GENERAL DEFECTS ANALYSIS OF MASONRY BUILDINGS DAMAGED IN WENCHUAN EARTHQUAKES AND ITS INSPIRATIONS

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ABSTRACT: General design or construction defects of masonry buildings damaged in Wenchuan 8.0magnitude earthquake, which occured on May 12, 2008, were summarized. Based on Seismic Design Code of Buildings （GB50011-2001）, some typical earthquake damages of the masonry buildings investigated on-the-spot , including buildings with irregular section planes, with unreasonable partial tectonic design, with unreasonable height-width ratio exceeding the limited value, and with uncertified material performance indexes and construction qualities, were presented. The design defects of the damaged masonry buildings in Wenchuan earthquake were analyzed, the main reasons why so many masonry buildings were severely damaged in Wenchuan earthquake were founded, which can provide valuable references for the seismic design and construction of the masonry buildings during the reconstruction of disaster areas in the future.

KEYWORDS: Wenchuan earthquake, masonry buildings, seismic design code, general defects
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1. INTRODUCTION

China is a country with very serious earthquake disaster in the world. Shown in the statistics data, land area of China only accounts for 7 percent of global land area, the numbers of mainland earthquake accounted for one third. There 41 percent of the regions' intensity of seismic area belong to seven-degree and more than seven-degree, and 50 percent of the cities, 67 percent of the big cities with more than millions population locate in the serious earthquake district. Between the circum- Pacific Ocean seismic zone and eur-asian seismic zone, the earthquake fault zones in Chinese land are very active, which are pressed by Pacific Plate, Indian plate and Philippine Sea Plate. Since the 21st century, the Chinese accumulated death toll in the earthquakes is 550,000, accounting for 53 percent of the global total death toll in earthquakes. The seriousness of the earthquake disasters is one of China's basic national conditions, and the buildings' collapse and destruction are the very important reason causing casualties, according to incomplete statistics, more than 95 percent of the death toll in earthquakes were killed by buildings' collapse.

A 8.0(Ms) magnitude earthquake occurred at 14:28 on May 12, 2008, which caused serious loss of lives and properties, the epicenter located in Wenchuan County Aba autonomous Prefecture. Authors of this paper quickly rushed to the earthquake site as soon as possible when the earthquake occurred, and did much work such as rescue, Seismic intensity Determination, Disaster Loss Assessment, Building Safety Appraisal, Earthquake Damage Scientific Investigation, which lasted for more than fifty days. The investigation in the earthquake site indicates that a lot of Masonry Buildings are self-built buildings, many buildings are undefended or lack of seismic fortifications concept during their design and construction. Many formally designed buildings are breach of basic regulations of the Chinese current "Seismic Design Code" (GB50011-2001) in Sichuan earthquake-stricken area. The seismic fortification target isn't met, which is "undamaged under minor earthquake, repairable under moderate earthquake, no collapsing under strong earthquake ". The masonry building were not suffered such severe damage and did not caused such a serious loss of lives and properties if they were designed and constructed following the instructions of Seismic Design Code. Some attention cruces in the future masonry buildings' design and construction were pointed out according to the seismic fortification improper buildings, which were damaged in Wenchuan earthquake. The reasons why the masonry buildings were severely damaged in Wenchuan earthquake were analyzed according to the Seismic Design Code and the lessons were summarized, which will be valuable reference to masonry buildings' design and construction, to the construction management.

2. WENCHUAN EARTHQUAKE GENERAL SITUATIONS

Wenchuan 8.0 (Ms) magnitude earthquake took place on May,12, 2008, the earthquake-stricken areas included six provinces (autonomous regions and municipalities), which is Sichuan, Gansu, Shanxi, Chongqing, Yunnan and Ningxia, the areas severely damaged are more than 100,000 square kilometers.30 provinces in china were affected by the earthquake, such as Liaoning, Shanghai, Guangxi, Qinghai, and so on. The earthquake disaster

was particularly severe, 69180 persons died, 374，008 persons were injured, 17，398 person dismissed. Total 47，642.5 kilometer water supply lines and 53，295 kilometer road were damaged, 11，962 schools were broken down, 5.4619 million rooms collapsed and more than 23 million rooms were damaged.

