EARTHQUAKE HAZARD CENTRE NEWSLETTER

Vol.19 No.4 APRIL 2016 ISSN:1174-3646

Contents

Editorial

In today's newspaper of April 20th, an article recounts stories of survival from collapsed buildings after the Ecuadorean earthquake of two days ago. Three people had been pulled from the rubble 32 hours after 7.8-magnitude earthquake.

Sadly, when the media is drawn to these dramatic rescues attention is diverted from those hundreds who were killed and the thousands injured. Also there is generally little mention that it is possible to build safely and to prevent this loss of life and large number of injuries.

On last night's TV news, images were screened of many collapsed and very badly damaged buildings. It looked as if many unreinforced masonry walls, load-bearing, infill and partition walls, collapsed. Let's hope that in the rebuild such walls will be either be physically-tied back to structural elements or reinforced to prevent their future collapse. And also that where unreinforced masonry buildings are rebuilt, confined masonry construction will be, because of its good safe track record, the preferred structural system. For a small additional cost it is possible to design and build in masonry without fear of collapse during an earthquake.

The Ecuador earthquake occurred a day after a damaging quake hit Kumamoto, Japan. Here too tremendous damage was caused, in part by large landslides. But the death toll will be far less due to many of the Japanese houses being timber frame, an absence of unreinforced masonry construction, and generally improved building standards for reinforced concrete buildings. Even with their timber frame construction, many older houses collapsed, and it is likely that their heavy tiled roofs would have contributed to this situation.

The three summarized articles in this newsletter are based upon preliminary reconnaissance surveys following the 26 Oct 2015 Afghanistan-Pakistan earthquake and the 16 Sept 2015 Coquimbo, Chile earthquake. In Pakistan the seismic vulnerability of non-engineered adobe and masonry construction was cruelly exposed. Of all construction materials, due to their weight, low tension strength and lack of ductility, they are the most likely to collapse. Most of the damage in Chile also occurred to buildings with similar materials, but reinforced concrete and timber buildings performed well. The Chilean authors' initial view was that the good performance of engineered structure reflected improved building codes.

As always, all these earthquakes serve to remind us that one day a damaging quake will strike every earthquake-prone region. Rather than the media focussing on survival stories wouldn't it be so much better if we could read about how safer construction had prevented more wide-spread destruction. The excellent publication "Building regulation for resilience: managing risks for safer cities" by the World Bank Group and GFDRR which has just become available free on-line points the way forward to achieving this goal. More about the ideas in this document will be featured in coming newsletters.

Virtual Site Visit No. 41: Masonry Infill and Partition Walls

This site visit actually comprises visiting two buildings in separate countries. What is similar in both buildings is the use of heavy masonry infill and partition walls.

The first building, located in Izmir, Turkey, consists of a reinforced concrete frame building with large numbers of masonry walls (Fig. 1). The main structure has been completed and construction of the masonry walls has begun. As seen in Figure 2, the walls consist of perforated masonry units. The perforations are helpful in reducing the seismic weight of the building, but nonetheless these walls are hazardous during a damaging earthquake. There are no mechanical connections between walls and structure nor reinforcement in the wall itself. The only connections to the sides and tops of the walls are of mortar. During an earthquake when the structure sways, cracks will open up and along these mortar joints and the walls will become unstable. Some might rock for a few cycles of shaking and many will collapse.

The same problem is observed on the next building site, in Kolkata, India (Fig. 3). Here the earthquake hazard is greater due to the more solid blocks. The difficulty of forming a reliable structural connection between the top of a wall and the RC beam is evident. Not only do walls like these need some physical connectors, like reinforcing bars projecting from the sides of the columns and some other details that tie the wall to the underside of beams and slabs, but the walls themselves need reinforcement. Otherwise, as well as falling into and away from the building, they are likely to fail in bending at mid-height under face loads.

