have killed thousands of children in the area.

Most of the damage seen could have been either mitigated or reduced by incorporating sound seismic design, known standard construction practices, and good quality control. Such approaches can both save lives and protect structures.

It is important to understand that these practices are not difficult to implement; they are simple and cost-effective.

All parties who assisted in this earthquake reconnaissance urgently suggest that such efforts be undertaken, because the failure to do so in this volatile seismic area could result in more devastation and unnecessary loss of life when the next earthquake hits Sumatra, or any of the risk areas of Indonesia.

It is recommended that a seismic risk mitigation strategy be organized for both West Sumatra and other potentially hazardous areas of Indonesia. The highest priority should be given to schools, mosques, and bridge structures, because these groups of structures are extremely vulnerable to earthquake damage and impact large populations.

14 References

Institute of Technology, Bandung, Indonesia, http://www.itb.ac.id
United States Geological Survey, http://www.usgs.gov

Miyamoto International, Inc.
Structural and Earthquake Engineers
1450 Halyard Drive, Suite One
West Sacramento, CA 95691
t 916.373.1995
f 916.373.1466

www.miyamotointernational.com