AIRCURRENTS

POST-DISASTER SURVEY FINDINGS FROM THE 2009 PADANG EARTHQUAKE

01.2010

EDITOR'S NOTE: Dr John E. Alarcon, Research Associate in AIR's London Office, co-led the Earthquake Engineering Field Investigation Team's (EEFIT) mission after the M7.6 earthquake that occurred off the coast of Sumatra last September. In this article, Dr. Alarcon recounts the event and presents some preliminary findings on the distribution of damage in the city of Padang and surrounding region.

By Dr John E. Alarcon

THE 30TH SEPTEMBER 2009 PADANG, SUMATRA, EARTHQUAKE

Just before dusk on 30th September 2009, a M7.6 earthquake occurred about 55 kilometres west northwest of the low-lying coastal city of Padang (est. pop. 900,000), the capital of Indonesia's West Sumatra province. The epicentre of the event occurred in the same subduction region as the M9.1-9.3 2004 Sumatra-Andaman earthquake that generated a tsunami resulting in the deaths of more than 200,000 people. September's quake caused more than 1,100 fatalities and injured another 2,900 people, a third of them severely. More than 270,000 buildings in Padang and Padang Pariaman regency suffered various degrees of damage.

As a transit point for tourists headed to other islands, Padang is home to many hotels, some of which were either severely damaged or collapsed. Hospitals and a large shopping centre in Padang were also significantly affected. The earthquake is estimated to have caused total losses of between USD$ 750 and US$860 million, and insured losses of more than US$40 million, which represent about 5% of the ground-up losses.

TECTONIC SETTING AND SEISMIC HISTORY

Indonesia is located on the Pacific Ring of Fire, where the largest earthquakes in the world have been recorded. Within Indonesia and along the western coast of Sumatra, seismicity is controlled by the subduction of the Indo-Australian plate beneath the Sunda plate at the Sunda trench (Figure 1). The Sunda trench was the source of September's earthquake.

The relative motion between the Indo-Australian and Eurasian plates varies along Sumatra, with a slip rate of about 52 mm per year at the northern end of the island, in the region of Ache, and about 62 mm per year at the southern end. Onshore is the Sumatran crustal fault system, about 1,900 km in length and running roughly parallel to this portion of the Sunda trench. Its strike-slip motion is caused by the oblique convergence between the Indo-Australian and Sunda plates and the strain partitioning the subduction zone thrust fault and the Sumatran crustal fault.

The Sumatran fault system is highly segmented, with the majority of segments being less than 100 km long. As a result, the potential earthquake rupture length within the Sumatra fault system is not likely to produce earthquakes that exceed magnitudes of about 7.5 (McCaffrey, 2009).

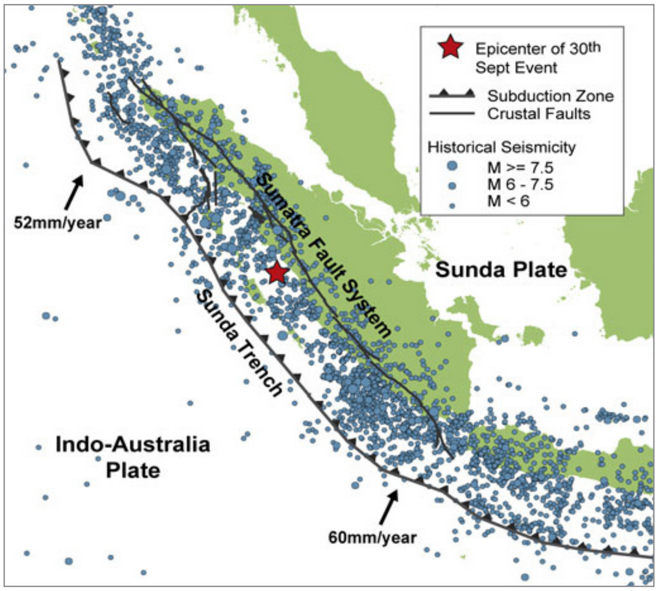

Figure 1. Tectonic setting of Sumatra (Source: AIR)

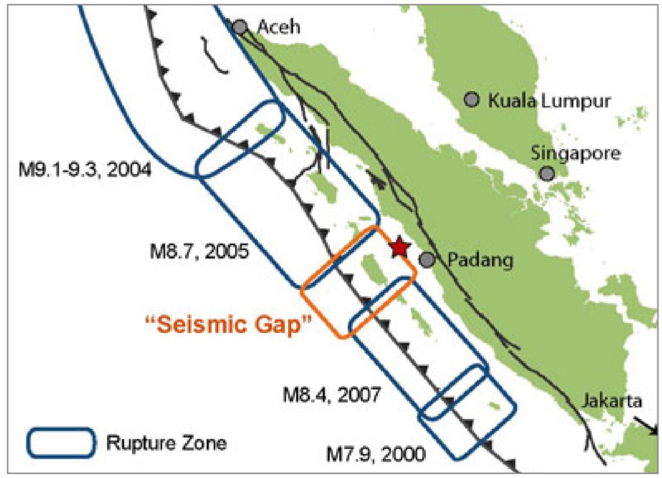

Figure 2: The outlined areas represent the approximate fault rupture areas of recent events while the red star shows the epicentral location of the 30th September earthquake. (Adapted from Vigny, 2009).

