Damage survey of 2008 Wenchuan earthquake in different regions

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1. Introduction

On May 12, 2008, an earthquake that the measured magnitude of 8.0 on the Richter scale, hit the Chinese province of Sichuan, and the epicenter was in Wenchuan. More than 69 000 people were confirmed dead, more than 374 000 were seriously injured, and more than 18 000 were reported missing.[1] The earthquake had a distinctive feature, which started from Wenchuan County, and the earthquake is not in a point, but broke down in the northeasterly direction. Therefore, the seismic intensity towards the northeast is greater than the southwest. Wenchuan earthquake epicenter intensity as high as 11 degrees, to Wenchuan County and Beichuan County arranged two centers strip distribution, the area of that is about 2419 square kilometers.

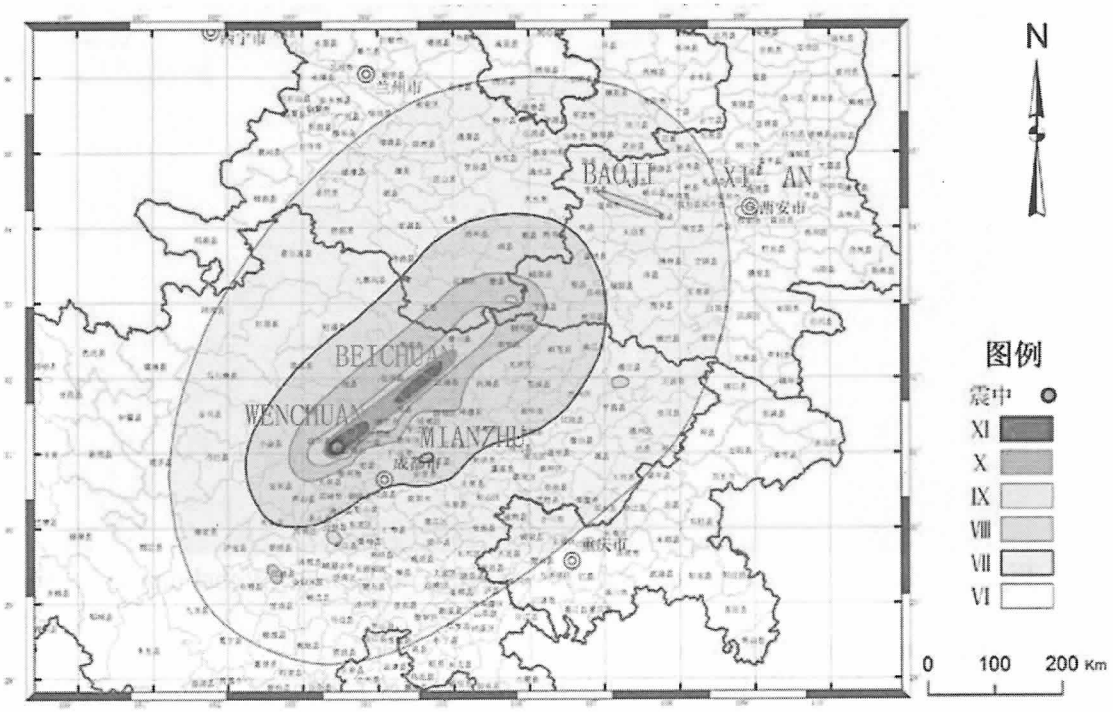

Fig.1. Seismic intensity distribution

In the week the earthquake occurred, Xi'an University of Architecture and Technology dispatched the experts in the field of civil engineering rushed to quake-stricken areas, and assessed victimization housing in Mianzhu and Baoji. The linear distance of the two places to Wenchuan is 85 kilometers and 480 kilometers respectively.

The following is the investigation in the three areas.

