Wenchuan Earthquake May 12th, 2008

EERI/GEER Reconnaissance Team Field Report 8/3/08 to 8/11/08

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BUILDING STRUCTURAL TYPES & PERFORMANCE: There were three structural system types that predominated our limited building survey. The two primary building types are low-rise unreinforced brick bearing wall buildings, with large rural application, and mid-rise mixed brick-concrete buildings, which made up most of the large scale dense urban housing. The concrete moment frame buildings were not nearly as prolifically used, but stood out almost anomalously in terms of significantly better performance adjacent to dramatically collapsed brick buildings.

I. Unreinforced Masonry (URM) Bearing Wall Buildings:

Three basic types of URM buildings were observed in the affected regions:

1) 1-3 stories pure URM bearing wall buildings with timber and shingle roof structure;
2) Reinforced concrete storefront for the first story with 2-3 stories of pure URM bearing wall above; and
3) 3-7 story mixed brick-concrete system.

Low-rise pure URM buildings are frequently used for housing in rural areas. Although apparently disallowed by the Chinese Building Code, the walls were predominantly single-wythe (11-12 cm wide), particularly for one or two story houses. Precast hollow-core panels (typically 235x50x13cm) were used for the floor systems. There is no mechanical connection between the precast panels and the supporting brick walls. Trusses were typically not used for the roof structure, rather timbers would be supported by gaps in the URM gables and shingles would be placed on slats connecting the timbers. This roof structure did not restrain the gables and top story walls from out-of-plane movement, resulting in collapse of the top story walls. Many collapsed buildings of this type were observed in the affected regions and it is anticipated that many more were demolished and removed prior to the reconnaissance visit.

In small towns it was very common to see 2 or 3 stories of load bearing URM on top of one story of a reinforced concrete frame used for street-level storefronts. These buildings were principally large rectangular buildings, with precast hollow-core panel floors, bearing on transverse brick walls, and with longitudinal perimeter walls with significant openings. Roof system may be timber and shingle, similar to the pure URM buildings described above, or precast hollow-core panels. Similar to the pure URM structures, single-wythe load bearing masonry walls were frequently observed in the upper stories. Failures in these buildings were predominantly concentrated in the upper stories, with limited damage to the first story reinforced concrete frame (see examples below). This building type seemed to be “strong” in transverse direction, and “weak” in longitudinal direction, perhaps subject to “directionality effects”. Nonetheless, we know this building type to historically perform poorly in earthquakes.

Three to four story pure-URM buildings, similar to that described above but with out the reinforced concrete first story, were also observed in the affected regions. The performance of this building type was “poor” to catastrophic. There were a significant number of complete collapses of these buildings; reportedly many of the older school buildings were of this building type. Apparently this building type was “outlawed” by the 1976 Chinese building code. However, there many, many examples of rural buildings of this building type which suffered catastrophic collapses. It was pointed out by CEA that these buildings were not likely “engineered” nor adhered to good quality control oversight.

A mixed brick-concrete system was very commonly used for long rectangular three to seven story apartment buildings in larger cities such as Dujiangyan. Standard drawings for similar mixed brick-concrete buildings (Southwest 03G601), indicate that in addition to a reinforced concrete ring beam, reinforced concrete vertical elements (columns) should be located at maximum spacing less than or equal to 3.9 m along the load bearing walls, similar to “confined masonry” used in many parts of the world. Observations in the field, however, suggested that the damaged buildings incorporated a ring beam with widely spaced vertical elements, frequently only located at the corners of the building (see example below). Due to the lack of confinement from the limited vertical elements, this building type tended to behave as an unreinforced masonry structure. The masonry walls were typically two wythes thick or 24 cm. Precast hollow core panels are used for floors and roofs, bearing on reinforced concrete beams. Transverse reinforcement in the concrete elements were typically # 3 undeformed bars with fairly wide spacing of 12” or greater. There is no connection of floor planks to the bearing beams or to perimeter ring beam, except by contact, bearing and friction. There is great variation in the size of concrete elements (columns as small as 8” nominal, or thickness of the brick wall) and “random” spacing. As with other URM buildings, there seems to be “directional” strength in the transverse axis due to the regular spacing of brick shear walls, and weaker in the longitudinal direction, with only the two perimeter long walls with significant openings. In some buildings of this type, there were internal longitudinal corridor walls, so longitudinal “directional weakness” is not so clear. In street-front zones, non-code conforming soft-story conditions are created at the ground floor by business “storefronts”. Storefronts were frequently formed using reinforced concrete frames; however, in many damaged structures the frame only supported the front half of the building with the back of the building supported by load bearing masonry walls. Figure below shows damage to the front and back of one such building in Dujiangyan. The 1989 Chinese Building Code has very specific provisions for this building type.

