

Performance of Masonry-Infilled RC Buildings in the M6.0 Mae Lao Earthquake on May 5, 2014

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ABSTRACT: On May 5, 2014, a moderate earthquake of M6.0 hit several districts in Chiang Rai, Thailand, including Mae Lao and Phan districts. The shallow earthquake caused unprecedented damage in recent Thai history. One person was killed by a collapsed masonry panel. The Ministerial Regulations concerning seismic resistant design of buildings have been promulgated only since 1997. Furthermore, private buildings lower than 15 m do not require for seismic design. Consequently, a large building stock contains inadequate seismic resistant structures. Most of the residential houses are 2 storeys, featuring a soft storey with small reinforced concrete (RC) columns, and they constitute the largest population with moderate to severe damage. Many recently built school buildings with a soft storey system coupled with torsional irregularity suffered significant damage. Shear failure in short columns and shear distress at column joints induced by the strut force from the un-reinforced masonry (URM) infill has been commonly noted. The advantage of masonry infill panels in providing an alternate load path for gravity load has been witnessed which prevented total collapse of the buildings.

1 INTRODUCTION

A moderate earthquake hit Chiang Rai province in northern Thailand on May 5, 2014 at 11:08:43 UTC. According to the United States Geological Survey (USGS 2014), the epicentre of the M6.0 earthquake was located at latitude 19.656°N, longitude 99.670°E about 6 km southeast of Mae Lao district at a depth of 6 km. It is the biggest earthquake in almost a century in Thailand. Shaking from the main shock was felt by people in many provinces in northern Thailand, and in high-rise buildings in Bangkok. Most severe damage to structures was witnessed in Mae Lao and Phan districts in Chiang Rai province. Less damage occurred in nearby districts including Mae Suai, and Muang of the Chiang Rai province.

The earthquake caused an unprecedented damage in recent Thai history. A total of 11,369 buildings (both private and public) were reported to suffer various degrees of damage, with 475 unsafe for occupancy, 2180 potentially repairable and 7714 safe for occupancy (DPT 2014). One person was killed by a collapsed masonry panel.

This paper presents damage to buildings mainly in Mae Lao and Phan districts (Fig. 1), most of which are of non-seismic design. An extensive account of building damage has been documented by Lukkunaprasit et al. (2015). Therefore, focus is made on performance of masonry-infilled reinforced concrete buildings only. A quantitative assessment is not within the scope of this study. Lessons learned should be valuable for countries of similar seismicity and socio-economic setting.

2 **OBSERVED GROUND MOTIONS**

Seven Thai-Meteorological-Department stations were able to record moderately strong ground motions due to the main shock. The ground condition in the area is classified as site class D according to ASCE7 (2010). Comparison of the recorded peak ground accelerations (PGA) to estimates from ground motion prediction equations by Sadigh et al. (1997), Boore et al. (1997), Abrahamson and Silva (1997) and Idriss (1993) is shown in Figure 2. The estimates from Sadigh et al. and Idriss's equations fit the observed data reasonably well, predicting PGA of 0.2–0.3g at 10 km from the epicentre.



Figure 1. Locations of epicentre and surveyed buildings.



Figure 2. Recorded PGA and estimates from ground motion prediction equations.

3 BUILDING CODES AND LOCAL DESIGN AND CONSTRUCTION PRACTICE

The Ministerial Regulation No. 49, B.E. 2540 under the Building Control Act B.E.2522 concerning seismic resistant design of buildings in Thailand has been promulgated only since 1997. Public and essential buildings are required to be seismic resistant against PGA of up to 0.15g (g is the acceleration due to gravity) on rock site. Private buildings not taller than 15 m are exempt from this requirement. Consequently, a large building stock consists of buildings of gravity load design type with inadequate seismic resistance. Therefore, unless specifically noted, the buildings reported herein fall into this category. In fact, most residential buildings not taller than 2 storeys are even non-engineered structures.

Most of the residential houses are 2 storeys high, featuring a soft storey with small reinforced concrete (RC) columns, typically 150–200 mm square columns, and they constitute the largest population with moderate to severe damage. Light transverse reinforcement is provided, typically 6 mm diameter round bars spaced at 150–200 mm. Unreinforced infill masonry (URM) panels are extensively used as non-structural partitions, with a small number of dowel bars (if any) connecting the panels and the boundary RC columns. Customarily, no dowel bar is provided to anchor URM with horizontal members. The ultimate compressive strength of concrete in buildings is normally in the order of 18 MPa (or even less for non-engineered buildings). Reinforcing bars usually have yield strengths of 240 MPa for plain round bars and 300 MPa for deformed bars. Bricks, cement blocks (for infill panels) and mortar are of low quality, in general.