2.1 The Earthquake Parameters

The name of earthquake: Wenchuan 8.0 (Ms) magnitude earthquake
Earthquake occurrence time: On May 12, 2008 at 14:28:04 Beijing Ti me.
Magnitude: Ms=8.0.
Macroscopic epicenter: Aba Tibetan-Qiang Autonomous Prefecture, Wenchuan County, Sichuan Province.
Microscopic epicenter: the geographic coordinate 31.0°N、103.4°E (measured by China seismic network), Yingxiu town, Wenchuan County.
Earthquake focus depth: 14 kilometer
Intensity of the meizoseismal area: degree XI
Number of aftershock: 9,304 times M ≥ 1.0 Earthquake aftershocks were recorded by Sichuan digital seismic network among them 157 times M 4.0 to M 4.25 times of M5.0 to M 5.9 and 5 times of M6.0 to M 6.9.
The Largest Aftershock: occurred at 16:21 on May 25, On May 25, 2008 Beijing Time. Epicenter located in Qingchuan County Sichuan Province. Magnitude M_L 6.4
Fig.1 showed the distribution of aftershocks more than M_L4.0

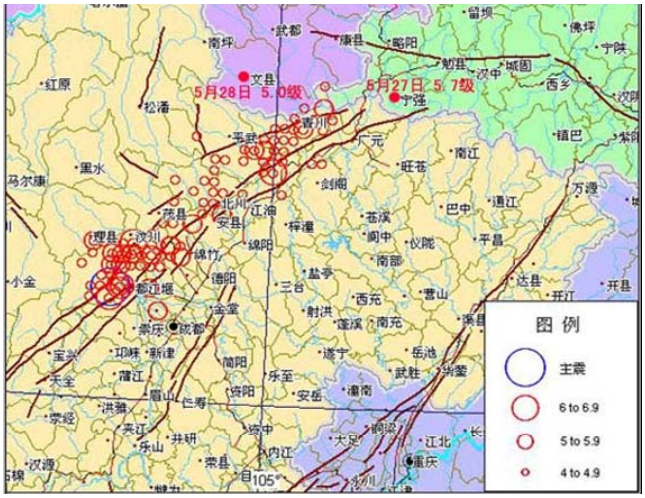


Fig. 1 Distribution of aftershocks

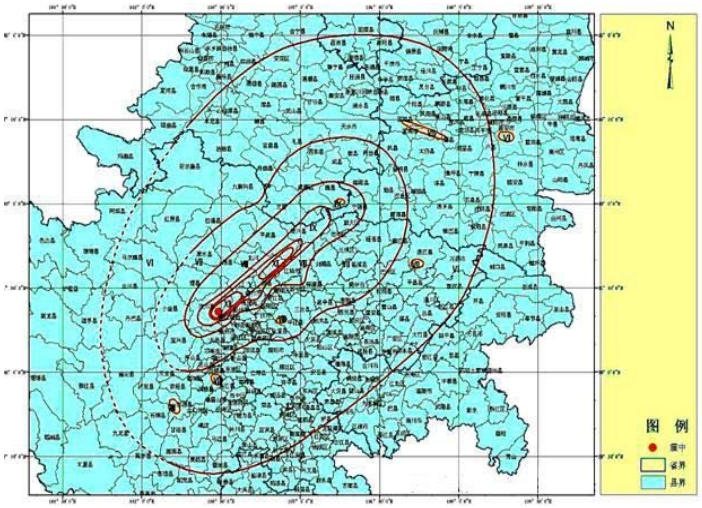


Fig. 2 The map of intensity distribution of Wenchuan earthquake

2.2Intensity Distribution General Situation Geological Structure and seismic Background

2.2.1 Intensity Distribution General Situation

As shown in Fig.2，the 8.0 (Ms) magnitude earthquake with intensity XI in its epicenter, centered in Yingxiuwan town, Wenchuan County and Beichuan County. The meizoseismal zone with the intensity more than IX and serious destroyed is very near to the earthquake fault, and developed along the earthquake fault like a long belt.

