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.

This report provides more details on the five and seven-story buildings in Dujiangyan. Two structural systems were common: (1) load-bearing masonry (unreinforced or partially confined) and (2) reinforced concrete frame with masonry infill. 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.

Dr. Hausler is a graduate of the civil engineering program at University of California, Berkeley and the Founder and CEO of Build Change, an international non-profit engineering company that designs and trains builders and homeowners to build earthquake resistant houses in developing countries. See www.buildchange.org and contact elizabeth@buildchange.org.

The visit was made possible by Dr. Gretchen Kalonji on the UC side and Profs. Guan Ping and Tang Ya on the Sichuan University side. Dr. Hausler was hosted by Prof. Li Bixiong, the director of the civil engineering department at Sichuan University. Kind assistance from all parties, including several students at Sichuan University, is greatly appreciated.

Fig 1. Precast concrete plank rubble, collapsed multi-story unreinforced masonry building, Dujiangyan.

Fig. 2. Partially collapsed six-story unreinforced masonry apartment building with precast concrete plank floors, Dujiangyan.

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.

<u>(1) Load-Bearing Masonry</u>

Like their rural one- and two-story counterparts reported on separately, the collapse of multi-story unreinforced or partially confined masonry buildings was widespread. These buildings were mixed use, commercial ground floor/residential upper floors and therefore often had an open frame ground floor. The ground floor frame elements experienced damage much like that of the RC frame with masonry infill buildings (discussed next). Upper stories may have had some confining tie columns and bond beams cast after the masonry wall was built. However, these elements were not present in many structures.

The collapsed and heavily damaged buildings employed precast concrete planks for the floor, and like low-rise residential, rural counterparts, the precast concrete planks were not well connected to the walls. Instead of being confined by the ring beam, if present, they rest on it. Some planks have small diameter (4mm-6mm) steel bars plastered to the bottoms which held them in place at the wall.

Fig 3. Five story unreinforced masonry building, damage to open frame ground floor, Dujiangyan. IMG0166

Fig 4. Five story unreinforced masonry building (4th column from left in Fig. 3), shear failures in first story columns, Dujiangyan. IMG0168

Fig 5. Five story partially confined masonry buildings, damage to open frame ground floor and second floor, Dujiangyan. IMG0183

Fig 6. Five story partially confined masonry buildings (Fig. 5), damage to open frame ground floor and second floor, Dujiangyan. IMG0189

Fig 7. Five story masonry buildings, damage to open frame ground floor and second floor, Dujiangyan. IMG0216

Fig 8. Five story masonry building (6th column from left in Fig. 7), shear failures in first story columns, note large spacing between ties, lack of hook, and use of large, rounded aggregate, Dujiangyan. IMG0219

Fig 9. Five story masonry building, collapse probably prevented by adjacent buildings, Dujiangyan. IMG0243

Fig 10. Five story building (Fig 9), debris from adjacent building collapse already removed, Dujiangyan. IMG0287

Fig 11. Ground floor column failure (rightmost column in Fig. 9), Dujiangyan. IMG0240

Fig 12. Side view of five story building (Fig. 10), note lack of connection between ground story column and upper floor columns and beam. IMG0254

Fig 13. Partial collapse of six story masonry with precast plank floor, Dujiangyan. IMG0267

Fig 14. View from streetside of six-story building in Fig. 13, Dujiangyan. IMG0282

Fig 15. Partially collapsed buildings (Fig. 13 on right), debris already removed from collapsed building in foreground. IMG0252

Fig 16. Close-up view of partial collapse of building in back of Fig. 15, note precast planks resting on top of, rather than connected to, ring beam, Dujiangyan. IMG0280

Fig 17. Backside of buildings shown in Fig. 10. IMG0263

Fig 18. Shear failure in ground floor masonry, building shown in Fig. 17 (left) and Fig. 10. IMG0266

Fig 19. Partially collapsed URM with precast concrete plank, Dujiangyan. IMG0324

Fig 20. Partially collapsed URM with precast concrete plank, Dujiangyan. IMG0335

Fig 21. Seven story masonry building with shear cracks, Dujiangyan. IMG0300

Fig 22. Shear cracks through columns in six-story confined masonry building, Dujiangyan. IMG0307

(2) Reinforced Concrete Frame with Masonry Infill

Collapsed and damaged reinforced concrete frame with masonry infill buildings were observed in Dujiangyan, although not as numerous as their unreinforced or partially confined masonry counterparts. One complex of like buildings in Dujiangyan showed many of the failure and damage mechanisms common to reinforced concrete frame with masonry infill buildings in Asia: (1) shear failure at the top of ground floor columns, in which the masonry wall was pushed out of the way (Figs. 24 and 25), (2) shear failure at the top of column-beam joint at the corners, which may have been exacerbated by the diagonal strut effect of the masonry infill wall (Figs 23 and 26), (3) in-plane shear failure of masonry infill (Fig. 27), (4) out-of-plane overturning failure of masonry infill (Fig. 28). Note that to prevent the latter failure mechanism, steel anchors were used to connect the infill wall to the columns, but the construction quality of this detail was mixed (Figs. 29 and 30). Directionality may have played a role in the damage pattern in these and other buildings in this complex.

Damage to ground floor/soft story columns in new, six-story apartment buildings is shown in Figs. 31 and 32.

Fig 23. Damaged six-story reinforced concrete frame with masonry infill, Dujiangyan. IMG0714

Fig 24. Shear failure at top of ground floor column, six story building from Fig. 23. IMG0705

Fig 25. Adjacent masonry infill panel (see Fig. 24). IMG0702

Fig 26. Shear failure in corner column. IMG0712

Fig 27. In-plane shear failure of masonry infill wall, note that thin horizontal band at mid-height was not sufficient to prevent crack propagation. IMG0715

Fig 28. Overturning failure of masonry infill wall Shear failure in corner column. IMG0717

Fig 29. Steel for connection between infill wall and column, note that bolt holes in column have been plastered over. IMG0711

Fig 30. Steel connection between infill wall and column. IMG0668

Fig 31. Damage to ground floor columns, new six-story apartment building, Dujiangyan. IMG0718

Fig 32. Soft ground story failure of new apartment building IMG0721