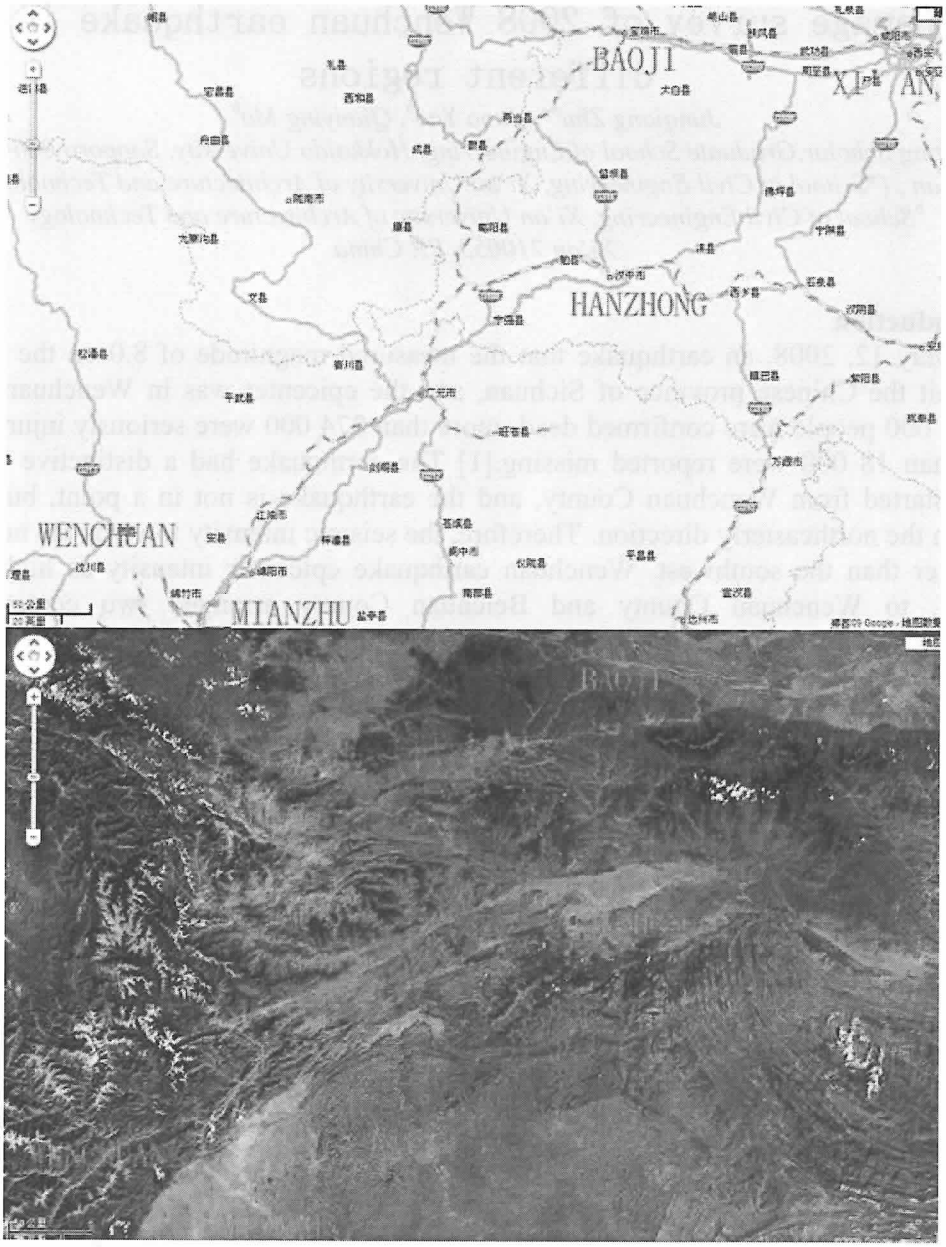

Fig.2. Administrative map and Satellite imagery range from Wenchuan to Xi'an

2. Buiding damage in Wenchuan

At 14:28:04 on May 12 (Beijing time) occurred a large earthquake, the source locate at 31.021 degrees north latitude, 103.367 degrees east longitude over 10 kilometers underground. Yingxiu Town of Wenchuan County is the epicenter.

A period of time after the earthquake, aftershocks continued. According to security considerations, only rescue workers are permitted to enter Wenchuan, so there is no expert of our university arrived at Wenchuan. To compare the damage aspect, a number of Wenchuan photos are selected from the Internet in the following. In this section, all of the photos are from the Internet.