4 OBSERVED PERFORMANCE OF MASONRY-INFILLED RC BUILDINGS

4.1 Collapse of masonry walls

Many new single storey houses were built with the first floor resting on ground (Fig. 3a). Columns are customarily made of precast concrete with a small cross section of 120x120 mm, usually not meeting proper standard even for gravity load requirement. These non-engineered columns have very little reinforcement and are not suitable for seismic-prone area. Although the columns are not very strong, the steel roof beams and cement tiles are rather light-weighted. Masonry walls using hollow cement blocks are popular because of their low cost. The prevailing damage in this type of house is partial out-of-plane collapse of masonry walls due to lacking of anchorage between the wall and column (Fig. 3a). This failure mode caused one fatality in Thailand for this earthquake event as the earthquake occurred during day time. If it had occurred during night time, many more fatalities might have resulted as the walls would have collapsed on to sleeping inhabitants. Figure 3b shows similar out-of-plane masonry collapse in Phan Pitayakom school in Phan district. Although the wall was constructed up to the bottom of the beam, masonry wall still collapsed because there was no dowel bar or

connector to prevent out-of-plane movement of masonry wall away from the beam.



Figure 3. Out-of-plane collapse of masonry walls due to lack of anchorage to the columns at (a) a one-storey house in Mae Lao district; (b) Phan Pitayakom school in Phan district.

4.2 Shear failure induced by short column effect

A common feature of traditional Thai houses in rural areas is the elevated first floor above ground to avoid blocking water flow and stay dry during seasonal flood. Such houses are often supported by small non-ductile concrete columns at the ground level with open space, creating a soft storey system which is vulnerable to damage (Fig. 4a). Masonry wall rising up to only partial height of the column restrained flexural deformation of the columns and resulted in shear failure occurring before formation of flexural plastic hinge, which is the so called "short column" effect. School buildings typically have masonry walls about 1 meter tall and glass windows above the masonry walls creating short column effects also. Figure 4 shows such failure type found in many buildings in the affected area.



Figure 4. Shear failure in short columns at (a) a one-storey house in Mae Lao district, (b) a temple; and (c) Phan Pitayakom school in Phan district.

4.3 Soft storey collapse

Two to three-storey RC residential buildings similarly feature a soft storey at ground floor with small columns. Two of the collapsed buildings are shown in Figure 5. The three-storey residential building

in Figure 5a had no wall in the first storey as it was intended to be parking garage. Therefore, the first storey was very flexible and weak compared to the upper storeys; thus, lateral deformation concentrated only in the first storey causing collapse of the first storey and the whole structure.

The two-storey building with an extended portion on top in Figure 5b was about 3 km from the epicentre. Besides the soft storey, the building also had torsional irregularity due to the eccentrically placed URM partitions. The building was severely damaged and was on the verge of collapse from the main shock, with shear failure in both unrestrained interior columns and partially-restrained perimeter columns exhibiting short column effect after the adjacent cement block louvers were destroyed. It is noteworthy that all occupants managed to evacuate safely. On the next day with some strong aftershocks the building totally collapsed.



(a)

(b)

Figure 5. Collapse of three-storey RC buildings with a soft first storey in Mae Lao district.

Figure 6 shows that a one-storey house with elevated first floor (same house as in Fig. 4a) was able to escape from soft storey collapse because some panels of masonry walls helped resisting lateral force. Despite being hazard themselves, masonry walls can help resisting lateral load and prevent soft storey collapse if they are constructed appropriately.



Figure 6. (a) An elevated one-storey reinforced concrete house in Dong-mada sub-district, Mae Lao district; (b) masonry infill resisted lateral force and suffered severe diagonal cracks.

4.4 Torsional irregularity in plan

School buildings in Thailand typically have a long rectangular floor plan with single bay frames of 6 to 10 m span in the transverse direction and multi-bay frames of 4 to 4.5 m spans in the longitudinal

direction. Most schools have 2 to 4 storeys where the ground floor serves as a large open space, creating a first soft storey system. Unfortunately, many recently built school buildings have not been constructed with proper seismic design even though the regulations call for design for a peak ground acceleration of about 0.15g. Consequently, several buildings with a soft storey system coupled with torsional irregularity suffered significant damage. The three-storey RC building at Wat-Muang-Nga kindergarten school in Phan district (Fig. 7) has an open space on the ground floor, except the two end bays to the north of the building which accommodate a staircase and a rest room with URM partitions. Due to torsional deformation, the column farthest from the stairwell was under the most seismic demand, resulting in crushing and splitting cracks at the bottom. Altogether, 14 columns were damaged to varying degrees, mainly in flexural mode.



Figure 7. A three-storey RC school building with a soft first storey coupled with torsional irregularity at Wat-Muang-Nga kindergarten school in Phan district.

