EARTHQUAKE HAZARD CENTRE NEWSLETTER

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Contents

Editorial: Earthquake engineering in the new decade

Already, less than one week into the new decade, we have been reminded of the constant danger from earthquakes. The Solomon Islands were struck by two damaging quakes within an hour of each other. The first, a Magnitude 6.5 at a shallow depth of 10 km was followed only 45 minutes later by a Magnitude 7.2 at a depth of 30 km. The following day a 6.9 aftershock hit the region. The quakes and an ensuing tsunami caused considerable destruction and damage to buildings.

Meanwhile the cleanup and assessment of damaged buildings continues in Padang, Indonesia, following the September 30, 2009 Magnitude 7.6 quake. About 1000 people lost their lives and significant damage was caused to 140,000 houses and 4000 other buildings. The timing of the quake could not have been better. At 5:16 pm offices and schools were largely empty. Many of these building types experienced considerable damage or complete collapse.

Although the next newsletter will feature an extended article about the Padang quake, a few observations are made now based upon initial reports of damage.

One of the reoccurring themes of damage to RC multi-storey buildings are the problems caused by unreinforced masonry infill walls. As is already well known and predictable by engineers and architects practicing in seismic regions, many such walls either fell out of their frames devastating (fortunately) empty classrooms and offices, or caused soft storeys. Even in relatively new buildings, built since 2000, the stiffness and strength of infill walls above relatively weak ground floors led to severe column damage at that level. This type of construction is inherently flawed.

Even though these buildings were no doubt designed for the relatively low loads that ductile frames allow, the frames did not display ductile behaviour. To date there has been no mention of a frame that has performed in a truly ductile fashion. That is, for plastic hinges to form at the ends of beams and the base of ground floor columns and for no other structural damage to have occurred. Even though unseparated infill walls represent a major problem, there is no escaping the need for RC frame design and construction to be taken to another level of safety. The only known method to date is to use Capacity Design. Incidentally, two relatively new steel framed buildings also collapsed, so it is not just of issue of problems with RC as a material.

It appears that all of the damage observed so far has been extensively and repetitively documented in previous earthquake reports and also dwelt with in earthquake engineering text books or codes. So clearly, at least in Indonesia, but probably also in every seismically prone country in the world, the first step in progressing earthquake engineering in this decade is to revisit what we know and to improve the extent and quality of its application on building sites.

Virtual Site Visit No. 19: RC Shear Wall Building

This building relies upon RC shear walls to resist seismic forces in both principal orthogonal directions. Two shear walls, one at each end of the building resist transverse loads while internal shear walls resist forces acting in the longitudinal direction.

The reinforcement in one of the transverse walls is shown in Fig. 1. As usual there is a concentration of vertical steel in the chords or flanges of the wall in order to resist the bending moments arising from horizontal loads. There is also a considerable amount of horizontal shear reinforcement. Brittle shear failure must always be prevented. According to the Capacity Design principle, the wall shear strength must exceed the bending strength so as to guarantee ductile seismic behaviour.

Fig. 2 illustrates the wall completed to first floor level. It has reinforced concrete masonry walls on either side that are designed for gravity loads only as well as providing the necessary fire resistance along the boundary.

In Fig. 3 we can see three relatively short RC walls inside the building. There is no evidence of RC coupling beams so it can be assumed that each wall will act independently but they will all be tied together at each floor level by the RC floor diaphragm.

Since all the lateral forces on this building are resisted by shear walls, it means slender columns can be used to resist gravity forces acting from flooring away from the walls. Relatively small section steel columns are visible in the background of Fig. 3. Because they are not expected to resist any horizontal forces they are of minimal dimensions and enable the side walls to be as transparent as possible. That is but one of the benefits of separating lateral load resisting elements, in this case shear walls, from elements (columns and beams) carrying gravity forces.

Fig. 1 RC shear wall reinforcement between reinforced concrete masonry walls.

Fig. 2 Poured ground floor level transverse shear wall.

Fig. 3 Internal RC shear walls acting in the longitudinal direction.