The boundary of X intensity and IX extended toward the basin in Mianzhu city and Shifang city, which was affected by the frontal fault displacement and slip of Longmen Mountain, it was much slighter in Dujiangyan city. Intensity of the transitional zone on Piedmont Basin edge rapidly decayed to the east, but relatively smooth to the west. Intensity distribution of north-south is asymmetric, identical intensity area in the north is bigger than in the south, Fault rupture spread to the north-east in interior region of Gansu and Xianxi. The strongest aftershock took place in the northern fault part in May. Area of degree VI distributed very widely in Sichuan Basin and hilly area, and extended to the western region in Chongqing city and the northern region of Zhaotong in Yunnan, however, it is smaller relatively in western part of Sichuan Province.

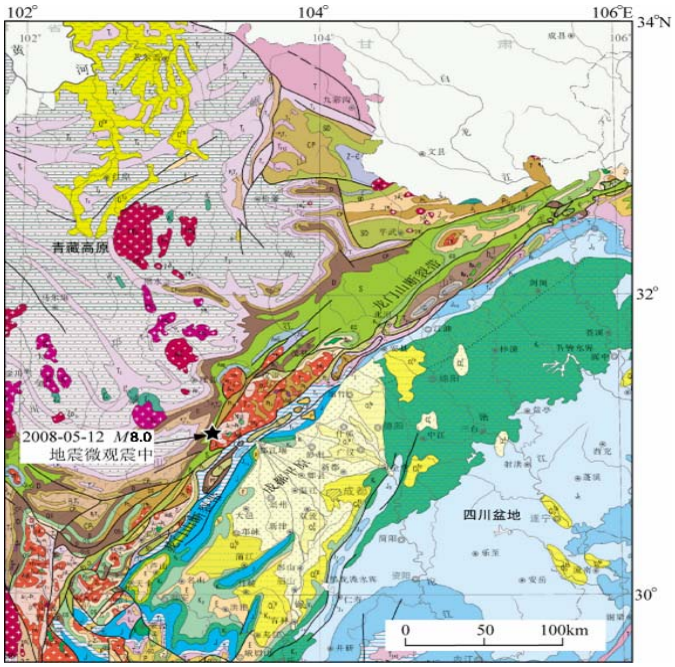


Fig.3 The topography map of Longmen mountain fault zone

Fig.4 The focal mechanism sketch Map of Wenchuan Earthquake

2.2.2 Geological Structure and seismic Back ground As shown in Fig.3， the 8.0 (Ms) magnitude earthquake occurred in the NE-Trending Longmen mountain fault zone which locates in the intermediate section of South - North seismotectonic zone, the eastern boundary of the Qinghai-Tibet Plateau.