These two examples illustrate dangerous unconnected and unreinforced masonry walls. But what can be even more dangerous is the impact of such walls on the structural frame members around them. Connection details and separation strategies that have been discussed in early newsletters and shown in other best-practice examples need to be implemented.

Figure 1: Reinforced concrete building with masonry walls.

Figure 2: Some of the masonry walls.

Figure 3: A RC frame building with external masonry walls.

A Summary of the article "A Note on The Strong Ground Motions and Behaviour of Buildings During 26th Oct. 2015 Afghanistan–Pakistan Earthquake" by Dr Naveed Ahmad, PhD, P.E.(Structures), December 2015. *The full article can be downloaded from he EERI website.*

Background

On Monday the 26th October 2015 at 02:09 Pakistan Standard Time, an earthquake of Mw 7.5 occurred in the Hindu Kush Mountains, at an intermediate depth of about 210 km, within 48 km SSW of Jarm Afghanistan that was followed by numerous aftershocks. The earthquake shaking has been felt significantly in Afghanistan, Pakistan and neighbouring countries even at large distances and observed to be one of the most damaging earthquakes in Pakistan.

This earthquake has caused widespread destruction in Afghanistan and northern side of Pakistan. In Pakistan alone, the event resulted into the deaths of 232 people and injured other about 1500 people. The earthquake significantly affected structures and infrastructures: about 10 million building structures are damaged, which also included about 1400 school buildings.

Adobe & Stone Masonry Structures

Rubble stone masonry structures in dry condition or mud mortar and adobe/mud structures performed very poorly in this earthquake and have shown severe damage, partial and total collapse. It is due to the low strength of materials and poor construction practice (not using any confining beam and column elements). Furthermore, due to rain a few days before the earthquake event, these structures were in wet condition when subjected to ground motion shaking, thus they possessed less strength. Topographic effects at ridges have also played role in amplifying ground motions and increasing the duration of shaking, because of focusing of seismic waves. During the field survey, it was observed that the building owners have re-constructed their damaged and collapsed buildings using the same building materials (stone and mud) and construction practice, thus, retaining the risk for future events.

Brick Masonry Structures

Brick masonry structures of very old construction, 70-80 years older, also performed very poorly in Peshawar, due to building materials' deterioration because of aging. These buildings have shown severe damage and roof collapse. However, the same structures where timber-framing laces were used, performed well and the structures remain intact. These observations were made in Peshawar, particularly in Awqaf buildings.

Brick masonry and brick masonry confined structures have performed poorly and have shown severe damage in case of ground motion amplification on alluvium soil due to local site effects or due to localized foundation settlement. Poor performance of [infill] masonry structures was also observed due to improper construction of these structures, particularly confining elements were built before the masonry walls and no toothing of RC elements to masonry walls has been carried out.

Reinforced Concrete Structures

The recently constructed reinforced concrete structures in KP are those primarily designed to the building code of Pakistan, and are detailed as per the ACI-318 recommendations. These structures have performed very well, as per the expectation, during the earthquake. In few cases, damage like horizontal and vertical cracks have been observed in these structures at the infill-frame interfaces and minor diagonal cracks have been observed in masonry infill, primarily in regions where ground motions were amplified due to local site conditions.

In case of reinforced concrete structures designed to gravity or under designed, damage has been observed also in the structural members, particularly in the columns. The damage in these structural types are aggravated due to local site effects.

Conclusions: Lessons Learnt

The following conclusions are drawn from the earthquake ground motions and observed building performance during the earthquake event.

Buildings' Performance

• The high number of building collapses observed in this earthquake event, despite the moderate shaking severity, point to the very high vulnerability of building stock in the KP Province of Pakistan.

• Many buildings of non-engineered (adobe & rubble masonry) and semi-engineered (brick masonry & confined masonry) construction have incurred severe damage and experienced partial and total collapse and performed poorly in case of ground motion amplification due to soft-soil conditions and topographic effects (ridges effects). The poor performance of [infill] masonry buildings also attributed to the improper construction practice – no toothing was observed between column and masonry i.e. confining columns were built first and masonry after. Proper confined masonry construction requires building the masonry wall first, after placing reinforcement skeleton for confining columns, and then pouring concrete for columns later.