On the other hand, the offshore Sunda trench is known for producing mega-thrust earthquakes, including the M8.8-9.2 in 1833, the M8.3-8.5 in 1861, the previously mentioned M9.1-9.3 in 2004, the M8.7 in March 2005 and the M8.4 in September 2007. In a recent study, Aydan et al. (2007) identified a segment of the subduction zone facing Padang that has not ruptured in the previous 213 years (Figure 2). The segment on which this so-called "seismic gap" exists has the potential to produce an earthquake with magnitude greater than 8.7; such earthquakes on segments near Padang have been estimated to have recurrence intervals of approximately 260 years (Zachariasen et al., 1999).

However, the earthquake of the 30th September was assigned a magnitude of 7.6 by the BMKG (the Indonesian geological and meteorological agency)—considerably lower than would be expected from an earthquake that would "fill" the seismic gap—and it occurred at a depth of about 71 km, suggesting that it occurred within the deep Benioff zone of the subduction area. Thus some seismologists argue that the potential for a large magnitude event adjacent to Padang is still latent—that is, the seismic gap is still present.

LESSONS LEARNED DURING THE POST-DISASTER SURVEY

The city of Padang and the nearby mountainous region to the north, in Pariaman regency, were extensively surveyed with the objective, among other things, of evaluating the actual performance of structures and comparing it to expected performance as specified in design codes. What follows is a summary of findings.

Residential Structures

Damage to residential structures was not widespread, with the most severe damage concentrated in certain areas of Padang city and towns in Pariaman regency. Residential structures here are predominantly one- to two-storey high buildings constructed of confined masonry. Since temperatures in the region average 27°C throughout the year, houses typically have high ceilings for ventilation purposes, with roofs composed of wood frames with corrugated-galvanised iron sheets fixed on top (Figure 3). These light-weight roofs significantly reduce lateral inertia compared to structures with concrete slab roofs, and their ubiquity is one of the reasons for the relatively low damage ratios to residential structures, most of which are uninsured against the earthquake peril. In low-income areas or in small villages, unreinforced masonry (URM) and wooden houses, or a mixed of masonry and wood, were also observed. Here, URM buildings sustained significantly more damage than wood frame houses. By contrast, wealthy sectors of Padang and Pariaman have a number of houses constructed of moment resisting frames with infill walls, which experienced various degrees of shear cracking.

Figure 3: Residential house in Padang (left) and typical roof configuration (right). (Source: AIR)

Commercial Structures

Commercial buildings in Padang can be divided into two categories: small to medium retail trade businesses such as those found in Padang's Chinatown, and large commercial business mainly represented by hotels and large shopping centres. Businesses in the first category occupy structures similar to the residential building stock and thus large numbers of collapsed structures were not observed; rather, most of the observed exposures exhibited no or only moderate damage. On the other hand, a significant number of large commercial structures, mainly of moment-resistant frames of reinforced concrete (RC), suffered significant damage or even collapse. The predominant failure mechanism of RC structures was soft storey failure. Many of these buildings provide public access at the street level; if these accesses involve large openings for garages or commercial space, they can, if not properly taken into account in the design process, lead to pancake-style collapses of the ground floor.

The second cause of observed failures in RC buildings was the result of poor reinforcement in columns, particularly in terms of spacing of links in the column/beam joints.

The results of a number of interviews carried out during the survey confirmed that hotels and large commercial structures (i.e., shopping centres) were in fact insured against the earthquake peril—a circumstance that undoubtedly led to the relatively large reported insured losses from this event.

Figure 4: Examples of severe damage and collapse of Hotels in Padang. With the exception of the Bumiminang Hotel (top left) that suffered severe damage to infill walls, though the structural elements behaved generally well, most failures in hotel structures occurred due to soft storey failure, as shown in the other panels. (Source: AIR)

Industrial Facilities

Industrial buildings performed very well during the earthquake, with most industrial facilities showing little or no structural damage. However business interruption played an important role since for all practical purposes all production in Padang stopped for a week due to electrical power cuts (service in Padang was cut as a precaution against fires igniting due to short circuits). Even after power was restored, machinery had to be recalibrated before start-up; nearly 40 days after the event, most industrial production had not yet reached 100% of pre-earthquake levels.

Figure 5: Cement plant (left) and rubber plant (right) in Padang. Only minor damage was observed, though business interruption was likely an issue for these insured facilities. (Source: AIR)

Governmental buildings, most of them three- to five-storey high RC structures, suffered severe damage. According to senior engineers from Bung Hatta University, about 80% of governmental buildings in Padang were severely damaged or collapsed. As in the case of hotels, the principal cause of failure in governmental buildings was due to soft storey failure.