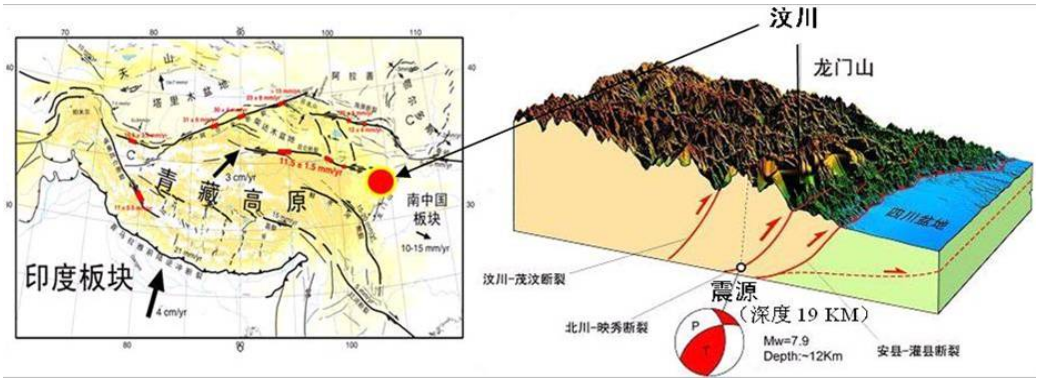


Fig. 5 The map of causal mechanism Wenchuang Earthquake

As shown in Fig.4，Fig.5，on the geological structure, The Longmen Mountain Fault Zone is Fracture folded zone, which is made by the orogenesis in Mesozoic Era and acted still with different levels in the Cainozoic Era to the late of Quaternary Time. The Longmen mountain fault zone is a huge active one, running from the north to the east, which is formed by the three major active fault zones, the Maoxian-Wenchuan fault zone, the Yingxiu-Beichuan fault (also known as the Zhong tanpu fracture), the frontal fault from the northwest to the southeast in turns. The fault zone is of a strong inverse thrust motion and a dextral horizontal slip movement component from northwest to southeast. According to investigation of active structures, the three major fault zones are of activities in the late of Quaternary Time moved in different levels in the middle-southern Longmen mountain fault zone, the average vertical slip rate of each fault zones is about 1mm / a. In addition, Neozoic foreland basin-Chengdu Plain locating on the southeast of the Longmen Mountain fault zone was made by the Neozoic inverse thrust motion along the fault zone. Tectonic activity in southwest section of Longmen Mountain fault zone is stronger than that in northeast section. Microscopic epicenter located near the southwest edge of Longmen Mountain fault zone. According to the focal mechanism solution and the aftershocks' distribution, a conclusion can be elementarily drawn that the occurrence of Wenchuan 8.0 (Ms) magnitude earthquake is perhaps related to the sudden movement along the middle segment of Longmen Mountain fault zone and its inferior detachment fault.

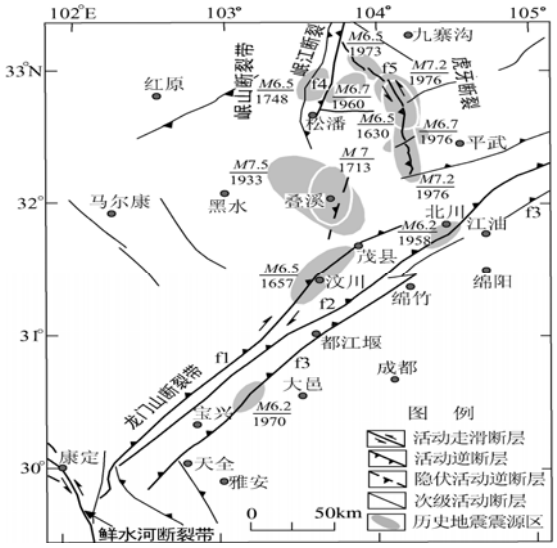


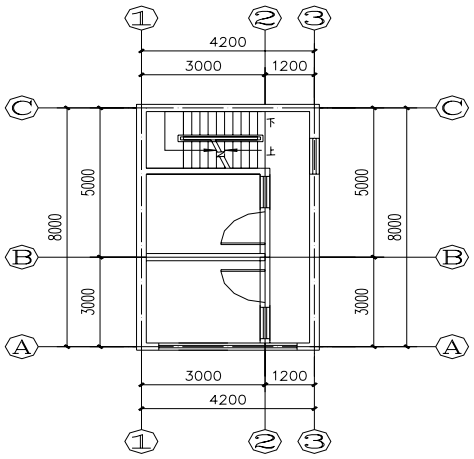
Fig.6 Longmen Mountain fault zone and distribution of m≥6 earthquakes