- Significant amount of medium to good quality construction (brick masonry buildings) performed very poorly in case of local differential settlement due to local soil failure, which was primarily due to improper drainage and blockage, causing water ponding, that kept the foundation soil wet for years and resulted in the foundation soil losing its shear strength capacity for carrying vertical and lateral loads. This calls for attention to improve building drainage systems.

- Buildings designed to the recent seismic building code of Pakistan & UBC-97 and detailed as per the ACI recommendations performed up to the expectations, even in case of ground motion amplification. However, damage to infill walls have been observed, which calls for using soft (flexible) infill in these structures. Furthermore, pounding effects in these structures have been observed which calls for attention in future designs to use soft joint filler in expansion joints to minimize hammering effects during earthquake.

- Structures with timber laces and timber framing have performed better, even in case of using low strength infill materials. However, in case of large panels, masonry material detachment and panel out-of-plane failure have been observed.

A Summary of the article "M8.3 Coquimbo, Chile Earthquake and Tsunami: Preliminary Reconnaissance Observations"

by the two teams sponsored by the National Research Centre for Integrated Natural Disasters Management, CIGIDEN, and the Department of Structural and Geotechnical Engineering of the Pontificia Universidad Catolica de Chile. *The full article is available on the EERI website, www.eeri.org.*

Introduction

On Wednesday, September 16th, at 19:54 local time, a Mw 8.3 megathrust subduction earthquake struck offshore the coast of the Coquimbo region in Central Chile. Eleven minutes after the earthquake, a tsunami warning was issued by the Hydrographic and Oceanographic Service of the Navy (SHOA), and the National Emergency Office (ONEMI) ordered the evacuation of the coastline along the country, mobilizing more than 1 million people. Around 20:30 hour local time, tsunami waves had already arrived to Coquimbo, Atacama and Valparaiso regions. Wave heights recorded offshore by SHOA reached 4.5m in Coquimbo, 1.9m in Valparaiso and Pichidangui, 1.66m in Chañaral, and 1.05m at Juan Fernández Islands in the Pacific Ocean.

The last official information released by ONEMI on October 7th showed a death toll of 15 people, 2 reports of alleged casualties, 5 injured, 57 sheltered, and 26,773 people affected by the earthquake and tsunami. In addition, 2,281 houses were destroyed, and 2,404 houses

Figure 4: Non-structural damage decreased the capacity of providing healthcare services in the Coquimbo hospital (left). Some of the hardcopies of the medical records, without digital backup, were lost in the region (right) (Photos: Claudio Fernández).

Figure 5: Structural damage in the slabs of a RC building in La Herradura, in the city of Coquimbo (Photos: Claudio Fernández).

were reported to have major structural damage and were declared uninhabitable. ONEMI has dispatched a total of 163 emergency houses to different municipalities in the Coquimbo region to the date.

Severe damage was observed in adobe constructions in interior small cities and rural communities of Coquimbo region, as expected, where we estimated a stock of 18,055 residential structures (9% of the total structures in the region).

The day after the earthquake, 96,705 people (41% of the region) in the Coquimbo region were reported without electrical supply and 9,070 (3.8% of the region) without potable water. The quick response of the authorities allowed for a fast recovery of utilities: people without electricity on September 18th were 32,123 (13.6% of the region), and only 1,183 by September 19th (0.5% of the region). Road opening and debris removal operations were also expeditious in the most affected locations in the region.

