Seismic Damage of R/C Frame Structures in Ms8.0 Wenchuan Earthquake

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ABSTRACT:
All materials of this paper derive from the author's 80 days field investigation of the Great Ms8.0 Wenchuan Earthquake. R/C frame building structures have been suffered different kinds and different levels damage in different affected areas of Ms8.0 Wenchuan Earthquake. R/C frame structure is one of the major types of building structure in Sichuan area. All existing R/C frame structures are constructed in 3 stages: before 1990, during 1990 and 2001, and after 2001. These buildings shows different damage patterns in earthquake such as masonry infill wall damage only, beam-end with infill wall damage, column-end with infill wall damage, bottom story damage, mid-story damage even total collapse. It discloses almost all drawbacks of the structural design, construction and management. This paper summarizes 5 kinds of damage patterns together with the damage cause analyses of R/C frame structures. Results shows that infill wall contributes much to the seismic capacity of the R/C buildings, the pattern of column-end with infill wall damage usually caused by wrong design concept, the pattern of mid-story damage mostly are caused by the story stiffness change in corresponding story, and so on. The author hopes that this paper can provide some useful information for both of design and construction of future R/C frame buildings during reconstruction of Ms8.0 Wenchuan earthquake.

KEYWORDS:
Ms8.0 Wenchuan Earthquake, Damage pattern, R/C frame structure

1. OVERVIEW

The Ms8.0 earthquake in Wenchuan, China on12 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 to multi-story) construction can be attributed in large part to either use of unreinforced masonry with precast concrete plank roofs and floors or use of masonry walls without seismic design satisfying the bottom line of seismic requirements or both. R/C frame structures is one of the major types of building structure in Sichuan area and have been suffered different kinds and different levels damage in different affected areas of Ms8.0 Wenchuan Earthquake. Generally, all existing R/C frame structures are constructed in 3 stages: before 1990, during 1990 and 2001, and after 2001. These buildings shows different damage patterns in earthquake such as masonry infill wall damage only, beam-end with infill wall damage, column-end with infill wall damage, bottom story damage, mid-story damage even total collapse. It discloses almost all drawbacks of the structural design, construction and management. This paper summarizes 6 kinds of damage patterns together with the damage cause analyses of R/C frame structures. All information comes from the author's 80 days field investigation immediately after the 5.12 major earthquake.

2. DAMAGE PATTERNS OF R/C FRAME STRUCTURES

2.1 Damage of Masonry Infill

The masonry infill damage is one of the most prominent damage patterns of the R/C structures in the great

Ms8.0 Wenchuan earthquake from the immediate neighborhood area of the fault rupture to the lightly affected area far away from the rupture, from the multi-story (no more than 15 stories) to the high-rise R/C buildings. The damage degree and pattern of the masonry infill changes from the connection damage along the beam bottom and column edge only to the visible single directional diagonal cracks, to the "X" type cracks, to the local or total collapse, while left the beams and columns of the R/C frame without any visible damage.

The damage degree and pattern of the masonry infill shows in fig.1~fig.6, it can be seen that even in the immediate neighborhood area of the fault rupture, there is intact R/C frame only with few lightly damaged masonry infill existing, for example, fig.1, the 4-story R/C office building (Baoshan Group Ltd.) who is located in Longmenshan town, with very stable rock base, where is only about 20 kilometers far away from the major Longmenshan fault rupture. Another rectangular 4-story R/C office building (Chuankuang Group Ltd.) who is located at the Jiangyou county town in the east of about 40 kilometers away from the major rupture, its' masonry infill also shows similar performance, fig.2. This kind of slight damage is also found in most high-rise R/C buildings (15-story over) in Chengdu city, fig.3. The only difference is the damage usually happened in the mid-level stories in high-rise buildings instead of the bottom stories of multi-story buildings.

Fig.1 4-story office building of Baoshan Group ltd.

Fig.2 4-story office building of Chuankuang Group

Fig.3 High rise building in downtown Chengdu

Fig.4 Building with serious damaged masonry infill

Serious damage to the masonry infill of the R/C frame structures is found in all over the affected area with damage intensity over the 7 degree (Chinese seismic intensity standards). Most serious damages of the masonry infill happened in the first floor of most R/C buildings, fig.4~fig.5. Generally, with the floor increasing the damage becomes lighter gradually except for the staircase tower. This phenomenon is coincided well with the knowledge that the seismic story drift of R/C buildings is usually larger than other upper stories, from numerical analysis. It's obvious, due to the controversy of the relative larger story drift of the frame in first floor and the limited deformability of the masonry infill, during the strong ground shaking, the lateral movement of the frame will inevitably cause obvious damage to the masonry infill.