As shown in Fig.6，three times M6.0-M6.9 earthquakes in the middle south section of the Longmen Mountain fault zone were recorded in the history, they were Wenchuan M6.5earthquake on April 21, 1657, Beichuan M6.25earthquake on February 8, 1958 and Dayixi M6.25 earthquake on February 24, 1970. No Ms≥6.0 earthquake was recorded in the northeast section of the Longmen Mountain fault zone. Since 1630 four times M7.0-M7.5 earthquakes and five times M6.0-M6.9 earthquakes in Songpan – Pingwu region neighbor on the Longmen Mountain fault zone. The frequencies and intensities of earthquakes occurred in the Longmen Mountain fault zone in the past 400 years are not as high as those in the Songpan–Pingwu region and Diexi region.

3. ANALYSIS TO THE EXAMPLES OF MASONRY BUILDINGS DAMAGED IN WENCHUAN 8.0(MS) EARTHQUAKE

3.1 Construction's height-width Ratio Exceeded the Limitation

a) Dwelling house's integrated graph



b) Dwelling house's planar graph

Fig.7 photos and planar graph of a masonry building in Qingxi town

The damaged building shown in Fig.7 was a self-built four-floor masonry building, it located at Qingxi town, Qingchuan county, Sichuan province , its geographic coordinate is $32^0 27'40''$ N, $104^0 50'07''$ E.

The designed seismic intensity of the buildings in Qingxi town is 7 (Ms), the basic designed acceleration of ground motion is 0.10g，it is classed into the third group of design earthquake,and the seismic intensity is degree Ⅷ in this serious earthquake. The building with height 12.9 meters and building area 134.4 square meters was built in 2004 by MU10 clay brick and M7.5 cement mortar, the thickness of the walls was 240mm, considering no the earthquake resistance protection, and the first floor was a garage and the rest three floors were habitable rooms. Its plane form is rectangular, the qualities of construction and strength of cement mortar were qualified. The upper three floors except the first floor is constructed with circle-beams, but without the heel posts, the floor slab was preformed, wooden roof truss without diagonals were adopted.

Affected by the Wenchuan earthquake, there were individual transparent declined cracks in the gable wall, and few pervious declined cracks in the inner cross walls. As shown in Fig.7, in the forth floor, the gable wall fractured along the window and the windows deformed seriously and partly fell down, the roof truss collapsed. The damage degree of this masonry building is in the middle level and a little serious than it.

Excepting for that the Wenchuan 8.0(Ms) earthquake is very serious, the building's height-width ratio exceeded the limitation is the very important reason caused the masonry building was damaged seriously. Suggested by the "Seismic Design of Building" (GB50011-2001), the total maximal height-width ratio of the multistory buildings should accordance with that in Table 1.

Table 1 the maximal height-width ratio

Seismic Fortification Intensity	6	7	8	9
the maximal height-width ratio	2.5	2.5	2.0	1.5

In additions:

（1）The total width of the buildings with single corridor doesn't account the width of the corridor in.

（2）The height-width ratio of the buildings should be properly reduced when its planar graph nearly approach to square.

Fig.8 Another masonry building in Qingxi Town damaged slightly

The masonry building shown in Fig.7 located in 7 degree seismic fortification intensity region, thus according to Table 1, its maximal height-width ratio should be 2.5, according to its planar graph shown as Fig.7, its height-width ratio was 4.3, far beyond 2.5, which made the building's lateral rigidity very weak and is the most important reason caused this masonry building to be damaged seriously.

Another four-floor masonry building built in 1998 shown in Fig.8 was far less than 100 meters away to the building above, this building constructed circle-beams in each floor, its height-width ratio is reasonable, was slightly damaged, it can be dwelled in after simple repaired.