Coastline Damage

The tsunami triggered by the earthquake caused severe damage in the city of Coquimbo and coastal town of Tongoy. The tsunami waves in Coquimbo reached 4.5 m and a run-up distance over 500 m from the coastline. As a result, the rock fills along the shoreline were destroyed, large vessels and fishing boats were tossed onto the streets, and the area was left literally with tons of tsunami debris. Although RC buildings and steel frame facilities within the inundation zone performed well, the flooding interrupted lifelines and critical utilities (electricity, potable water, natural gas), forcing residents to move out. Several light-weight facilities and non-structural components were swept away by the waves, shutting down production in the port and commerce along the coastline.

Impact on Hospitals

A specific survey on the seismic performance of the nine hospitals located in Coquimbo region was conducted. The main objective was to gather information on the response of these facilities, specifically on their physical damage,

Figure 6: Spalling of concrete was observed in structural elements in the hospital of Illapel (Photos: Claudio Fernández).

reduction or loss of medical services, and change of healthcare demand and patient inflow. This information will be used to better understand and simulate the functionality of hospitals and the healthcare network during future earthquakes. Fortunately, most hospitals in the region were overstocked with medical supplies, fuel for the backup generator, and potable water in the backup tanks when the earthquake occurred, since they were preparing for the Chilean national festivities weekend that started September 18th, when the number of emergency patients usually increases due to the large amount of tourists that visit the region.

In general, hospitals underwent only non-structural damage and loss of contents, affecting the normal functionality of healthcare services. In some of the hospitals, hardcopies of medical files and records did not have digital backup and information was lost (Fig. 4). Despite this, the healthcare network experienced only a minor reduction of its capacity. A notable exception was Coquimbo's hospital, which sustained severe non-structural damage in one of its buildings. Patients and services from the upper floors were relocated internally in the hospital, significantly reducing its overall capacity.

Building Performance

A visual inspection and preliminary damage assessment was conducted on 20 RC buildings with 8 stories and higher, located along the coastline in Coquimbo, which represents about 20% of these types of buildings along the coastline. Additionally, three structures were inspected at Illapel: the city's hospital (2 stories RC moment frame building), one adobe structure that belongs to the Municipality of Illapel, and a two storey RC housing building.

Buildings in the Coquimbo bay had severe non-structural damage due to the direct effect of tsunami waves. The buildings affected by the tsunami and located in the inundation zone (Coquimbo bay and Peñuelas) presented two repetitive patterns: (i) non-structural elements in their first story were completely destroyed by the wave, and (ii) ground settlement around the buildings. In some cases, a series of very narrow vertical and diagonal cracks ($e<0.2$mm) were observed in RC walls and/or RC slabs.

In La Herradura, Coquimbo, a 16 story RC building with an irregular C-floor plan and no construction joints underwent structural damage in the slabs at the intersection with walls from the 3rd storey and above (Fig. 5). Concrete crushing was observed in the slabs, probably due to the large bending and shear induced in the floor diaphragms aggravated by the horizontal irregularity of the building, and the small slab thickness.

The Coquimbo Hospital presented severe damage in non-structural components, ceilings, partition walls, and spalling of the concrete cover in some RC columns. Likewise, buildings in Illapel showed significant damage in structural and non-structural components. In the Illapel's hospital, the concrete spalling in some beam-column joints exposed the rebar (Fig. 6), some very thin horizontal cracks were observed in partition walls, and the ceiling collapsed in many rooms. The adobe structure located in the Municipality and non-confined masonry walls of a 2 stories house were also severely damaged by the ground shaking, and joints between structural and non-structural components were exposed.

Closing Remarks

The overall assessment is that the impact caused by this megathrust earthquake in the built infrastructure was less than expected in part as the result of the fresh memory of the recent large earthquake in 2010 and the continuous effort of the country to be better prepared for such extreme events. It was apparent that the lessons learned from the Maule earthquake were implemented in the successful evacuation of more than 1 million people along the coast of the country. The good performance of engineered masonry structures and RC buildings designed after 2010 might be indicative of the progress in seismic and material codes, but further analysis is required to substantiate this point.

A more detailed analysis of the field reconnaissance data collected by CIGIDEN's teams on the earthquake and tsunami impacts in the built and social environment will be soon submitted for publication, and will also be presented in the forthcoming world conference in Earthquake Engineering (Chile, 2017).

