OBSERVATIONS AND OPPORTUNITIES FOR TECHNICAL ASSISTANCE
12 May 2008 Wenchuan, China Earthquake
Dr. Elizabeth Hausler
30 June 2008

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. Some villages have few to no buildings that remain standing.

The overwhelming losses in this earthquake in both urban (multi-story) and rural (one or two-story) construction can be attributed in large part to use of unreinforced masonry with precast concrete plank roofs and floors (Fig. 1). There is, however, at least one compelling example of excellent performance of confined masonry houses reportedly built according to the Chinese Seismic Code. Observations on residential building performance which can be used to inform rebuilding efforts follow. See also the corresponding detailed reports in (1) low-rise residential buildings, (2) mid-rise residential buildings, (3) Xiao Yu Dong bridge, and (4) Gao Yuan bridge.

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.

Fig. 1. CAUSE OF SO MUCH LOSS…and the case for confined masonry. 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, within 500m of evidence of permanent ground displacement (See Fig. 2)*

Fig. 2. Permanent ground displacement, Gao Yuan

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.

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.

OPPORTUNITIES FOR COLLABORATION

Opportunities may exist for collaboration on topics included but not limited to the following:

(1) Permanent housing reconstruction
(2) Landslide hazard mitigation
(3) Assessment and retrofit of damaged multi-story buildings, particularly RC frame with masonry infill
(4) Assessment and retrofit of vulnerable buildings in other parts of China
(5) Bridge reconstruction.

(1) Permanent Housing Reconstruction (Single Family)

The Joint Chinese-US Reconnaissance Meeting held in Beijing on 10-11 June lists "Inexpensive methods for rural prescriptive residential construction" first on the list of technical assistance requested. I heard from homeowners, local and international NGOs (there are a few on the ground), and academic partners that this is now an urgent need. Here's a rough outline of what needs to be done. *Note I made good progress on item 1 and started on item 2 during my first visit. I hope to return to Sichuan in late July or August to complete item 2, for which a collaborative partnership is suggested*

1: Understand Why Houses Collapsed

→ CAUSE OF FAILURE: For the rural areas I have visited so far, the biggest killer was unreinforced masonry wall with precast concrete plank roof and floor (see Figs 1 and 3 Table 1). There is no (or weak) connection between the planks and the walls, and no ring beam to confine the planks.

Fig. 3. Collapse of precast concrete plank on masonry wall, near Xiao Yu Dong bridge.

Simple, single story unreinforced masonry houses with pitched timber truss roofs performed better (see Table 1 and the Low-Rise Residential Buildings Report). I found examples of this structural system at all performance levels. There were collapses, but there were also villages in which these simple URM buildings with lightweight timber roofs were standing with a few minor cracks, while nearly all the piles of rubble had precast concrete planks jutting out of them.

Fig. 4. Confined masonry two-story house, no damage, Gao Yuan.

→ PROMISING SOLUTION: I visited one village in which some 2-story buildings were built by a private company in 2006 using confined masonry reportedly per the Chinese Seismic Code (see Figs. 1 and 4 and the summary table). Flawless performance. Other unreinforced masonry buildings in the same village with the precast concrete planks collapsed (Fig. 1). Some homeowners built single story unreinforced masonry kitchens with timber roofs, and they performed well overall (a few gable wall cracks; only one building damaged beyond repair).

2: Identify and Validate Low-Cost, Culturally Appropriate, Sustainable Earthquake-Resistant Housing Solutions

→ Housing Subsector Study: A detailed housing subsector study is needed to identify

- Common structural systems
- Locally available building materials, sources, quality, and cost
- Skill level of local builders, and commonly used tools
- Architectural and cultural preferences
- Climate considerations and other hazards, such as high winds, landslides, flooding.

Setting appropriate seismic design criteria and performance goals (also listed as a technical assistance need in the Joint Chinese-US Reconnaissance Meeting) is essential at this point.
The structural systems identified so far include the following (see Table 1 for photos):