Fig.3. Comparing photos of Wenchuan before and after earthquake occurred [2]

Fig.4. Part of Wenchuan after earthquake occurred [3]

Fig.5. Collapsed building of Wenchuan [4]

Fig.6. Collapsed building of Wenchuan [5]

Fig.7. Collapsed building of Wenchuan [6]

Fig.8. Collapsed building of Wenchuan [7]

Fig.9. Collapsed building of Beichuan which is another epicente. [8]

Fig.10. Collapsed building of Beichuan [9]

3. Investigation in Mianzhu

Mianzhu is located in north-west of Sichuan Basin, and covers an area of 1245.3 square kilometers, east-west width of 42 kilometers, and north-south width of 61 kilometers. The north-west of Mianzhu is belonging to Longmenshan region, and the south-east is part of the Chengdu Plain. The Mianzhu's northwestern region is mountains,

and the southeastern is plains, and the northwest to the southeast of it from high to low, altitude 504 to 4405 meters. There are 19 towns and 52 million people in Mianzhu before the earthquake. In the following, different types of housing damage in Mianzhu are introduced.

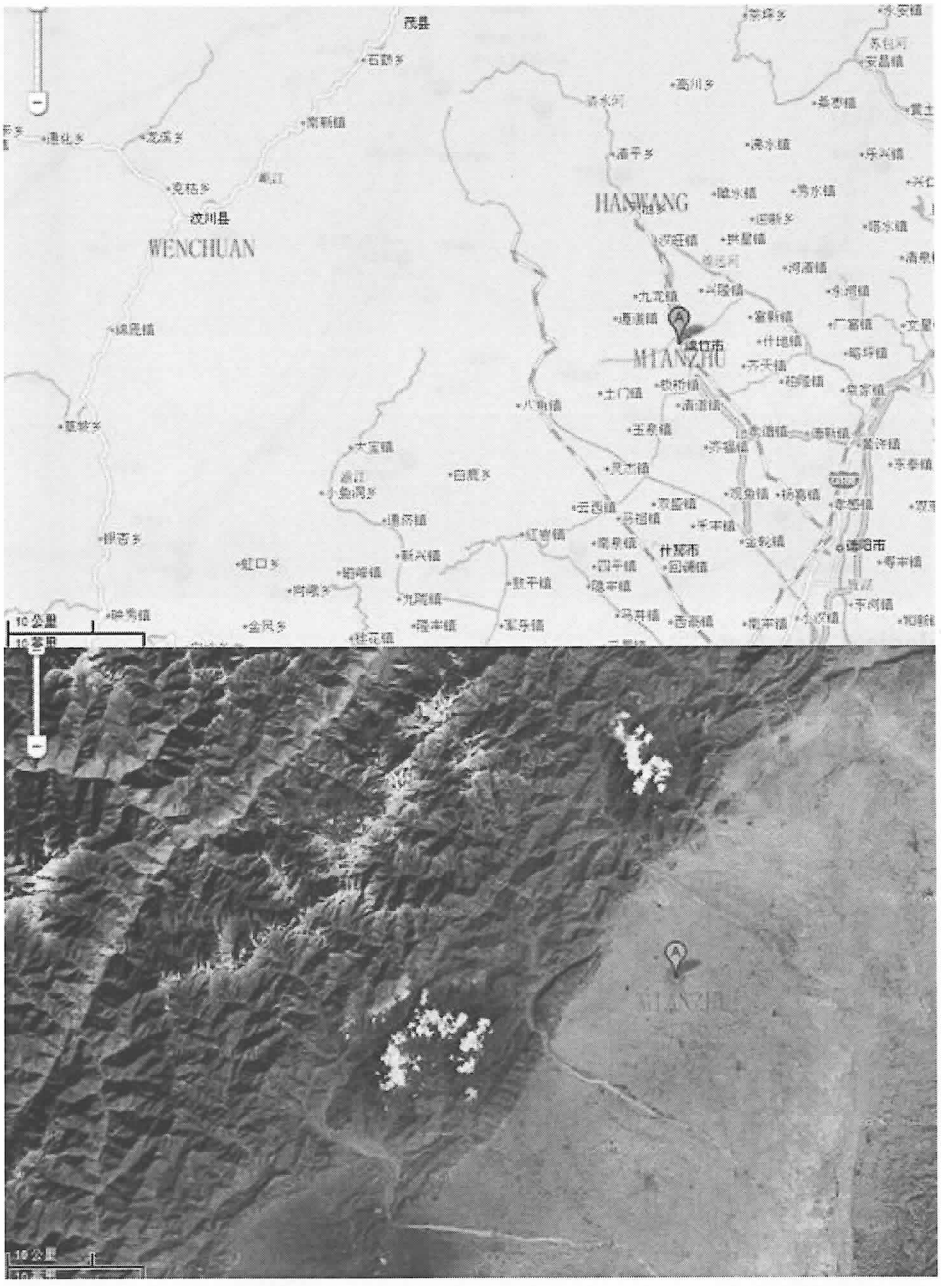

Fig.11. Administrative map and Satellite imagery of Mianzhu

3.1 Geological disasters

After the earthquake, the geological structure is very unstable; the possibility of occurrence of geological disasters has increased. The occurrence of earthquake aftershocks, as well as the impact of precipitation will cause the fault zone, collapse,