Summary of Learning from Earthquakes – The Mw 6.3 Abruzzo, Italy, Earthquake of April 6, 2009.

From the Earthquake Engineering Research Institute newsletter, June 2009.

INTRODUCTION

On Monday April 6, 2009 at 3:32am, local time, an Mw 6.3 earthquake with shallow focal depth (10km) struck central Italy in the vicinity of L'Aquila, a city of about 73,000 people. The earthquake killed 305 people, injured 1,500, destroyed or damaged estimated 10,000-15,000 buildings, prompted the temporary evacuation of 70,000-80,000 residents, and left more than 24,000 homeless.

GROUND MOTION RECORDS

56 of the approximately 300 digital strong-motion stations operated by Italian Strong Motion Network recorded the shock. Five stations, all on the hanging wall of the rupture, were located within 10km of the epicenter, and all recorded a horizontal peak ground acceleration exceeding 0.35g.

Fig. 4 Detail of 18th century wall strengthening system, where no ties connect the beam to the wall.

Fig. 5 Roof and cupola collapse in the Santa Maria di Collemaggio Abbey in L'Aquila. The reinforced concrete ring beam did not prevent the collapse of the cupola.

HISTORIC MASONRY BUILDINGS

Typical damage observed in L'Aquila consisted of generalized cracking of the masonry walls, especially between openings and in corners, leading to the loss of the superficial plaster and sometimes causing localized collapses on poorly reinforced cornices and above window lintels. Complete collapses of masonry structures in the historic center of L'Aquila were rare, although the severe damage observed in many rubble stone walls might trigger demolition of some of this building stock. Firefighter squads and the survey team also observed failures of floor slabs inside buildings, which rendered the structure unsalvageable. These floor collapses might have been triggered by out of plane deformation of walls and subsequent loss of support for the floor beams.

The superior performance of many of the masonry buildings in L'Aquila can also be attributed to the better quality of material (e.g.; bigger size, squared stones) and construction that could be afforded by the richer families that have lived there historically. Several masonry buildings observed within the historic center of L'Aquila had crossed ties (catene) situated adjacent and parallel to the walls, with the purpose of limiting the out of plane deformation of the buildings. These structures generally performed well, displaying only minor cracking in their

Fig. 6 Collapse of a masonry building in Tempera with concrete ring beam retrofit.

Fig. 7 Typical damage to infill walls.

walls and corners.

After the large major earthquake on the region in 1703, attempts were made to strengthen masonry walls by inserting a large (approximately 20 cm diameter) timber into the wall with wood or iron ties through the perpendicular wall. In Paganica, we saw numerous examples of this approach, where the first story was built after the 1703 earthquake using the timber –and-ties technique, but 2nd and 3rd floors were added in the 19th century without ties, as the technique was forgotten (Fig. 4).

Another interesting retrofit from the modern era was the use of the concrete ring beam to stiffen the wall and prevent collapse. This was used on a number of churches (Fig. 5). Unfortunately, this system proved to be ineffective, and many structures, such as the building in Fig. 6, collapsed. The additional mass of the beam, the inconsistency between the deformation of the beam and that of the walls, and the lack of positive connection between the beam and the masonry walls above and below are reasons that were brought up to explain the generally poor results of this retrofit technique.

A church near Monticchio had its front façade separate from the lateral walls due the inability of the wood connection beams to keep the structure in place; however, other parts of the façade tied with iron rods performed well, showing no separation of the structural elements.

REINFORCED CONCRETE BUILDINGS

The older RC buildings in the region use smooth reinforcing bars, unconventional lap splices and in some cases, poorer quality construction materials. The frames are almost always designed with no consideration for the layout of masonry infill walls both in plan and elevation, as these are considered to be non-structural elements, and their inclusion is thought to lead to conservative design. The framing is filled in with one or two wythes of hollow clay or concrete blocks, and sometimes finished with wrap-around clay brick facades or stucco. Partitions are of thin hollow clay blocks.

Fig. 8 Collapse of part of the Duca D'Abruzzi Hotel caused by a softstory mechanism. The far part of the building was saved by a seismic separation joint.

