SITE URGENT STRUCTURAL ASSESSMENT OF BUILDINGS IN EARTHQUAKE-HIT AREA OF SICHUAN AND PRIMARY ANALYSIS ON EARTHQUAKE DAMAGES

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ABSTRACT:

Several experts from Tongji University went to the disaster area of Sichuan to carry out the site urgent structural assessment on important buildings just after the event of 5.12 Wenchuan Earthquake. The buildings, which have the severe structural defect on the main structural members or the possibility of collapse or falling down of the structural members are judged to be dangerous buildings, which should be demolished soon. In this paper, the outlines of the urgent structural assessment and the structural conditions of the damaged buildings in the extremely heavy disaster area of Qingchuan County are introduced. The earthquake damaged buildings are primarily analyzed. Some suggestions are proposed to guide the site structural assessment and to enhance the seismic capacity of building structures.

KEYWORDS: Sichuan earthquake, urgent structural assessment, dangerous buildings, masonry buildings, earthquake damage, seismic capacity of buildings

1. INTRODUCTION

The massive earthquake of M8.0 occurred in Wenchuan County at 14:28, May 12th, 2008. On the request of the ministry of housing and urban-rural development, Tongji University organized expert groups for carrying out the site urgent structural assessment of important buildings in the disaster area of Sichuan province. The first group, which consists of 6 experts including the authors with the head Lu Xilin, came to Guangyuan City on May 16th and returned to Shanghai on May 23rd. The first export group worked in the urban area, Qingchuan county and Cangxi county of Guangyuan City.

Although Qingchuan County is 202km from the epicenter of Wenchuan earthquake, Qingchuan County belongs to the extremely heavy disaster area because Qingchuan and Wenchuan lie in the two ends of Longmen mountain earthquake faults. Till July 25th, there are 36 big after-shocks (over M 5.0), while 7 big after-shocks took place in Qingchuan county, including the largest one (M6.4) happened in Qingchuan at 16:21, May 25th. Qingchuan County locates in mountain area, with the highest elevation 3837m. The urban area of Qingchuan County is located in a narrow region between two mountains and besides one river. Geological hazards induced by earthquake, such as land slides, debris flows are the main potential danger to public safety.

During our work in Guangyuan, we experienced 5 big after-shocks (over M5.0). A big after-shock (M5.4) whose epicenter is in Qingchuan took place at 14:06 of May 19th, when the authors were in a 4 storey building named as Qingchuan Hotel for site urgent structural assessment. About 10 minutes later the strong after-shock(M5.4), severe landslide happened on Shiziliang Mountain which is in the back of Qingchuan county and rocks fell to post and telecommunication office of Qingchuan County.

The main work of this paper is to introduce the work of site urgent structural assessment in Qingchuan County, and to investigate the earthquake damaged building, then to analyze the structural damages. Finally some suggestions are given based on the analysis and research on damaged buildings.

2. SITE URGENT STRUCTURAL ASSESSMENT FOR IMPORTANT BUILDINGS

2.1 Purpose and Principles

The main purpose of the work is to prevent the possible collapse of import buildings under the after-shock including schools, lifeline engineering structures(such as water supply department, power supply department, hospitals, communication, etc), banks, television and broadcast offices, police stations, emergency command center and so on.

The principle of site urgent structural assessment is that the buildings with potential risk of collapse in after-shocks should be demolished immediately. These dangerous buildings have four structural features as following:

1) Masonry buildings with severe cracks or partial collapsed; 2) reinforced concrete structures with steel bars fractured or yielded; 3) buildings with evident large integral inclination; and 4) buildings with some potential falling components.

2.2 Achievement of Structural Assessment

Brick masonry buildings (including bottom frame and inner frame masonry structures) are widely used in Qingchuan County because of economic consideration. Site urgent structural assessment was proceeded for total 133 buildings (about 150,000m^2) in Qingchuan County, which are almost masonry buildings. 66 buildings judged to be demolished soon because of the severe structural defect on the main structural members or the possibility of collapse of the structural member connected to the destroyed members.

3. INVESTIGATION ON EARTHQUAKE DAMAGED BUILDINGS

During the site urgent structural assessment, investigation of earthquake damaged buildings is concentrated in brick masonry buildings due to the rare use of other structural type except brick masonry structure. Despite of many buildings destroyed or heavily damaged, there are still some buildings with only slight damage or no damage. The common characteristics of these well or nearly well preserved buildings guarantee the good seismic performance of structures to withstand the strong earthquake, which including transverse load-bearing wall, smaller bay (no more than 3.9 m), longitudinal wall with small openings, cast-in-place tie column and tie beam, the rectangular plane and the same plane of the upper and lower floors without change in elevation, etc.