Fig.13. Landslide in Jinhua town

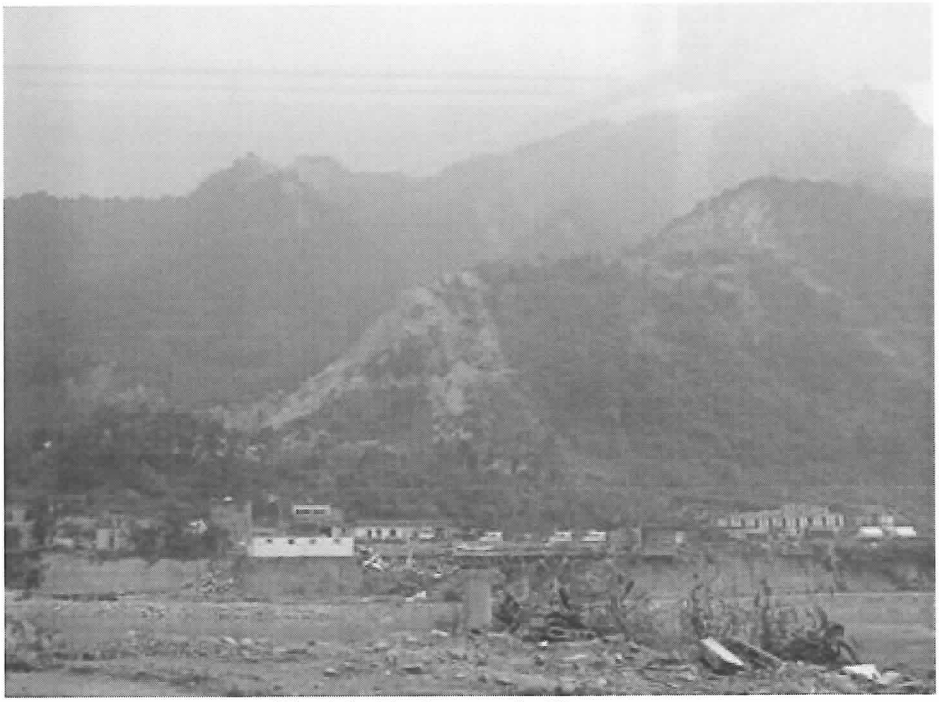

Fig.14. Fault zone in Hanwang

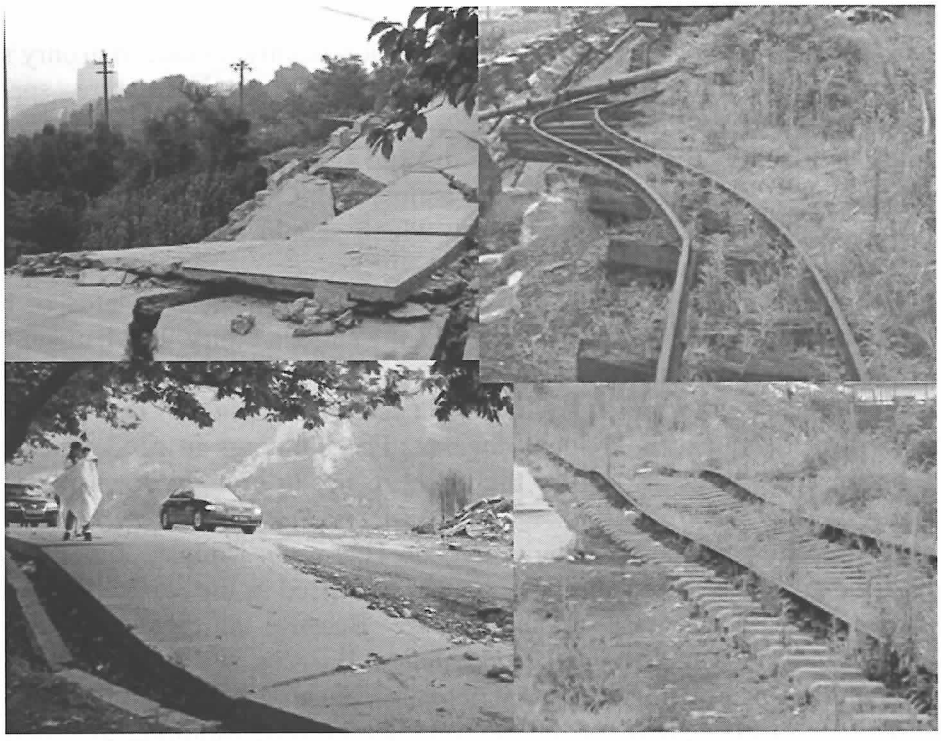

Fig.15. Destruction of roads and rail in Hanwang

landslides, and mud-rock flows. These geological disasters not only caused the collapse of many buildings and houses, causing heavy casualties, but also a large number of roads, railways, bridges, communications and other infrastructures have been destroyed.

Fig.16. Destruction of roads flyover overpass in Mianyang

3.2 Damage of buildings

The type of the building structure in Mianzhu region mainly include: masonry structure, masonry structure with bottom frame, frame structure, wood structure, space truss structure and high-rise structure.

The house assessed by the experts will be marked as four grades: A, the basic well; B, mild damage which can be used after simple maintained; C, moderate damage which can be used after reinforced; D, serious damage which should be removed or large-scale reinforced.

Through surveys to Mianzhu City and seven towns, it can be convicted of Mianzhu City urban construction in the earthquake suffered a serious injury. In Mianzhu City, the A grade to the D grade construction accounted for: 14%, 24%, 29% and 33% respectively, The seismic fortification intensity of Mianzhu City is 7 degree. The actual seismic intensity of this earthquake is about 9 degrees. The buildings in accordance with the building design code, basically realize the target of not to brought down under the big earthquake.

However, different from Mianzhu City, in Hanwang, Jinhua, Jiulong, Zundao, Xinglong, Guangji towns, there are many houses collapsed in the earthquake, towns and rural housing, suffered the most serious damage. Because the current management in construction is only administered by Construction Bureaus in China, only the public buildings, government buildings and commercial residential buildings are overseen. As for the townships in rural areas and farmer's private housing building, the building was not included in the scope of the Board of Management. Although the moderate (C grade) and severe (D level) damage of buildings surveyed accounted for 70 percent of the total number of buildings, but the number of collapsed building are not many.

In the following, the damages of several sorts of structures are shown.

3.2.1 Damage of masonry structures

The masonry structures of Mianzhu urban areas are mostly 4-6 storeys, and in the villages, the masonry structures are mostly divided into single-layer and multi-storey masonry structures. Single-storey masonries mostly are built with huts, while the multi-storey masonry structures are built with fabricated reinforced concrete roof and floor.