Fig. 9 The interior of the City Planning Offices in L'Aquila. Note that the building exterior has very minor detectable damage.

We found widespread damage to exterior infill walls and interior partitions, varying from small cracks to collapse along with minor or no damage to structural elements. Several buildings completely lost their masonry infill walls at lower stories Fig. 7. This kind of damage extended to newer buildings, including structures that have been recently completed. In L'Aquila, the team also observed about 15 older low-to-mid-rise apartment buildings and one large hotel that suffered dramatic failures (Fig. 8), generally due to a soft-story at the first story. At all the collapse sites, the team noticed the remains of column-beam connections that showed insufficient transversal reinforcement in the form of 6 mm diameter stirrups, at a spacing of 25cm or more. In some cases, there were also poor distributions of fine aggregates and cement in the concrete, with a very porous core of disconnected larger aggregates. Short overlap of longitudinal rebar connecting columns between the upper and lower stories, short anchorage lengths of the longitudinal beam reinforcement, and smooth rebars may have been responsible for the reduced structural strength and ductility of these buildings.

In summary, reinforced concrete buildings in L'Aquila region behaved, on average, fairly well, considering the limited seismic design requirements and the severe ground shaking, often exceeding the design level. From the perspective of the repair cost, however, reinforced concrete buildings showed higher losses due to widespread extensive damage to masonry infill walls and internal partition walls (Fig. 9).

Summary of the article: "The 2008 Sichuan Earthquake – Assessment of damage and lessons learned."

By H. Kit Miyamoto, Amir S.J. Gilani, and Tom Chan. From Structure Magazine, January 2009.

The 2008 Sichuan Earthquake was a large-magnitude event that caused unprecedented casualties and damage. Close to 90,000 people were classified either as fatalities or as unaccounted for. More than 4 million people were displaced, and the number of collapsed or seriously damaged structures exceeded 25 million. The reconstruction cost alone (not including financial losses) is estimated at over US$150 billion. As astounding as these numbers seem, they were not unexpected, given the region's seismicity, its population growth, and the local design and construction practices.This area of China was classified as a moderate zone (similar to Zones 2 to 3 in the corresponding U.S. codes). However, close examination of past events shows that this site and its surroundings have historically been susceptible to large earthquakes. China's rapid economic growth over the past

Fig 10: URM wall and RC floor plank collapse, Juyuan Middle School.

Fig 11: Soft-story collapse, Hanwang Hospital.

Fig 12: Captive column failure, Hanwang High School.

Figure 13: Column flexural damage, Mianzhu Experimental

three decades has resulted in major industrial development, population growth, and increased building construction in the affected area. Unfortunately, not all the commercial and residential buildings were designed, detailed, or constructed to provide adequate life-safety and property protection. The schools and hospitals were especially hard-hit in this earthquake. For collapsed buildings, the lack of ductility, the absence of a well-defined load path, the building design irregularity, and the construction practice and quality control were the primary contributing factors. Many schools constructed with unreinforced masonry (URM) walls collapsed. Non-ductile reinforced-concrete (RC) buildings performed slightly better: Many of them sustained significant damage. Light industrial buildings also fared better; however, many of these structures had equipment and nonstructural damage, resulting in extended business interruptions.

While some of the surveyed damage is unique to China, many observations also apply to other locations, including many parts of the United States. For example, in past earthquakes in California, URM and non-ductile RC buildings have performed poorly; nonstructural and equipment damage has been widespread even from moderate earthquakes, leading to financial losses; and lifeline damage and interruptions have occurred. Fortunately, robust assessment techniques and both conventional and innovative retrofit strategies are available to address such vulnerabilities.

THE SEISMIC EVENT

The May 12, 2008, magnitude 7.9 Sichuan (Wenchuan) Earthquake struck along one of the faults at the base of the Longmenshan Mountains, approximately 1,550 kilometers (1,000 miles) southwest of Beijing, China. This shallow earthquake occurred on relatively stiff soil, and, as such, large seismic waves reached the surface and propagated rapidly without losing much energy. This resulted in a rupture length of more than 200 kilometers (130 miles). This event is classified as an X on the Modified Mercalli Intensity (MMI) scale, indicating violent shaking and heavy damage. The main shock was followed by a number of aftershocks, including a magnitude 6.0 aftershock on May 25th, 13 days after the main shock, which caused additional casualties and damage. Very high horizontal and vertical ground accelerations (on the order of 0.6g) were recorded. Such high values point out the need to revise the design maps for this area.