The earthquake damage information of buildings is summarized as below.

3.1 Through Diagonal Cracks or Through X-shape Cracks on the Wall

Through diagonal cracks or through X shape cracks on the wall are common phenomena of earthquake induced structural damage, which can be found in almost damaged buildings. This earthquake damage belongs to shear failure, which is caused by principal tensile stress exceeding shear strength of masonry. The through diagonal cracks usually appear mostly on the bearing transverse walls of the first to third floors, while X-shape cracks is very popular on the longitudinal walls, especially between the door or window openings of nearly every floor. When there are many pre-embedded pipelines, wire pipes and wire boxes in the wall, the width of this kind of crack will generally exceed 1mm because of the weakened section, which means more severe damage of building. Quite a number of walls lose their bearing capacity for the failure of the brick and mortar. Typical phenomena of through diagonal cracks or through X-shape cracks on the wall are shown in Figure 1. The right picture of Figure 1 shows the influence of many wire pipes and wire boxes in the longitudinal wall.

Figure 1 Typical phenomenon of through diagonal or X-shape cracks on the wall

3.2 Horizontal Crack on the Wall

Horizontal cracks on the wall usually appear at the wall near the elevation of floor or roof. The through horizontal crack along mortar joint enlarges the damage and results in collapse of pre-cast hollow slab. Meanwhile, horizontal cracks also appear on the end of some bearing brick columns, which lead to decrease and even losing of the structural capacity. Although not many this kind of damage was found in the investigation of Qingchuan, partial collapse of buildings caused by this kind of cracks was not seldom seen in other disaster region, such as Wenchuan county, and Beichuan county. This kind of cracks means horizontal shear failure of walls. It can be deduced that the large vertical ground motion leads to this kind of earthquake damage. Typical phenomenon of horizontal cracks on the wall is shown in Figure 2.

Figure 2 Horizontal cracks on the wall or the bearing brick column

3.3 Separation of Walls at the Intersection of Longitudinal and Transverse Walls

Due to the strong earthquake action, some longitudinal and transverse walls separate from each other. This kind of earthquake damage causes instability of walls and leads to out-of-plane collapse of walls. This phenomenon is common to appear on the rowlock wall and half width wall although it can occasionally be seen in solid wall, which is usually caused by bad or no indenting in the construction of wall. In the condition of wooden roof truss, this damage can be easily found in the top floor with partial collapse of the external wall. The left picture of Figure 3 shows the separation of inner walls, while the right picture of Figure 3 demonstrates the damage of wooden truss caused by the separation of the longitudinal and transverse wall.

Figure 3 Separation of walls at the intersection of walls

3.4 Damages of Wooden Truss

Wooden roof truss is frequently used in Sichuan province. The severe damage of wooden truss is shown as a large number of roofing tiles falling, failure of wooden roof truss and crack on the bearing. And in extreme condition, the damage of wooden truss will leads to the split of longitudinal and transverse walls and the partial destroy of the buildings. The typical damage of the wooden truss is shown in the left picture of Figure 4.

One more thing mentioned is that the severe damage of the little slop roof on the roof structure (as shown in the right picture of Figure 4), which is recently used as heat insulting layer of slab flat in addition to monitor the traditional wooden roof architecture in Sichuan.

Figure 4 Damage of the wooden truss

3.5 Damages of the Stair Part

Comparing with the other part, the damage of stair is relatively severe. The earthquake damage focuses on the crack and even split of bearing transverse wall while not very severe damage were found on the reinforced concrete stair, as shown in Figure 5.

Figure 5 Typical damage of bearing wall and concrete slab in the stair part

The left picture of Figure 6 shows the severe damage (partial collapse) of the stair part in the building with irregular plane. From the layout of this building as shown in the right picture of Figure 6, the stair part is the convex part of the T-shaped plane.