Fig.17. Destruction of masonry structure in Hanwang

Fig.18. Destruction of masonry structure in Hanwang

Fig.19. Destruction of masonry structure in Mianzhu

Fig.20. Destruction of the wall forms in Mianzhu

Fig.21. Destruction of structural edge column of masonry structure in Mianzhu

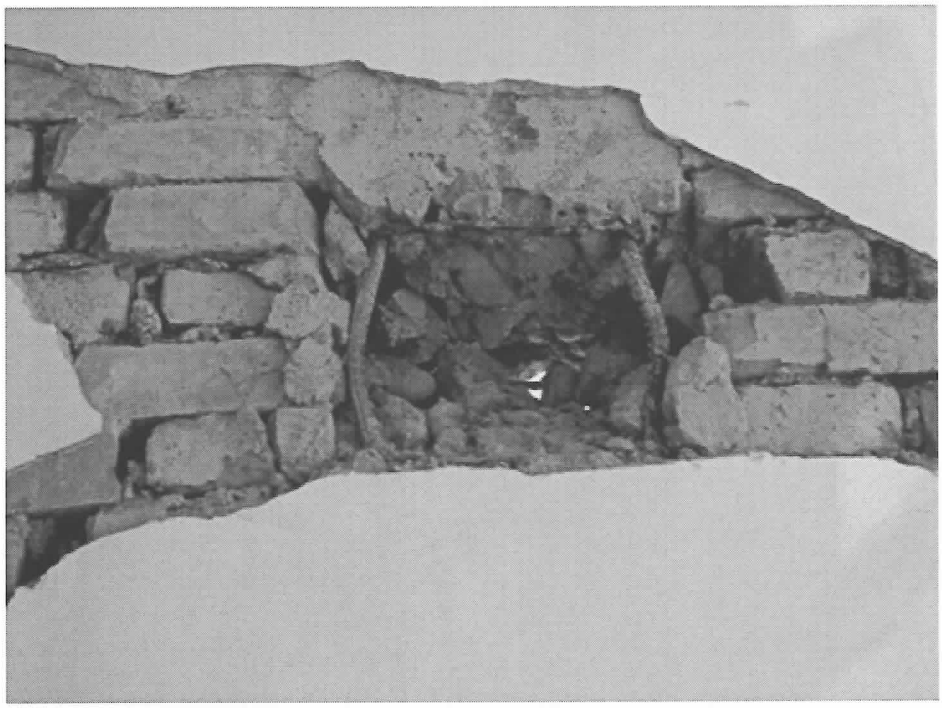

Fig.22. Destruction of structural central column of masonry structure in Mianzhu

Fig.23. Level cracks in the masonry structure at the bottom in Mianzhu

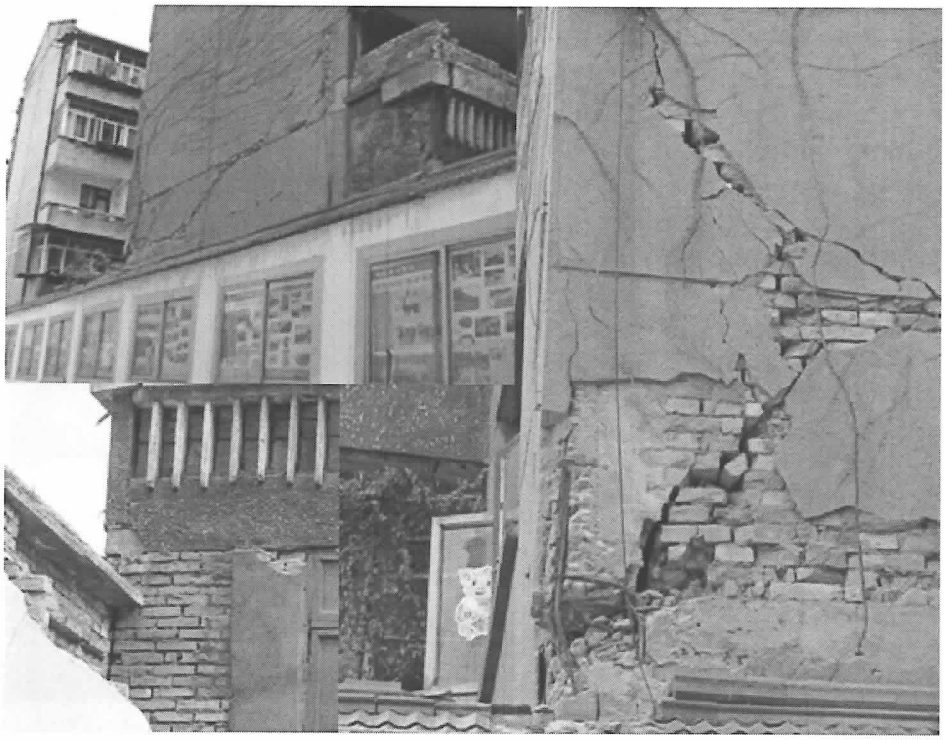

Fig.24. Wall damage of masonry structure with a surrounding wall in Mianzhu

Fig.25. Wall damage of masonry structure in Mianzhu

Fig.26. Destruction of masonry structure in Hanwang

Fig.27. Destruction of masonry structure in Hanwang

Fig.28. Destruction of masonry structure in Hanwang

Fig.29. Secondary disaster caused by protruding parapet and staircase damage in Mianzhu

Fig.30. Corner damage caused by the stiffness change of a building in Mianzhu

3.2.2 Damage of masonry structures with bottom frame

In the street constructions in China, the ground floor of it is often used as a shop, so it is made into the framework of the structure, and the upper stories are produced for the masonry structure.

Fig.31. A damage of masonry structure with bottom frame in Hanwang

Fig.32. Wall damage in second floor of masonry structure with bottom frame in Mianzhu

Fig.33. Wall damage in second floor of masonry structure with bottom frame in Mianzhu

Because of using precast slab as floor to build house is fast, relatively cheap, then throughout the country, it have been widely applied. However, collapsing house with prefabricated floor can be seen everywhere, Many people had lost their lives in this sort of buildings. These mixed structure buildings are the most vulnerable in the earthquake.

To some extent, the use of precast slab to build a house just like building block. Firstly, build up surrounded wall, and put the precast slab on the walls at both ends as the floor. And then construct the wall on the precast slab, put another precast slab, and so on. Although the concrete pouring will be finished between the wall and the slab, but this does not able to make the precast slab stick to the wall firmly. If no other technical measures to enhance the overall housing, then when subjected to strong earthquakes, walls will shake up with different frequencies, prefabricated slab will be fiercely pull out from the end of the fixed off weak, and ultimately to make the overall collapse of the housing from the top down.

From above photos of the damage of masonry structure with bottom frame and masonry structure, the destruction of such forms has been shown.

3.2.3 Damage of frame structure

Comparing the masonry structures which load-bearing components are floors and walls, the frame structures are plates, beams and columns. In theory, the integrity and solidity of frame structure is better than the masonry structure. However, specific to a certain building, the key is how the design is reasonable, and the construction is in line with the norms or not.