The four-storey RC building at Tesaban 1 school in Phan district (Fig. 8) has an open space with the stiff infilled RC stairwell placed way off the centre of mass of the structure. Eight columns suffered moderate to severe damage, and one corner column (Fig. 8b) was stressed beyond Life Safety Performance Level. The infill panels at the stairwell were significantly damaged. It is interesting to note that another similar building at Ban Don Tan school has essentially the same structural design in general, but the end frame on the other side of stairwell is infilled with a URM panel on the ground floor (Fig. 9a). This infill contributes significantly to reducing the torsional irregularity, leading to less seismic demand on the building and hence less damage than the other building at Tesaban 1 school.





Figure 8. (a) A four-storey RC school building with a soft first storey together with torsional irregularity at Tesaban 1 school in Phan district, Chiang Rai province; (b) severe damage at the corner column.



Figure 9. (a) A four-storey RC school building with a soft first storey at Ban Don Tan school in Phan district, Chiang Rai province; (b) shear failure in column and joint.

4.5 Shear failure of column or joint due to strut force from masonry wall

Although masonry wall in Ban Don Tan school helped reduce torsional irregularity in plan and resist the lateral force in the first storey, the two boundary columns of the URM infill panel on ground floor were severely damaged by the strut force exerted by the large infill panel which is 10 m long (Fig. 9b).

A building at Mae Lao Witayakomschool (Fig. 10a) also suffered shear failure at a beam-column joint of an end RC frame with URM infill panel. The column was so severely damaged in shear caused by the huge strut force from the URM panel that the column was almost pulled out of the joint (Fig. 10b). It is noteworthy that the URM panel provided an alternate load path for gravity load for collapse prevention. Joint failure due to poor construction was also observed at some beam-column cold joints.



Figure 10. (a) Damaged three-storey RC school building at Mae Lao Wittayakom school in Mae Lao district, Chiang Rai province; (b) shear failure of beam-column joint induced by strut force from URM panel.

5 DISCUSSIONS

The primary failure modes of buildings related to infill masonry walls are (1) masonry wall collapse, (2) shear failure of short columns, (3) collapse of soft first storey, (4) exterior columns failure due to torsional irregularity in plan, and (5) shear failure of column and beam-column-joint due to strut force from masonry wall. Despite these shortcomings, masonry infill walls can provide lateral stiffness and strength to resist lateral force in buildings (Figs. 6 and 9). The house in Figure 6 or the school in Figure 9 might have collapsed at the first storey if there was no masonry wall to help resisting lateral force. Therefore, it is still controversial whether to advise people to attach the masonry walls to columns, or disengage them by leaving some gap between masonry walls and columns.

For large engineered buildings with big column size, strength and stiffness of masonry walls may not be significant compared to that of primary structural components, so it might be appropriate to isolate masonry walls from the columns and beams, so that the complex interaction between masonry walls and beam-column frame is avoided. However, in the case of small non-engineered houses of lowincome families, or medium-size buildings with limited construction budget, masonry walls can increase lateral stiffness and strength of buildings in resisting lateral force. Furthermore, constructing masonry wall attached to the columns is easier and more economical than trying to isolate the masonry wall from the frame in a safe manner. The issues to keep in mind when allowing masonry walls to take part in resisting lateral load is to avoid: (1) short column effect by not having wall opening, e.g. window or door, near the column, (2) torsional irregularity by having balance amount of walls on both sides of the building floor plan, and (3) shear failure in column and joint due to strut force by increasing shear resistance of the joint and column using closely spaced stirrup reinforcement near the corner of wall panels where strut force is likely to occur. In any case, walls should be prevented from out-of-plane collapse by providing a beam either reinforced concrete or steel at the top of masonry wall and providing sufficient anchorage between the wall and beam. If budget is ample, the masonry walls should also be reinforced by wire mesh to increase wall strength, and suppress diagonal cracks and out-of-plane collapse of the walls.

6 CONCLUDING REMARKS

The Mae Lao earthquake has given lessons as well as clues for rehabilitation and future design which are valuable not only for Thailand, but also for countries of similar seismicity and socio-economic setting. Although many lessons have been well recognized in a high seismicity region, they do reiterate the fact that a poor structural system is also vulnerable to severe damage or even collapse under moderate hazard.

Field evidence from this event has clearly indicated the benefits of URM infill in RC frames in enhancing performance of RC buildings, with which the collapse of some buildings might have been deferred, thereby allowing safe evacuation (refer to section 4.3 and 4.5). However, the transfer of the huge strut force from URM panels to the columns and beam-column joints must be carefully considered in design. Appropriate measures should be taken to avoid detrimental shear failure.

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