Fig.5 seriously damaged masonry infill

Fig.6a. beam-column damage of R/C frame

Fig.6b. beam-column damage of R/C frame

Fig.6c. beam-column damage of R/C frame

2.2 Damage of Beam-Column

Well designed R/C frame shows very good performance even located very close to the fault rupture, for example, an almost finished new R/C frame building, fig.6a~c, the masonry infill still has not constructed, the damage of the beam-column demonstrates the stronger capacity of the R/C frame structure comparing with the next door masonry building, who is also in construction and also almost finished. In this case, the relatively severer and concentrated damage happened in the two corner staircases shows the weakness of the corner

staircase in earthquake. The column end damage of the peripheral columns shows the coupling effects of the bending, shearing and torturing deflection. The beam end damage shows the typical behavior of the moment frame under earthquake, it's a kind of expected seismic damage. Assuming, if the masonry infill is constructed in this frame, how it will be performed during the earthquake?

2.3 Damage of R/C Top-Story

Investigation shows that the damage of the top-story or the staircase tower of the R/C buildings mostly happened in areas with mid-distance, say about 80km or so, to the fault rupture. One example is a hotel building located in downtown Deyang City, fig.7, there is no structural damage observed in its' lower stories, but the top end of the column in the top story is seriously damaged with obvious yielding of the longitudinal reinforcement. Another example is an office building located in downtown Jiange county, fig.8, there are only some obvious masonry infill damages but without any structural damage in it's lower stories, also, the top end of the column in the top story is seriously damaged. Form the front façade, the building looks like a symmetric structure, but in fact, the whole building is separated by a vertical segregate opening immediately close to the right damaged tower part. Similar case is also found in the field investigation in Muyu town of Qingchuan County, the office building of the local town hall, fig.9 It discloses the amplifier effect of the top tower of the R/C frame building to the ground motion on one hand and the negative effect of the vertical stiffness change in a building on the other hand.

Fig.7 Column damage in top story

Fig.8 Top story damage

Fig.9 Top story damage

2.4 Damage of R/C Bottom-Story

The damage of the bottom story of R/C frame buildings is also one of the major damage patterns in affected areas especially in areas very close to the fault rupture. One example is a hotel building located in Hongbai town of Shifang county, fig.10, where most buildings suffered serious damage and only 40% remain standing after the major shock. It's a typical R/C frame building with seriously damaged bottom story. Most top-end of the bottom columns performed as concrete failure and reinforcement yielding with obvious buckling while most masonry infill walls shows fatal shear damage with typical diagonal "X" cracks or collapse. Similar case is also found in Yingxiu town, very close to the epicenter. They are the canteen building and corridor building connecting the classroom and another collapsed R/C frame canteen hall, of the Xuankou middle school. The bottom columns especially those with infill walls and staircases suffered serious damage but remained standing fortunately, fig.11. The damage also can be attributed to the coupling effects of the sharpen story stiffness change between the bottom floor and the upper floors, and the relatively larger story drift of the bottom floor in typical R/C frame structures under earthquake.

Fig.10 bottom story damage


Fig.11 bottom story damage

2.5 Collapse

Collapse of the R/C frame structures are also observed in areas immediately adjacent to the fault rupture. One example is a 9 story bank building located in downtown Beichuan county, which is the highest building in downtown Beichuan and totally collapsed to the riverside direction, fig.12. Another example is the abovementioned canteen hall of Xuankou middle school located in Yingxiu town, fig.13. The causes of the collapse are still in profound studying.

Fig.12 collapse of a 9-story frame building

Fig.13 collapse of a 4-story frame building

3. CONCLUSIONS

This paper provides 6 kinds of damage patterns together with the damage cause analyses of R/C frame structures. Results shows that infill wall contributes much to the seismic capacity of the R/C buildings, the pattern of column-end with infill wall damage usually caused by wrong design concept, the pattern of mid-story damage mostly are caused by the story stiffness change in corresponding story, and so on. The author hopes that this paper can provide some useful information for both of design and construction of future R/C frame buildings during reconstruction of Ms8.0 Wenchuan earthquake.

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