Two private hospitals (both uninsured) sustained heavy damage to non-structural elements and moderate to high levels of damage to columns. Even though the largest public hospital in Padang coped very well with the emergency, the building housing the outpatient clinic collapsed as a result of soft storey failure. This structural behaviour was surprising given that is something that design codes clearly aim to avoid due to the importance of hospitals after an event like this one. A point worth noting is that governmental buildings are the only structures for which, by law, supervision of the implementation of the codes during construction is implemented.

Figure 6: Collapse of governmental buildings in Padang, caused by soft storey effects. (Source: AIR)

As noted before, the occurrence of significant damage to RC structures (many, if not most of them insured) explains the relatively large insured losses from this event. This disproportionate damage was caused by several things, including soft storey effects, old design codes (see next section), poor reinforcement of columns, and possibly the lack of enforcement of design specifications during construction. From a ground motion perspective, causes for the apparent singling out of RC buildings may come from the frequency content of the incoming seismic waves; for example, given the earthquake's depth, the short period (high frequency) seismic waves may have attenuated much faster than seismic waves with longer periods (low frequency), which correspond to the natural period of vibration of tall RC buildings. Particular site effects caused by the soils beneath Padang are another potential cause for the observed damage distribution—a topic currently being researched at AIR. Interestingly, fire following earthquake was not an issue in Padang with only seven cases reported.

BUILDING CODES AND PRACTICES

Indonesia has a federal government in which each of its 33 provinces has administrative independence. Until the end of 2002, engineered structures were designed following local building design codes. From about 320 municipalities in Indonesia, only about 210 (70%) had local building regulations and of these, only about 45 actually regulated the technical parameters of design (the rest regulated only building permit processes and fees). In 2002 the Indonesian government approved a regulation in which engineered structures are obliged to meet the requirements of the national seismic code, the SNI-1726-2002. The current design code can be considered as having modern standards equivalent to those of Europe or the United States. In Western Sumatra, the pre-2002 code prescribes only that buildings be able to withstand ground motions with a return period of 200 years, while the new code establishes a 475-year return period for design ground motion.

Another potential issue of seismic design regulation in Indonesia is that the verification of code implementation during construction is not regulated. Compliance was particularly poor in the period prior to the formulation of the national code in 2002, and it was therefore not surprising that observed damage to older RC buildings was often the result of poor quality and spacing of reinforcement bars and, in some cases, of the concrete itself.

CLOSING THOUGHTS

The Padang earthquake severely affected the province of Western Sumatra, although the focal depth of the event undoubtedly mitigated the potentially catastrophic effects that might be expected from an earthquake of this magnitude. Of particular note, and perhaps contrary to commonly held perceptions, it was not the residential building stock of one- and two-storey buildings that suffered most; instead, taller commercial buildings of reinforced concrete with moment-resisting frames (mainly hotels and governmental buildings) suffered disproportionate—and severe—damage, driven primarily by soft storey failure and poor quality construction.

Given the seismic gap that many seismologists argue still exists along the Sunda trench, a much larger earthquake than September's event may still be "overdue" in the region adjacent to Padang—a situation that can only reinforce the importance of continued improvements in the vulnerability of buildings in this ever-growing provincial capital.

REFERENCES

AYDAN, O., IMAMURA, F., SUZUKI, T., FEBRIN, I., HAKAM, A., MERA, M., DEVI, P.R. 2007. A RECONNAISSANCE REPORT ON THE BENGKULU EARTHQUAKE OF SEPTEMBER 12, 2007. PUBLISHED JOINTLY BY JAPAN SOCIETY OF CIVIL ENGINEERS AND JAPAN ASSOCIATION FOR EARTHQUAKE ENGINEERING.

MCCAFFREY, R. 2009. THE TECTONIC FRAMEWORK OF THE SUMATRAN SUBDUCTION ZONE, ANNUAL REVIEWS OF EARTH AND PLANETARY SCIENCES, 37, 345-366.

VIGNY, C. 2009. THE EARTHQUAKE OF PADANG, SUMATRA OF 30 SEPTEMBER 2009: SCIENTIFIC INFORMATION AND UPDATE. GEOSCIENCE DEPT., ECOLE NORMALE SUPÉRIEURE.

ZACHARIASEN M, SIEH K, TAYLOR FW, EDWARDS RL & HANTORO WS. 1999. SUBMERGENCE AND UPLIFT ASSOCIATED WITH THE GIANT 1833 SUMATRAN SUBDUCTION EARTHQUAKE: EVIDENCE FROM CORAL MICRO-ATOLLS. JOURNAL OF GEOPHYSICAL RESEARCH; 104:895-919.

ABOUT AIR WORLDWIDE CORPORATION