



OVERVIEW

The $M_w7.9$ earthquake in Wenchuan, China on 12 May 2008 was catastrophic in terms of lives lost and buildings destroyed or damaged: 69,185 people killed, 374,171 injured, 18,467 still listed as missing. More than 7.79 million houses were destroyed, and 24.5 million damaged.

The overwhelming losses in this earthquake in both urban (multi-story) and rural buildings can be attributed in large part to use of unreinforced masonry with precast concrete plank roofs and floors (Figs. 1 and 2). There is, however, at least one compelling example of excellent performance of confined masonry houses reportedly built according to the Chinese Seismic Code (Fig. 2).

This report provides more details on the three masonry systems: (1) unreinforced masonry with timber roof, (2) unreinforced masonry with precast concrete plank roof, and confined masonry. See Table 1 for a listing of the types of residential structures surveyed during the reconnaissance.

Observations were made by Dr. Elizabeth Hausler during a field reconnaissance to the earthquake-affected area between 15 and 24 June 2008. Dr. Hausler's visit to Sichuan was coordinated through the 10 + 10 Strategic Partnership between the University of California system and 10 universities in China. This report includes a short list of opportunities for collaboration identified during the field visit, in single family housing and other areas.

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Fig 1. Debris removal and recycling in heavily damaged Danan Village. A few unreinforced masonry buildings with timber roofs remain standing. Collapse of unreinforced masonry buildings with precast concrete roof/floor planks (shown under the worker's right foot) contributed to the majority of casualties in both urban and rural areas visited during the reconnaissance.



Fig. 2. Debris from collapse of unreinforced masonry buildings with precast concrete roof/floor planks (foreground), and 2-story confined masonry buildings with no damage (background) built in 2006 reportedly according to the Chinese Seismic Code. Gao Yuan Village, Wenchuan County



RURAL RESIDENTIAL BUILDINGS
12 May 2008 Wenchuan, China Earthquake
Dr. Elizabeth Hausler
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Exact positions are not available. Upon learning that visitors had been detained for traveling with GPS units in China, I opted to leave my GPS unit in left luggage at Jakarta airport. More detailed location information is available upon request.

(1) Unreinforced Masonry with Timber Roof

Single story unreinforced masonry buildings with pitched or hipped timber roofs experienced light to heavy damage. Compared to their counterparts with precast concrete plank roofs discussed in the next section, these simple URMs with lightweight roofs performed better. See Figs 3 through 18 for examples. As is typical for unreinforced masonry, gable wall cracks and failures were common. Materials used are as follows:

- **FOUNDATION:** Shallow strip footing using the same material as the wall.
- **WALLS:** Fired brick or concrete block masonry in cement or cement/lime mortar. Some collapsed buildings and walls appeared to have very little cement in the mortar. Half-brick wide wall using running bond is more common than the full-brick wide bonding used for houses with precast concrete plank roofs, discussed in the next section. The solid, fired clay bricks sampled during the reconnaissance measured 24 by 11 by 5 cm and are machine-pressed at local factories and fired with charcoal. Based on limited sampling, bricks in Pengzhou appear to be slightly better quality than those in the Jiezi area, which may be hand-pressed. Brick quality may be variable throughout the affected region, but in general, appears to be higher than in Southeast Asia, where bricks are mixed and pressed by hand and baked in wood-fired kilns. Timber is used for window and door frames.
- **CEILING AND ROOF:** Pitched or hipped timber trusses or timber rafters. Timber is not sawn; elements are tied with wire or joined with steel pins. Roofs are covered with clay tiles or corrugated ceramic or cement fiber sheets. Bamboo was common for ceilings.



Fig 3. Unreinforced masonry house with pitched timber roof, no damage, Danan Village. IMG0104



Fig 4. Unreinforced masonry house with brick and solid concrete block, displacement of clay tiles on roof, Danan Village. IMG0129



Fig 5. Partially collapsed unreinforced masonry with timber roofs in background, collapsed URM with concrete plank in foreground. Rural Pengzhou. IMG0122



Fig 6. Partially collapsed unreinforced masonry with timber roofs in background, collapsed URM with concrete plank in foreground. Rural Pengzhou. IMG0351



Fig 7. Crack in masonry gable wall, Danan Village.
IMG0116



Fig 8. Undamaged masonry gable wall, Danan Village
IMG0118



Fig 9. Typical ceiling. IMG0115



Fig 10. Typical truss. IMG0098



Fig 11. Corrugated cement and fiber sheets.
IMG1130



Fig 12. Typical traditional roofing system with simple
clay tiles, free to slide during shaking. IMG0094

New (2006) unreinforced masonry buildings with pitched timber roofs were observed in Gao Yuan village (Figs. 13 and 14). Damage was limited to the gable walls, except for the only building that wasn't finished (Figs 15 through 18). This building was more heavily damaged, perhaps because the interior and exterior wall tiling had not been completed.