The most severe damage was primarily concentrated along a band close to the rupture zone. Due to the directionality of the fault rupture, damage was most extensive perpendicular to the rupture direction. For many structures, if the lateral-load resisting members were stronger perpendicular to the fault, they fared better; whereas, if the lateral-load-resisting members were weak in that direction, severe damage or collapse followed.

SUMMARY OF OBSERVED DAMAGE

Unreinforced masonry (URM) bearing walls, hybrid URM column-concrete beam, and cast-in-place reinforced concrete (CIP-RC) moment frames were the most common construction for residential and commercial buildings, including schools and hospitals.

The URM buildings were the most vulnerable, and such structures have fared poorly in other earthquakes throughout the world. In the United States, many building collapses in past earthquakes in California and elsewhere were attributed to such construction because of its lack of ductility. In China, the problem was compounded when a unique system using URM walls and columns with reinforced-concrete (RC) beams, intended to confine the precast RC slabs, was used in design. In most cases, these slabs were not anchored to the beams and therefore did not provide any diaphragm action to distribute loading to the columns and walls, and they simply collapsed.

Multistory residential and commercial buildings using non-ductile RC framing also fared poorly. The main causes of damage were a soft story at the ground, a lack of confinement for the concrete columns and joints, and a captive column failure. In many buildings, infill URM or partition walls were used between RC columns. These walls typically terminated above the first story to allow for a parking garage at the ground level and introduced a weak or soft story at the base of the building, resulting in single-story side-sway collapse at ground level. Additionally, many infills did not extend the full height of a story because of windows or other openings. This configuration reduced the clear height of columns and prevented the formation of ductile flexural hinging, as well as caused brittle shear or compression failure of columns, compromising their vertical-load-carrying capacity.

Many schools and hospitals collapsed in this earthquake. The death toll in these structures exceeded 10,000, and more than 7,000 classrooms were damaged. In typical practice, essential facilities such as schools and hospitals are designed with a higher seismic force (importance factor) to account for a larger mandated factor of safety. In the Sichuan Earthquake, these buildings were disproportionately damaged. The main culprits were the poor detailing, lack of a well-defined load path, and inadequate ductility of the design and construction. Surprisingly, such damage was observed even in newer-vintage (constructed in the 1980s and 1990s) buildings.

The three-story Juyuan Middle School, approximately 20 kilometers from the fault rupture, was hit hard. The school, constructed in 1996, housed 1,000 students, and more than 700 died when the building collapsed. Construction consisted of non-ductile RC beams supported by URM walls, with precast concrete floor planks. This type of damage was quite common. A lab building adjacent to the collapsed school with similar construction, built in 1996, did not collapse. This better performance was likely due to the orientation of its URM walls.

The four-story Hanwang High School is within 10 kilometers of the ruptured fault, and sustained significant damage but no collapse. Construction consisted of CIP-RC framing and URM walls. The walls had extensive damage, and concrete columns failed because the URM walls created captive columns (Fig. 12).

The Mianzhu Experimental School is located about 20 kilometers from the fault rupture. Framing was comprised of non-ductile CIP-RC columns and beams, as well as URM infill walls, and there was significant structural damage. In particular, a large flexural demand and a lack of adequate confining transverse reinforcement resulted in severe column damage (Fig. 13).

DISCUSSION

One issue that was immediately obvious from a survey of damage in the Sichuan region was that, as far as the building structures were concerned, there were no new technical lessons to be learned for structural purposes and the earthquake did not produce any unexpected results. The type of damage observed has been seen repeatedly in many parts of the world. Nonetheless, it is the responsibility of the structural engineering profession to educate the public and officials about potential future events and, in particular, address the seismic vulnerability associated with URM and non-ductile RC buildings.