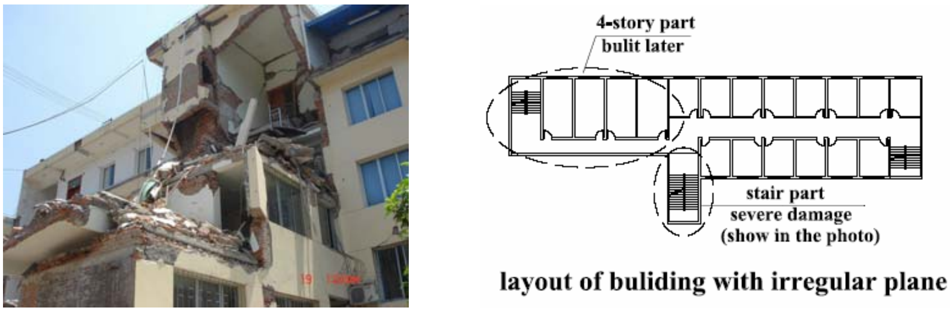

Figure 6 Severe damage of stair part due to irregular plane (T-shaped)

3.6 Damages of Nonstructural Components

By comparison with the structural components, the nonstructural components are heavily damaged as no reliable ties between the nonstructural components and the structural components. The main damage patterns of the nonstructural components are horizontal crack, diagonal crack, even partial collapse. Figure 7 shows the partial collapse of the parapet, which even leads to the damage of the roof slab. Figure 8 shows the typical damage of nonstructural components, such as the collapse of the fence in the corridor, fracture of the cantilever canopy, falling of the outside ornament. Severe damages are also found on the protruding member in the roof, which will be discussed later.

Figure 7 Partial collapse and fall of the parapet wall

Figure 8 Typical damages of nonstructural components

4. ANALYSIS OF BUILDING DAMAGES BY EARTHQUAKE ACTION

4.1 Importance of Seismic Protection

The structure of most countryside house is the mixture of adobe and masonry without seismic protection. And some buildings built earlier in the urban area did not take seismic protection into consideration. Theses buildings are severely damaged, as demonstrated in Figure 9.

Figure 9 Severe damages of countryside house and buildings without seismic protection

In the meanwhile, the buildings with seismic protection have good collapse resistant capacity under earthquake even if the design standard of that time is lower than the current standard. According to the magnitude of 5.12 Wenchuan Earthquake and its after-shock, the intensity of Qingchuan County is deduced to reach 9, which exceeds the current fortification intensity of 7. There was no school buildings collapsed in the urban area of Qingchuan County. Two teaching buildings of Qiaozhuang primary school and Qingchuan middle school have only slight damages, as shown in Figure 10.

Figure 10 Slight damages of teaching building of two schools

4.2 Influence of Unauthorized Reconstruction

Unauthorized reconstructions caused severe earthquake damages. A typical example is a collapsed 5-floors building, which is used as the mountain delicacies market in the 1st floor and dwelling house in 2nd to 5th floor. It was designed as a 3 story building supported with bottom reinforced frame and finally constructed with 2 more stories added without reasonable design. Due to the weak structural capacity of bottom frame and the poor structural integrity, the building was totally collapsed. The wrecks of the collapsed building are shown in Figure 11.

Figure 11 The wrecks of a collapsed 5 storey masonry building supported by reinforced concrete frame in bottom

The typical unauthorized partial reconstruction includes removing or adding wall, punching a large whole, rebuilding and closing balcony after completion. Figure 12 shows the partial damages of unauthorized reconstruction with nearly no damage on the main structural components.

Figure 12 Partial damages caused by unauthorized reconstruction
(closing balcony, demolishing and remodeling wall)

4.3 Influence of Building Irregularity

The buildings with irregularities of plane and elevation were damaged severe. Figure 13 shows the severe damages in the short part of a L-shape building. In Figure 6, the harmful influence of irregular plane (T-shaped) on seismic performance can obviously be seen from the severe damage of the stair part. And Figure 14 shows the severe damages in the position of staggered elevation.