In Wenchuan earthquake, though the above two buildings are roughly with the same conditions such as seismic intensities, site conditions, structure forms, floor numbers, building materials and construction qualities, one was slightly damaged, the other was severely damaged According the analysis above, it can be announced the masonry buildings' height-width ratio exceeded the limitation required by "Seismic Design of Building" (GB50011-2001) is the main reason caused them damaged seriously.

3.2 Building with irregular section plane

a) The front elevation

b) The back elevation

c) Damaged bottom wall

d) Damage form of the wall

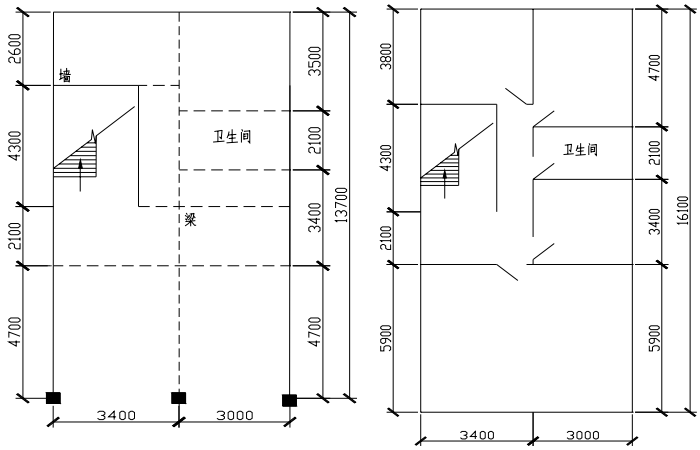
Fig.9 Photos of house building in Leigu town

The damaged building shown in Fig.9 was a self-built three-floor masonry house building, it located at Leigu town, Mianyang county,, its geographic coordinate is $32^0 47' \mathrm{N}$, $104^0 25' \mathrm{E}$.

The designed seismic intensity of the buildings in Leigu town is 7(Ms), the basic designed acceleration of ground motion is $0.10g$, it is classed into the first group of design earthquake, and the seismic intensity is degree X in this serious earthquake. The building with height 10.8 meters and building area 293 square meters was built in 2006 by MU10 clay brick and M7.5 cement mortar, the width of the walls was 240mm, considering no the earthquake resistance protection, its plane form is rectangular, the circle-beams and the heel posts were constructed with C20 cement mortar in each floor, the floors slab was preformed, wooden roof truss without diagonals were adopted. The total construction costs were over 200,000 yuan as well as good construction.

As shown in Fig.9, affected by the Wenchuan earthquake, there were several X-type transparent ramp cracks and crushed in the first floor's walls, the column broke at its top, there were several transparent declined cracks

in the stairwell's walls, and there were individual slight cracks in the stairwell's wall in the second and third floor, the roof tiles fell wholly. The damage degree of this masonry building is serious.



a) Planar graph of the first floor b) The planar graph of the second floor

Fig.10 The planar graph of the house building

Excepting for that the Wenchuan earthquake is very serious, the building's irregular plane and elevation is the main reason caused the masonry building damaged. Fig.10 showed the planar graph of the house building's first and second floor in Leigu town. There were just three 450mm*450mm columns in its front side, but no columns in its back side, thus formed no the enclosed frame structure. The stairwell was constructed in the left side of the house building, and departure from the building's center. According the Fig.10, the width of the second floor was 2.4m larger than that of the first floor, formed a typical top-heavy building, the upper bays were of small room, heavy mass, strong stiffness. Those in the first floor were mach smaller than those in the upper bays. Though the site conditions, good construction quality, high strength cement mortar the house building was of, the house building was severely damaged for the irregular section plane and the Mutation of the elevation stiffness.

