Collapse Mechanism of Multi-story Masonry Structure with First Soft Story

Xun GUO, Zhihua ZHENG & Fu HE
*Institute of Engineering Mechanics, China Earthquake Administration,
Harbin, 150080, PR China*

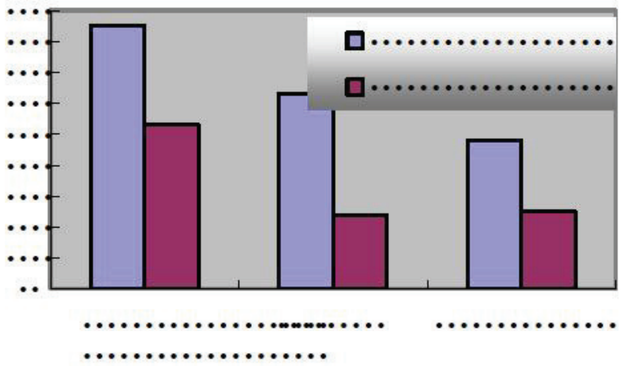
SUMMARY:
Earthquake casualties mostly come from the collapse of residential houses, this fact can be verified by numerous disastrous events such as Wenchuan earthquake (2008), Yushu earthquake (2010), Haiti earthquake (2010), Algeria earthquake (2003), etc. The much higher vulnerability in developing countries is related with the dense distributed unreinforced masonry structures. The most predominant characteristics of such masonry structures are: (1) there is no or very little reinforcement, thus lead to weak connections; (2) heavy mass lead to more earthquake inertial force; (3) the fortification earthquake intensity is usually very low. These characteristics will inevitably result in much higher collapse ratio during large earthquake. Detailed investigations on Wenchuan earthquake showed that properly designed multi-story masonry building could survive even in area with intensity of XI (PGA • 1.0g). One of the typical such buildings was studied in detail by field measurement, numerical analysis, as well as shaking table test of scaled down models. Two important key points for collapse resistant can be concluded as designing sufficient restrain on masonry blocks by measures such as tie beams and columns and balanced horizontal stiffness between each of the longitudinal axes at first story. Extended tests on series of scaled models and wall assemblies are carried out by both shaking table and Quasi-Static facilities, constitutive relations for wall segments and story assembly are derived by regression on the test results. These results lay a solid foundation for the retrofitting design of the great number of existing vulnerable houses.

Keywords: *Masonry structure, Collapse resistant, balanced stiffness, winged columns*

1. BACKGROUND

The M 8.0 Wenchuan earthquake which occurred in May 12 2008 killed nearly 89,000 people, but this was not a special case. The situation reflected in Wenchuan earthquake and the M7.1 Yushu earthquake which happened in April 14 2010 is quite similar with that of M7.8 Tangshan earthquake of July 28, 1976 and most of the earthquakes from several earthquake prone developing countries, such as Haiti, Algeria, Pakistan, India, Iran etc. The most unacceptable fact is that a lot of buildings collapsed during these large or even not very earthquakes and thus killed hundreds or thousands of people. Statistics from Wenchuan earthquake showed that the multi-story masonry buildings with first story used as shops (called object structures in this paper) were weakest in collapse resistant. The collapse ratio for this kind of buildings is as high as 85% in areas such as Beichuan and Yingxiu towns. Figure 1 shows one of the collapsed examples and collapse statistics. Such buildings are much popular in south of China with inventory of around 20 million, and about ten percent of the 1.3 billion total population live in them. It can be imagined that when the Wenchuan earthquake come in the near future, similar scene will reappear if the existing vulnerable buildings are not retrofitted. Anyway we can definitely do something if we carefully learn from previous disastrous earthquakes.

a) The collapsed first story which used as shops is very popular in Wenchuan earthquake



(b) Statistics of collapse ratio for several main types of structure in Wenchuan earthquake

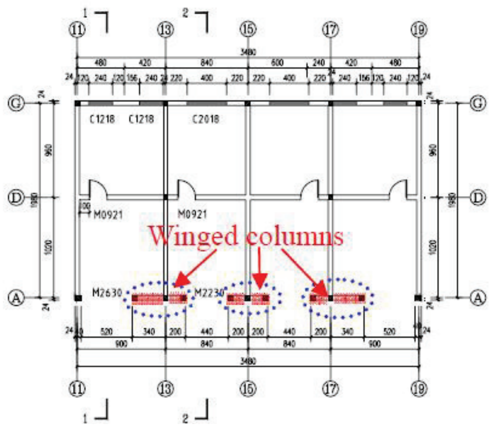
Figure 1. The collapse ratio of multi-story masonry with first story used as shops is as high as 85%

2. COLLAPSE MECHANISM ANALYSIS

Field investigation on Wenchuan earthquake showed that most of the object structures collapsed at first story in longitudinal direction and obvious torsion could be found. But there are four such buildings performed very well in the area of intensity XI (with equivalent PGA of 1.0g). One of them is showed in Figure 2 (a). These four buildings are regarded as model structures for further investigated. Comparing with other collapsed buildings, the common configurations in model structures are listed in shaded area at Figure 2 (b) which cannot be found in the collapsed multi-story masonry structures with first story used as shops. Figure 2 (b) is a plan view of the first story in the Apartment of Beichuan Communication Company. Column with shaded area in Figure 2 (b) is called winged column. Wall A in front is used for holding entrances of shops and therefore much more openings are needed; Wall B in middle is used for separating shopping area and living area, and door window openings are needed in this wall.