- TIMBER frame or timber frame with masonry skirt – probably safest locally appropriate alternative, but timber may be unavailable and cost prohibitive. Homeowners may also prefer a masonry structure because of climate and cultural preferences.
- UNREINFORCED MASONRY with precast concrete planks – should be prohibited, not an option. For permanent, rural homes, introducing other structural systems which use precast concrete components should be strongly discouraged.
- UNREINFORCED MASONRY with timber truss roof may be viable, low-cost alternative, for single story simple houses, provided good practices are followed. A more detailed evaluation of the properties of those structures that performed well is needed (can such good performance be contributed to simple configuration with sufficient shear walls in both directions, low mass at the roof level, good quality masonry workmanship and use of lime in mortar, use of a hipped roof instead of pitched to avoid masonry gable walls which tend to crack and overturn, all of the above, etc.)
- CONFINED MASONRY – in absence of timber, maybe the best solution for single family rural house, but may be expensive, and although it is codified and becoming more common in China, rural homeowners are not yet familiar with this technology.
- EARTH – earth structures reportedly do exist in some of the affected areas, although I did not see them first hand. Need to review their performance and evaluate appropriateness of using improved earth construction (reinforced adobe as is being promoted in Ica, Peru; cement-stabilized rammed earth as was used Bhuj, India; and/or interlocking compressed stabilized earth block as was also used in Bhuj, and is being promoted in Southeast Asia and China). Note the latter two technologies require seismic analysis and validation.
- Reinforced concrete block masonry? Lightweight steel frame? Other new technologies? There must be some reason these technologies are not already common, so introduction of a new technology should be very carefully evaluated in terms of cost, cultural appropriateness, availability of materials and tools, long-term use and sustainability.

→ Validation and/or Shaking Table Testing: Validation and analysis may be needed for some structural systems. In my experience in Indonesia, designing and building a simple house according to existing codes and guidelines results in a house that is too expensive for the average homeowner to build, and therefore not sustainable. The post-disaster reconstruction context is a great opportunity to create long-term change in construction practice, which is difficult if the technologies being promoted are too expensive, too difficult to build, or made with materials and skills that are not locally available. Experimental testing may be needed to bridge the gap between conservative, code-based engineering design, and affordable and locally sustainable but sufficiently earthquake-resistant construction. If done locally in China, it may also be a useful way of demonstrating earthquake-resistant features to homeowners, builders and engineers.

3: Produce Detailed Design Drawings, Prescriptive Guidelines, and Training Materials
The type of materials developed depends on the housing delivery mechanism discussed in the next section (i.e., will homeowners build themselves, will companies, government or NGOs build for them). Technical documents needed may include the following:

- Prescriptive design guidelines (for engineers and architects)
- Detailed design drawings, bills of quality, technical specifications and/or construction quality checklists for a range of housing options (homeowners need options)
- Simple step-by-step construction guidelines (for builders and homeowners)
- Promotional materials, such as posters and flyers with core messages such as
    - Precast concrete planks are deadly! Don't build with them!

- If you must build unreinforced masonry, use only single story, lightweight timber roof (provide details)
- Timber is safer, rebuild from timber (we have a poster like this for Indonesia, available upon request)
- For confined masonry, details on how to follow the three C's - configuration, connections, and construction quality. (Again, this is from our Indonesia program, in which it is the three K's. Big problem in Indonesia is connections – the first poster in our Indonesia series is on connections and available upon request).

We have developed all of the above for use in our programs in Indonesia for confined masonry and timber with masonry skirt. Some documents are available on our website; the posters and booklets are still in process with a graphic designer and available (in draft) on request.

4: Understand Who Will Rebuild, How Funds Will Flow, and When

I heard that that some local governments are already giving cash subsidies to homeowners who lost their houses. However, this could be a living allowance, rather than rebuilding funds. I understand from China Earthquake Administration they are developing the reconstruction plans now, and indications are that the plans will come out in the next months. My impression is that the government will not mass produce houses for rural homeowners, but rather provide cash and/or materials to enable homeowners to rebuild themselves, but I could be wrong.

Note there are several other major issues and challenges involved in post-earthquake permanent housing reconstruction, beyond the design and construction of the house itself. These include but are not limited to documentation of land ownership, identifying who is a legitimate recipient of reconstruction funds, master planning and resettlement, and so on. These other considerations can extend reconstruction start dates for months and years.

5: Encourage Building Code Enforcement and Use of Incentives

At present, building codes and standards are not enforced for rural, single family houses in China. This post-disaster reconstruction provides an opportunity to take a step toward building code enforcement for rural houses. Perhaps the Bhuj, India post-earthquake reconstruction model could be used, in which funds were released in installments, and construction quality verified by a third party auditor. But if building standards are enforced, it will be necessary to ensure sufficient funding and technical assistance is available for homeowners to meet the standard.

6: Disseminate Information and Build Houses

How to get the documents and technical knowledge into the hands of homeowners and builders before and during construction is already being discussed. How information is disseminated depends on who controls the cash and does the rebuilding – if homeowners rebuild themselves, trained local engineers/construction professionals will be needed in the villages. There are many opportunities and potential partner organizations; train the trainers programs targeted at local engineers, builders, NGOs, and others may add value.

7: Don't Forget About Income Generation

Rural small business owners produce those precast concrete planks. Probably not very friendly to put them out of business when they too have been affected by this earthquake and need a way to make money. If the Chinese government bans those planks and really enforces it, and/or the demand goes away because a PR campaign is effective, they will eventually stop producing them and hopefully be entrepreneurial enough to come up with other ways of earning money. But considering such economic factors in a reconstruction program is important.