As shown in Fig.11, the No.2 workshop building's roof tower of Jiuzhou Group, Mianyang City was destroyed seriously because of the whiplash effect.

a） Photo of No.2 workshop building b) Photo of damaged roof tower

Fig.11 Photo of the No.2 workshop building of Jiuzhou Group

a) Jiannanchun residential buildings b) Principle of damage

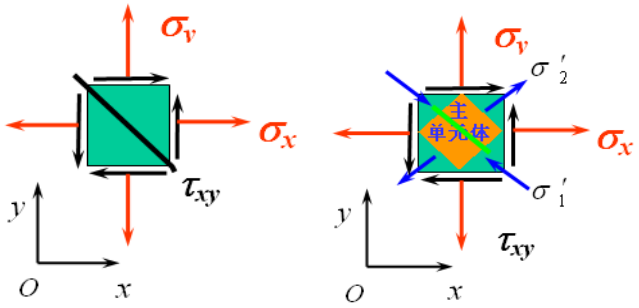
Fig.12 Photos of the residential buildings of Jiannanchun Group

The design and construction of such masonry building has broken gravely the prescriptive requirement of Seismic Design Code 3.4 "the regularity of architectural design and building's structure". Though the site conditions and the construction qualities were certified, the buildings were seriously damaged, and had no way to be reinforced. Plenty of Multistory chicken-leg type Masonry Buildings with Bottom-frame structure were destroyed with the base storey missing in Wenchuan earthquake, for the stiffness and shear strength of the base storey were weak. A considerable number of buildings with irregular section plane were severely damaged in Sichuan Disaster areas.

3.3 The structure with unreasonable local structures

The damaged buildings shown in Fig.12 were normally designed five-floor masonry house building of policeman's families buildings of

Jiannanchun Group, Mianzu City, Sichuan Province.The designed seismic intensity of the buildings in Mianzu City is 7(Ms), the basic designed acceleration of ground motion is $0.10g$, it is classed into the first group of design earthquake, and the seismic intensity there is degree Ⅸ to Ⅷ. The building with height 15.38 meters and building area 1980 square meters was built in 1999 by MU7.5 clay brick and M5 cement mortar, the width of the walls was 240mm, , its plane form is L-shape, the circle-beams and the heel posts were constructed in each floor, the floor slabs and roofs were preformed, their construction qualities were moderate.



a) Free body diagram of micro unit of wall b) 45° Main stress map

Fig.13 Analysis graph of the stress

Exterior walls of the buildings were split in the same positions where there were no effective link between 45° edge of diamond-shaped windows and the walls, which caused partial constructions completely collapsed. All the survival walls of the buildings had several transparent declined cracks, their failure degree was destroyed.

The main reason for the buildings' partially collapse was that the design of the diamond-shaped windows is unreasonable. As shown in Fig13 a), the micro unit force analysis of the walls was done. According to the shear stress mutual equal theory in Material Mechanics, the micro unit cracked in 45° direction, as shown in Fig13 b), when the principal tensile stress reached the limitation of the material tensile strength, which is just the reason why the exterior walls of the buildings cracked in 45° direction affected by the lateral component of an earthquake motion. The edges of diamond-shaped windows exactly were in 45° direction, moreover, the connection of window frame and the walling is very weak. The link of windows' frames and walls were very weak, which caused the partial constructions of the buildings collapse.

The lacking of the basic conception of mechanism in the architecture structures' design and the unreasonable design of the windows caused the partial collapse, which made the collapsed buildings can been reinforce repair. Other cases were ubiquitous in Sichuan disaster areas, such as the steel bar anchorage length was insufficient, longitudinal and lateral walls were not effectively jointed without biting force or tie bar.