The performance of the mixed brick-concrete building type varied greatly from “life safe” (with significant and perhaps unrepairable damage) to partial collapse and total collapse. This is where the “lateness” of the reconnaissance trip may have affected our survey of damage: so many buildings had been demolished. We saw many buildings with first story collapses (middle school in Yingxiu and factory housing in Dujianyan) and many top floor collapses, though these were often of the Type I UMB building type. There does seem to be evidence of directionality effects (strong forces in the direction of the building’s “weak axis”, though this was never conclusive and consistent observation. We saw evidence of orthogonal behavior (forces at a skewed angle to the principal building axes). This may have resulted in torsional behavior, yet hard to make engineering sense of this given the lack of “real” floor and roof rigid diaphragms. We observed many ground floor collapses even without soft story store front conditions. Other observations of the performance of this building type include: building “ends” with severe damage, perhaps coinciding with stair well construction; ‘end of block” effects; and severe damage or partial collapse at zones of detailing or material defect. Again, many of these performance observations were hard to turn into “sure” conclusions due to the nature of the “perishable data.”

It should be clearly stated that there were many examples of issues of poor quality control and material defects that may have contributed to this building type’s performance. None of these QC issues would necessarily be causative to collapse but may have greatly contributed to localized failures. These include:

Baseball sized smooth aggregates in concrete
Issues of “weak” concrete paste
“Black” brick (red on the outside, black core, due to insufficient production temperatures)
Concrete cover over reinforcing steel
Poor detailing (or execution) including lack of lap length, hooks, development length

II. Reinforced Concrete Moment Frames with Infill:

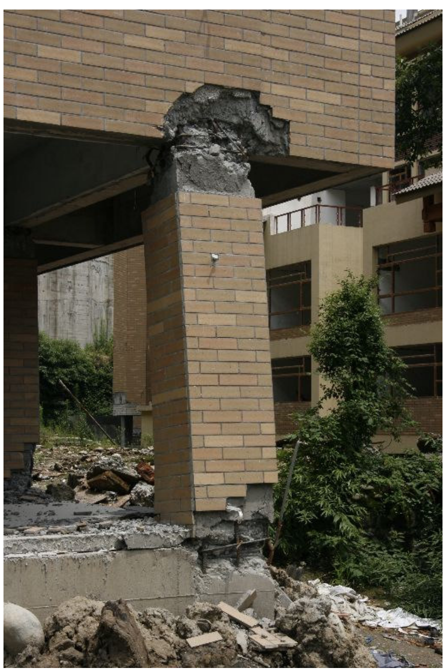
Though this was not a prolifically seen (again, perishable data issue) building type, it sometimes stood out as a “good” performer, especially in contrast to heavily damaged or collapsed brick bearing wall buildings around them. This building type varied in plan configuration, and number of stories, commonly with the now “standard” precast concrete panel floors and roof. Solid bricks, solid concrete block, and hollow clay tile were used as infill material, sometimes mixed within a single wall. The infill is usually “gapped” at the columns and the last course of brick at the top of the wall is placed at a 45-degree angle below the concrete frame beam. The ductility requirements contained in the Chinese Building Code, for concrete moment frames, has not been evaluated.

Better performance was observed in buildings with all brick or concrete block infill, or where hollow clay tile was only used in the upper stories. The figure below shows the collapse of a building with a hollow clay tile infill at the ground level.

Generally, the performance of concrete moment frame buildings was very good, of the building types we observed, especially sometimes in relation to the very poor performance of adjacent buildings (3-story middle school in Bailu; dining hall in Yingxi middle school). New twelve-story concrete frame-wall buildings performed exceptionally well (see below) in Joling where modest damage to URM buildings was observed.

In some cases, however, there was clear evidence of weak-column/strong-beam behavior, with distinct hinging at the top of the columns just below the beams. Column shear failures were observed at the top of the first story columns, frequently due to damage to infill walls or gaps in infill walls for windows, and hence, the creation of a captured column.

Significant damage to concrete moment frame structures were observed at a condominium complex under construction at the Yuan Shan City Garden in Dujiangyan. As shown in the figures below, the following damage typical of non-ductile concrete structures was observed in this complex: plastic hinging in soft first story columns; buckling of column reinforcement in interior joints with little or no transverse reinforcement; shear failure in exterior beam-column joints; and shear failures in short columns created by nonstructural concrete elements.



Concluding Observations: It is hard to sum up observations into a few bullet items. There were some structural engineering "puzzles" going into the reconnaissance trip, and many items remain a puzzle. Some of the issues may be clarified once CEA releases the ground motion data and it can be plotted against the damage areas. CEA has nearly completed an exhaustive survey of buildings in Dujianyan which may produce critical information on directionality, orthogonal forces, soft-story collapses, and end-of-block building failures. The principal structural engineering performance observations are contained in the building type descriptions above. A few additional items of note for future consideration:

- Clear examples of near fault pulse response; consider if thrust faults produce a vertical component of near-fault pulse
- Performance of mixed brick-concrete buildings versus number of stories: more demonstrative damage and collapse appeared in 6-7 story than in 3-4 story buildings
- Long ground motions of 60-120 seconds have been reported, but no real indication of effects of sustained cyclic loading on buildings
- Directionality effects remains a puzzle which may be clarified with more systematic analysis
- There was very little evidence of foundation failures