- Nearly all the collapsed buildings in the Sichuan Earthquake were constructed with very little seismic resistance, ductility, or redundancy. URM bearing walls, non-ductile RC moment frames, questionable load paths, lack of diaphragms, poor detailing, and undesirable structural configurations all contributed to the observed damage.

- Cost-effective retrofit options are available to address such vulnerabilities. Such retrofits have been successfully applied in California, Japan, and elsewhere.

Book Review: Construcción de casas saludables y sismorresistantes de adobe reforzado con geomallas, (Construction of safe and seismic resistant houses reinforced with geomesh) by Julio Vargas Neumann, Daniel Torrealva and Marcial Blondet, published by Fondo Editorial, Pontifica (feditor@pucp.edu.pe) Universidad Católica del Perú, 2007.

This publication actually consists of two small booklets each of 40 pages. Almost identical, one booklet is prepared for the mountainous region of Peru, while the other applies to coastal areas. The only minor difference between the two booklets is in the roof shapes.

Given the very poor seismic performance of adobe construction, these researchers have shown that if reasonably standard adobe construction has all walls lined on both sides with geomesh that is tied to the walls by ties passing through the walls, the seismic performance is very much improved. These booklets are really construction manuals, suitable for masons and even home builders. By following the instructions the application of this new technique will ensure far better seismic performance of adobe houses.

The booklet outlines the construction of a small four roomed house (Fig. 14). After an explanation of producing good quality adobe blocks, sketches show how to lay out and construct the foundations, including the anchoring of the lowest part of the geomesh. As adobe blocks are laid, lengths of rafia or plastic twine are embedded through the wall to tie the two layers of mesh together (Fig. 15). Then, after the construction of a wooden eaves-level ring beam, the geomesh is applied and wrapped around the walls then tied (Fig. 16). The house is complete after the roof is constructed and mud plaster has been applied over the mesh.
Due to the extensive number of cartoon-like diagrams even non-Spanish speakers should be able to follow the steps of construction and apply this method to their own situations. This technology represents the most reliable and affordable method to date for ensuring seismic safety of adobe houses.

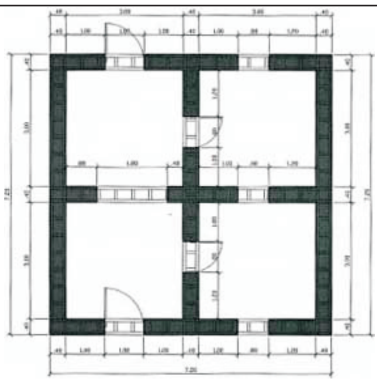

Fig. 14 Plan of the adobe house to be reinforced with geomesh

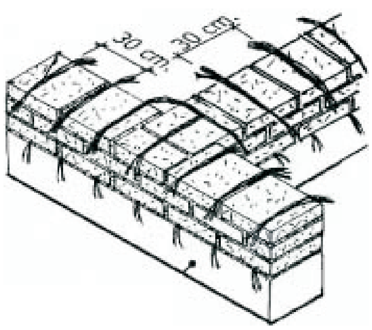

Fig. 15. A section of adobe wall with lengths of twine embedded prior to tying to the two layers of geomesh.

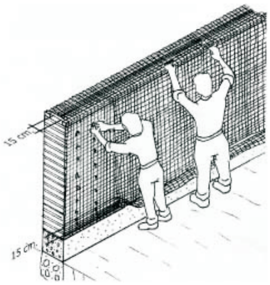

Fig. 16 Mesh being placed and tied.

First Announcement on Disaster Mitigation in Housing in India: An Agenda for Future
19th and 20th March, 2010

THE RESEARCH CONFERENCE TO IDENTIFY FOCUS AND TRENDS IN HOUSING RESEARCH FOR 2010-2025.

Papers by the subject experts relevant to the central theme are invited.
Contributions after review would be chosen for publication and oral presentations.
Last date for Submission of Full-paper: 1st March, 2010.
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Earthquake Hazard Centre
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