A Summary of the article "HOUSING - Illapel Earthquake"

by Juan Obando, David Ugalde, Diego López-García. *Refer to the EERI website, www.eeri.org, for the complete article.*

In the area affected by the earthquake, which includes the cities of Illapel (30,000 inhabitants), Coquimbo (200,000 inhabitants), and La Serena (198,000 inhabitants), the percentage of housing units with damage exclusively

caused by strong ground motion was low. However, greater damage was produced in dwellings as a consequence of the tsunami generated by the earthquake.
The dwellings in the affected area are mainly masonry structures (of one or two storeys), and the remaining dwellings are reinforced concrete structures, adobe structures and wood structures. The behaviour of each of these structural types and some images of the damage caused by the Illapel earthquake are described and presented in the following sections.

Masonry Structures of One or Two Storeys
The dwellings in the area affected by the earthquake were mainly masonry structures of one or two storeys, only a small percentage of which were damaged exclusively by the strong ground motion. Figure 7 shows damage to one house caused by the earthquake.

Reinforced Concrete Structures
Only one case of considerable damage (the Puerto Bahia condominium, Coquimbo), as far as the authors are aware of, was caused in reinforced concrete building structures as a result of strong ground motion. Overall, this type of structure stood up well to the earthquake. However, some reinforced concrete building structures presented damage in non-structural components at the first and second floors due to the tsunami.

The Puerto Bahía Condominium, Coquimbo
The damage in the Puerto Bahía building was the most interesting structural damage observed as a result of strong ground motion because of the particular kind of failure that only occurred in this building. The damage was concentrated in specific areas of the slabs and occurred at the same location of the slabs in almost all the floors of the building. This building has an irregular C-shape plan, and torsion could have imposed non expected stresses on the slabs, which might have not acted as rigid diaphragms. Besides, the wall located next to the failed slabs is discontinuous on the first two stories, creating a vertical irregularity. Apparently, the slabs did not have sufficient capacity to transfer horizontal loads effectively. However, other main structural elements such as beams and walls were not significantly affected by the earthquake, hence the building is repairable although it may be exposed to the same type of damage in a future earthquake. Figure 8 shows images of the damage produced in the Puerto Bahía building.

Adobe Structures
Adobe structures are old traditional buildings. The greatest damage due to strong ground motion was observed in this type of structures, some of which had or will have to be demolished. Damage to one house is shown in Figure 9.

Figure 7: Masonry structures affected exclusively by strong ground motion. Illapel.

Figure 8: Damage concentrated in specific areas of the slabs of the Puerto Bahia condominium. La Herradura, Coquimbo.

Earthquake Hazard Centre
Promoting Earthquake-Resistant Construction in Developing Countries

The Centre is a non-profit organisation based at the School of Architecture, Victoria University of Wellington, New Zealand.

Director (honorary) and Editor: Andrew Charleson, ME (Civil)(Dist), MIPENZ
Research Assistant: Caitlyn Lee, BE (Eng. Science), BAS

Mail: Earthquake Hazard Centre, School of Architecture, PO Box 600, Wellington, New Zealand.
Location: 139 Vivian Street, Wellington.
Phone +64-4-463 6200 Fax +64-4-463-6024
Email: andrew.charleson@vuw.ac.nz

The Earthquake Hazard Centre Webpage is at:
http://www.vuw.ac.nz/architecture/research/ehc

Wooden Structures

Wooden structures are typically found in rural areas and they performed well in the earthquake; there was no perceptible damage observed in these structures. However, in some wooden structures damage due to rockslides and/or the tsunami was evident. In contrast to reinforced concrete or masonry structures, many of the wooden structures impacted by the tsunami had severe structural damage or were completely displaced.

Figure 9: Damage caused by the strong ground motion in adobe structures. Communa de Canla Baja, km 283 at 5 route.