(2) Landslide Hazard Mitigation

Again, in the Joint Chinese-US Reconnaissance Meeting, "method to evaluate and/or mitigate hazards from rock (boulder) falls/slides in steep canyons" is listed under request for technical assistance. I am not a landslide expert but I'm not afraid of heights, and I can say that traveling on the road leading out of Dujiangyan toward Gao Yuan was by far the scariest part of this trip. The road is reduced to one lane in areas over fresh slides. It wasn't safe to get out of the car and take a close look, but some slides consisted of topsoil with river cobbles, others were rock/boulders larger than cars (Fig. 5). There was some work going on to contain soil from spilling onto the roadway with unreinforced stone masonry retaining walls (Fig. 6).

Fig. 5. Landslides near Gao Yuan.

Fig. 6. Stone masonry retaining wall construction near Gao Yuan.

(3) Assessment and Retrofit/Demolition of Multi-Story Buildings

Two types of multi-story buildings were responsible for most of the casualties and loss in urban areas: (1) reinforced concrete frame with masonry infill (Figs. 7 and 8), and (2) unreinforced, load-bearing masonry with precast concrete plank roof/floors (Figs. 9 and 10). The latter may have had some confining ring beams and tie columns, and often had an open frame ground floor.

Fig. 7. Damaged soft story columns in new, six-story reinforced concrete frame apartment building (Dujiangyan IMG0721).

Fig. 8. Shear failure in top of ground floor column, six-story reinforced concrete frame with masonry infill (Dujiangyan IMG0705)

My first impression of Dujiangyan, the largest urban area affected by the earthquake, was that the damage in the city was not that pervasive. It was difficult to see cracks and column failures by car, and much of the debris had been cleared, so some of building collapse sites just looked like empty lots. But after spending more time there, I realized that there are collapsed multi-story buildings throughout the city, and many buildings have been damaged, with damage ranging from significant structural to non-structural. See the Mid-Rise Residential Buildings Report for more information.

Fig. 9. Partial collapse of masonry with precast concrete plank floor, six-story (Dujiangyan IMG0335).

Fig. 10. Damage to masonry building with open frame ground floor (Dujiangyan IMG0286)

There are complexes of apparently identical buildings in which some buildings have significant structural damage, while others do not (due to directionality? Construction quality?). People have either moved out completely or are sleeping in tents in courtyards of these complexes. Also, there are some sites that were under construction at the time of the earthquake, and the builders/owners are not sure what to do with concrete that was just poured when the earthquake shaking occurred.

Maybe the Chinese government already has a plan for these structures, because it is not listed on the request for technical assistance. If not, here's how US-side may be able to contribute:

- Tagging/inspecting buildings
- Developing and implementing retrofit solutions – maybe this fits in to the NEES Grand Challenge on non-ductile concrete frame buildings?
- Sharing designs for multi-story new construction, which could include
    - "methodology to set seismic design criteria (performance goals) for various occupancy types given site seismicity" from the Joint Meeting.
    - a wider use and promotion of confined masonry for low-rise buildings – this earthquake has shown that building 2-story confined masonry buildings according the Chinese Seismic Code can perform well in strong shaking. Confined masonry is not common in the US, but it is widespread in developing countries; not many US-based engineers are not familiar with confined masonry, so this may be an opportunity for China to transfer knowledge to US.
    - green and energy-efficient building (i.e., design concepts beyond structural earthquake engineering).

There may be similar work for schools, however my impression is that the Chinese government is going to very closely control school reconstruction.

(4) Assessment and Retrofit/Demolition of Vulnerable Buildings (Elsewhere in China)

The degree to which one particular construction method contributed to casualties and loss – the use of precast concrete plank roof/floors on unreinforced or partially confined masonry walls – is significant. No doubt these buildings exist in other parts of China. An assessment and retrofitting scheme, starting with school buildings, might be an obvious next step once the immediate post-earthquake reconstruction needs in the affected area are met.

(5) Bridge Reconstruction

I observed two bridge collapses first-hand and saw a third on local TV news. Both collapses were exacerbated by permanent ground displacement. See Figs 11 through 14 and the Bridge reports for more information.

Fig. 11. Collapse of two spans of four-span reinforced concrete arch bridge, (Xiao Yu Dong IMG0038).

Fig. 12. Permanent ground displacement near Xiao Yu Dong Bridge. Note bridge is to the right of the photograph. (IMG0393)

Fig. 13. Collapse of one span of Gao Yuan bridge. (IMG0458)

Fig. 14. Collapsed span of Gao Yuan bridge. (IMG0472)