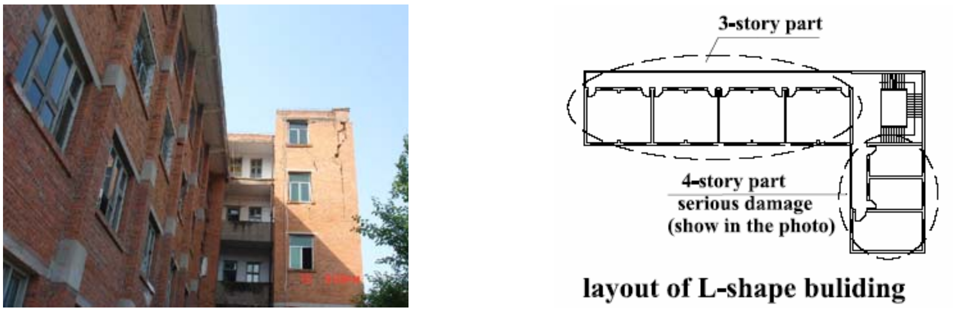

Figure 13 Severe damage of buildings with plane irregularity

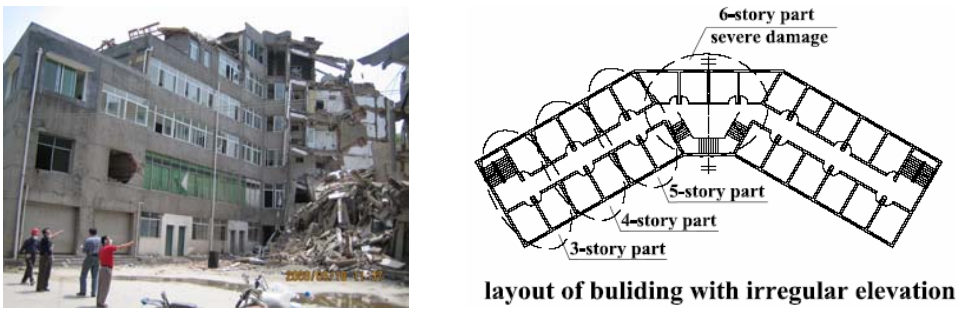

Figure 14 Severe damage of buildings with elevation irregularity

4.4 Influence of Protruding Members on the Roof

Protruding member on the roof belongs to the typical irregularity in elevation. Under earthquakes，the protruding part will have relative large deformation and result in severe damage because of the participation of high vibration mode called as the whipping effect. Figure 15 gives two typical damaged examples of protruding members on the roof.

Figure 15 Severe damages of protruding members on the roof

4.5 Role of Seismic Joint

It is proved in the previous earthquake damages that seismic joint is an important seismic measure. Figure 16 shows the severe damage, such as wall crash of two buildings and the diagonal crack on the wall of the relative small building , which is caused by unreasonable setting of seismic joint, with too small dimension of the joint.

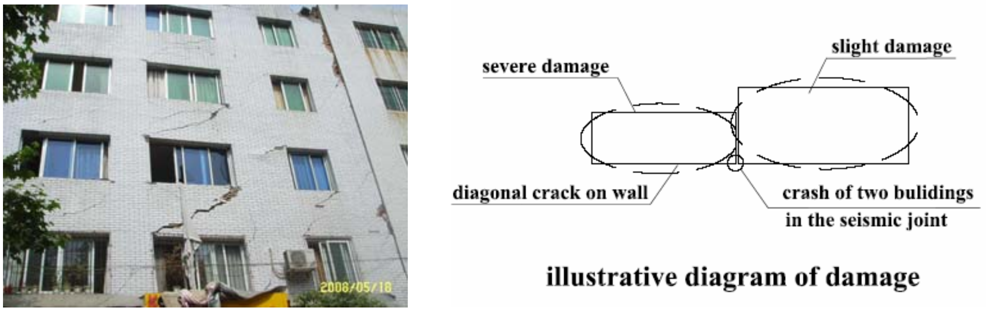

Figure 16 Damages caused by the unreasonable small dimension size of seismic joint

5. CONCLUSIONS AND SUGGESTIONS

Enormous cost is paid to gain the knowledge of earthquake damage. The site urgent structural assessment is useful to eliminate the potential danger of collapsing during the aftershock and hence will be favorable for overcoming the residents' panic psychology. The collected earthquake damage information will have reference value for later retrofitting and will direct to improve seismic behavior of newly-built buildings. The conclusions and suggestions are listed as following:

1. Site urgent structural assessment for important buildings related to livelihood is a valuable work with emphasis on the racing against time. This time we finished the work mainly on technicians' professional knowledge and project experience instead of instruments. The basic principle to decide the buildings whether to be demolished soon is that most structural component appeared severe defects or partial collapse while the other parts exist the possibility of falling down. If necessary, the calculation of wall area ratio index should be proceeded according to the appraisal code. For other buildings, a whole evaluation should be made after the on-site detecting according to the related technique standards.

2. Masonry structure will be the widely used according to the current Chinese national conditions. How to improve the collapse-resistant capacity is the key issue of the seismic protection goal, i.e. to ensure no collapsing under strong earthquake. In the current condition, it is suggested to raise the seismic protection level

for large-bay and large-space buildings. Schools, hospitals and some other public buildings should be specified as the buildings of second class, the seismic-safety level of some important members should be raised.

3. It is important to pay more attention to seismic protection in daily work and life and to raise the consciousness of designer, constructor, manager and the dweller. The government should enhance the supervision and management of seismic protection from the urban plan, design and construction. And more effort should be put on punishment of unauthorized construction and reconstruction. The quality of seismic design should be improved from the conceptual design, such as the choice of building site, the building shape and size, good structural integrity, the building regularity, the adequate seismic joint, reliable links for the nonstructural components.

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