3.4 adverse material performance index of Structural and Construction quality

a) Photo of a damaged two-floor building b) Damage form of the wall

Fig.14 Photo of the damaged two-floor house building in Leigu town

The damaged building shown in Fig.14a) was a self-built two-floor masonry house building, it located at Leigu town, Mianyang county, its geographic coordinate is $31^0 47'$ N, $104^0 25'$ E. The designed seismic intensity of the buildings in Leigu town is 7 (Ms), the basic designed acceleration of ground motion is $0.10g$, it is classed into the first group of design earthquake, and the seismic intensity there is degree Ⅹ in this serious earthquake. The building with height 6.3 meters and building area 220 square meters was built in 2006 by MU7.5 clay brick, lime and cement mortar, the thickness of the walls was 240mm, the circle-beams and the heel posts were constructed in each floor, the floor slab was preformed, wooden roof truss without diagonals were adopted. its plane form is rectangular. The construction qualities were poor , the mortar strength was less than M1.0. The wall was hollow.

As shown in Fig.14 b), there were few inclined perforative cracks on gable and a lot of inclined perforative cracks on the other walls. The wooden roof general collapsed. failure degree of this building is serious damage. Excepting for that the Wenchuan earthquake is very serious, to its own structure, the lower mortar strength and the hollow walls broke the rules of material performance index in "Seismic Design Code of Buildings" 3.9.3,

which made the buildings' shear strength low. The mortar strength and the walls' penetration ratio of the floor space are two important index of determine the seismic behavior of masonry buildings, large width room and lower mortar strength have unfavorable effect on building's seismic.

The mortar strength and hollow walls caused the weakness of the walls' shear strength. The shear strength of Concrete Structure is reduced greatly because cobbles were not only adopted as aggregate, but also their size is too large, which caused many masonry buildings in Sichuan disaster area destroyed and collapse. It is very common that many buildings with poor structure's performance index, poor construction qualities were destroyed gravely and collapse, which did great harm to the lives and properties in Sichuan disaster area. If the Design and Construction of masonry buildings obeyed the rules of "Seismic Design Code of Buildings", such cases would be completely avoidable.

4. CONCLUSIONS AND SUGGESTIONS

Wenchuan earthquake with 8.0 (Ms) magnitude and widely affected areas is the strongest earthquake since Tangshan earthquake occurred in 1976 in china. Many masonry buildings in the disaster area were greatly damaged or fell down, which did very great harm to the lives and properties there. Great number of masonry buildings considered no earthquake resistance protection or few earthquake resistance protections when they are designed and constructed, which exposes fully the seismic design's disadvantages of the masonry buildings' design and construction in china, Based on above analysis, basic regulations of "seismic design code" for buildings for masonry-concrete building play a very important role in earthquake disaster reduction. In order to reduce loss of lives and properties that brought by unpredictable earthquake in future, the following recommendations based on the experience and lessons of the earthquake can be made as follows:

(1) The seismic fortification target that is "undamaged under minor earthquake, repairable under moderate earthquake, no collapsing with strong earthquake" should be effectively carried out. Only in this way, loss of lives and properties could be reduced when the devastating earthquakes happen again.

(2) The current building structures' earthquake safe standard in our country should be improved. The building structures' earthquake resistant theory and anti-seismic technological should be deeply researched in various areas of China, and further strengthening compilation work of building seismic technical specifications and regulations should also be further developed.

(3) Anti-seismic construction and reinforce methods suitable for the masonry in the towns and countries should be further studied to reduce the damage of obsolete houses in earthquake. The seismic fortification level of public buildings such as schools, hospitals should be enhanced, at the same time. the old ones with this kind of construction should be reinforced and reconstructed.

(4) In order to ensure the long-term work life of construction and to prevent the replay of similar disasters, the study of earthquake preparedness and disaster reduction should be strengthened, the government administration section should strengthen the legislation and execution in Construction engineering such as construction Planning, design and construction, supervision, and should obtain gratifying achievement in earthquake's preparedness and disaster reduction work.

(5)It is the most important that people with such basic knowledge have consciousness on executing seismic design code of buildings. The people's awareness of earthquake preparedness and disaster reduction should be improved through strengthening the publicity of the structural seismic knowledge. In the same way, people will accept the scientific thinking of building and change the traditional concept of building.

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