Fig 13. Single story URM with timber roof, cracked gable wall (two story building is confined masonry, described later) Gao Yuan village. IMG0559



Fig 14. Single story URM with timber roof, no damage (two story building is confined masonry, described later), Gao Yuan village. IMG0560



Fig 15. In-plane damage to unreinforced masonry building, Gao Yuan Village. IMG0569



Fig 16. Interior unfinished gable wall, Gao Yuan Village. IMG0573



Fig 17. Damaged masonry wall not yet finished with ceramic tiles. Note cracks occur at the interface between brick and mortar. IMG0574



Fig 18. Use of more modern roofing tiles with ridges to prevent displacement. IMG0031

(2) Unreinforced Masonry with Precast Concrete Plank Roof/Floor

These buildings collapsed in massive numbers. Nearly every pile of rubble observed during the reconnaissance in the rural areas included these precast planks. They were responsible for building collapses in peri-urban areas as well; this structural system is the first collapsed encountered when traveling on local roads out of Chengdu towards Dujiangyan.

These buildings differ from their URM with timber roof counterparts in that the masonry bonding is usually full-brick wide for the first story, and a second story is common. The second story may use half-brick wide bonding. The precast concrete planks are not connected to the walls, nor were they confined by a ring beam, as is required in the Chinese Seismic code. Some of the planks have very short steel reinforcement available for a connection, but this steel appears to have been bent out of the way and plastered over. The planks are prefabricated by small businesses and sold for around US\$13 per plank, depending on the vendor and the size.



Fig 19. Collapsed URM with precast concrete plank, near Xiao Yu Dong Bridge. IMG0433



Fig 20. Lack of connection or confinement of precast concrete plank with URM wall, near Xiao Yu Dong Bridge. IMG0431



Fig 21. Collapsed two-story, rural unreinforced masonry with precast concrete plank floor and roof, Danan Village. IMG0085



Fig 22. Partially collapsed two-story, rural unreinforced masonry with precast concrete plank floor and roof, near Xiao Yu Dong Bridge. IMG0436

(3) Confined Masonry

Two-story confined masonry residential buildings built in 2006 reportedly according to the Chinese Seismic Code performed well in this earthquake. Located in Gao Yuan Village, within 500m of evidence of permanent ground displacement and a bridge collapse, no cracks or other damage was observed during a quick survey. These buildings were designed and built by a private company. Efforts to obtain detailed design drawings are currently being made. The walls are full-brick wide, the columns are cast after the wall is built as is typical practice for confined masonry (see an example of the tothing used at another building site near Pengzhou in Fig. 26), and the floors are cast-in-place reinforced concrete slab.



Fig 23. Two-story confined masonry, no damage, Gao Yuan village. IMG0552



Fig 24. Two-story confined masonry, no damage, tiled exterior, collapsed URM gate in foreground, Gao Yuan village. IMG0545



Fig 25. Two-story confined masonry, no damage, collapsed URM with precast plank in foreground, Gao Yuan village. IMG0586



Fig 26. Confined masonry exterior wall for industrial building under construction, note tothing and steel connection between column and wall, near Pengzhou. IMG0347

A Note on Transitional Shelter

Transitional shelters consisting of Styrofoam panels on steel frames were being erected in large numbers during the reconnaissance (Figs. 27 and 28). Rural homeowners had also taken the initiative to erect simple shelters using recycled materials (Figs. 29 and 30).



Fig 27. Transitional shelter near Jiezi. IMG1164



Fig 28. Transitional shelter near Jiezi. IMG1163



Fig 29. Homeowner-built transitional shelter, rural Pengzhou. IMG0072



Fig 30. Tents and transitional shelter, Danan Village. IMG0146