In order to find out the function of winged columns in collapse resistant, models with 1/5 scale are constructed for earthquake simulating test. The models showed in Figure 3 focus on performance of first story of the object structures. The first one (Model A) just comes from drawings of the Apartment of Beichuan Communication Company which adopts winged columns in wall A; the second model (Mode B) used the same configuration except the shaded area in Figure 2 (b) is removed. Earthquake record showed in Figure 4 captured closed to the epicenter of Wenchuan earthquake is used for input of shaking table.

(a) The survived 7 story masonry with first used as shops



(b) Plan view of the first story

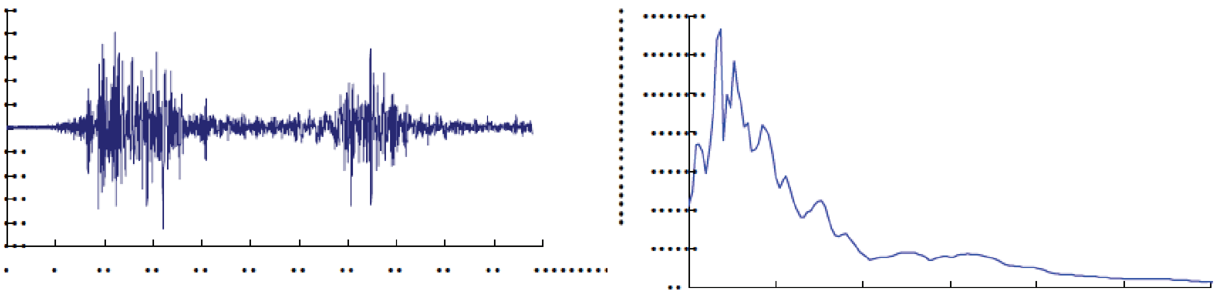
Figure 2. One of the survived model building and its first story plan view

Exciting results derived from the series shaking table test. The PGA of input record was increased from 0.1g to 0.7g, only minor cracks could be found in some walls of Model A; when the PGA reached 0.7g, the roof would slide back and forth, and the PGA could not increase any more. Figure 5 shows the status of Wall A and Wall C of Model A. But for Model B, when the PGA reached 0.4g, Wall C was crushed as showed in Figure 6 (a), and Wall B was similar; when the PGA reached 0.6g, it totally collapsed as showed in Figure 6 (b). Shaking table tests disclosed that the winged columns were key components for collapse resistant. Three longitudinal walls in Model B did not failed simultaneously. Wall C and Wall B failed first and Wall A failed at last. In fact, the longitudinal stiffness of Wall C and Wall B are much larger than Wall A in Model B, and earthquake inertial forces will be distributed in proportion to stiffness among three walls, therefore Wall C and Wall B bear most of the horizontal earthquake force in longitudinal direction. But the construction material and configuration resulted that the ductility of Wall C and Wall B is very poor, that means Wall C and Wall B are easy to collapse if the distributed earthquake inertial forces are higher that their capacities.

(a) Model A with winged columns (Wall A) (b) Model B with normal columns (Wall A)

Figure 3. Scaled models (1/5) of with and without wings

For Model A, the winged columns contribute much stiffness for Wall A, therefore the total horizontal earthquake inertial force in longitudinal direction will distribute uniformly among the three walls. This fact will greatly decrease the torsion effect at the first story. That means the balanced stiffness in longitudinal direction of Wall A, Wall B and Wall C survived this object structure with winged columns.



(a) Time history (b) Response spectrum

Figure 4. The input earthquake record and the corresponding response spectrum

(a) Wall A of Model A (b) Wall C of Model A

Figure 5. Status of model A after earthquake input at PGA of 0.7g

(a) Wall C after 0.4g (b) Totally collapsed after 0.6g

Figure 6. Status of model B after earthquake input at PGA of 0.4g and 0.6g

3. CONCLUSION REMARKS

Multi-story masonry building with first story used for shops is quite popular in South China. It is so urgent to retrofit the large inventory of such existing buildings. One of the model structures which performed very well during Wenchuan earthquake is analyzed in detail. Shaking table tests showed that the winged columns in front longitudinal wall can provide necessary stiffness for balance distribution of earthquake inertial forces among walls, and this will lead less torsion effect. Principals imply in winged columns used for retrofitting design of existing multi-story masonry structures with first story used for shops.

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