Fig.34. Frame structure of Mianzhu passenger bus station

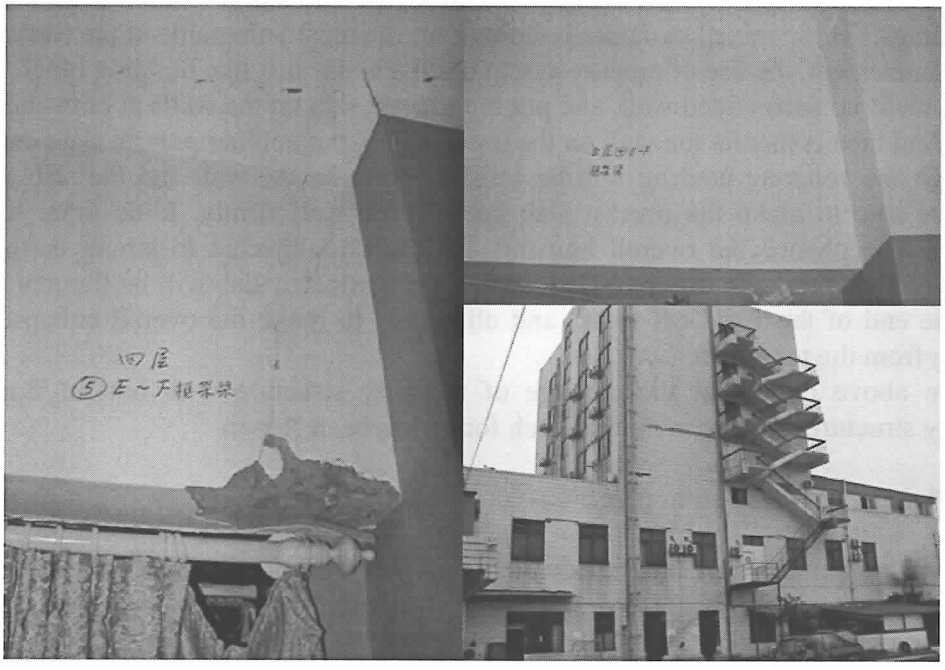

Fig.35. Beam damage of frame structure in Mianzhu

Fig.36. Beam and column damage of frame structure in Mianzhu

Fig.37. Wall damage of frame structure in Mianzhu

Fig.38. Damage of frame structure with precast slab floor in Mianzhu

Fig.39. Column damage of frame structure in Hanwang

Fig.40. Column damage of frame structure in Jiulong

Fig.41. Damage of frame structure in Hanwang

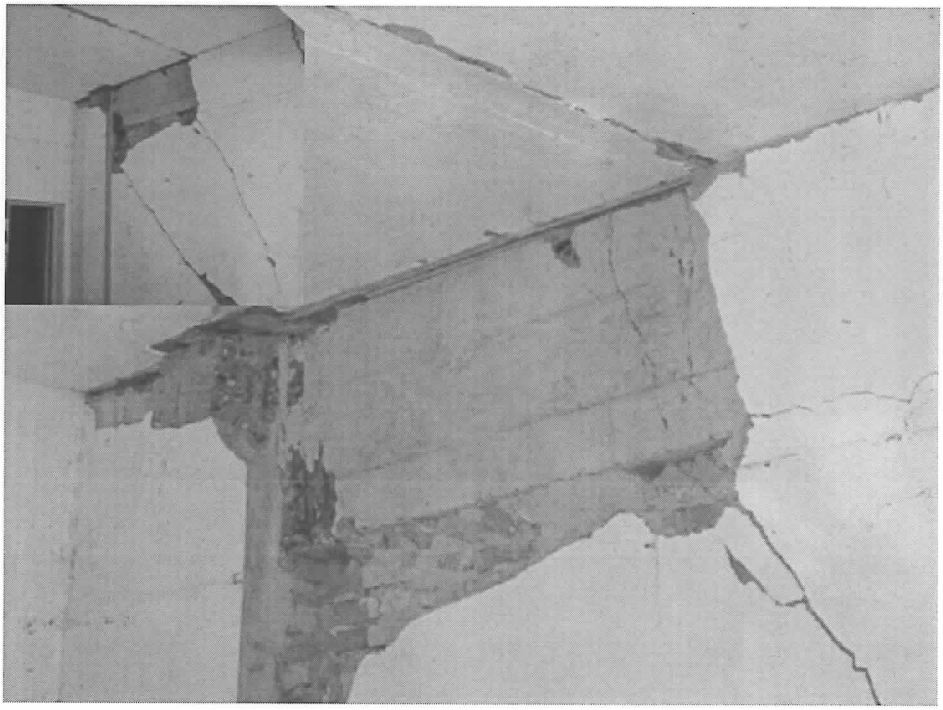

Fig.42. Wall damage of frame structure in Hanwang

Fig.43. Column damage of frame structure in Jinhua

3.2.4 Wooden structures

Due to light weight, anti-deformation, difficulty to collapse, wooden structure buildings have excellent seismic performance. There are many wooden temples and buildings withstand this strong earthquake in Sichuan.

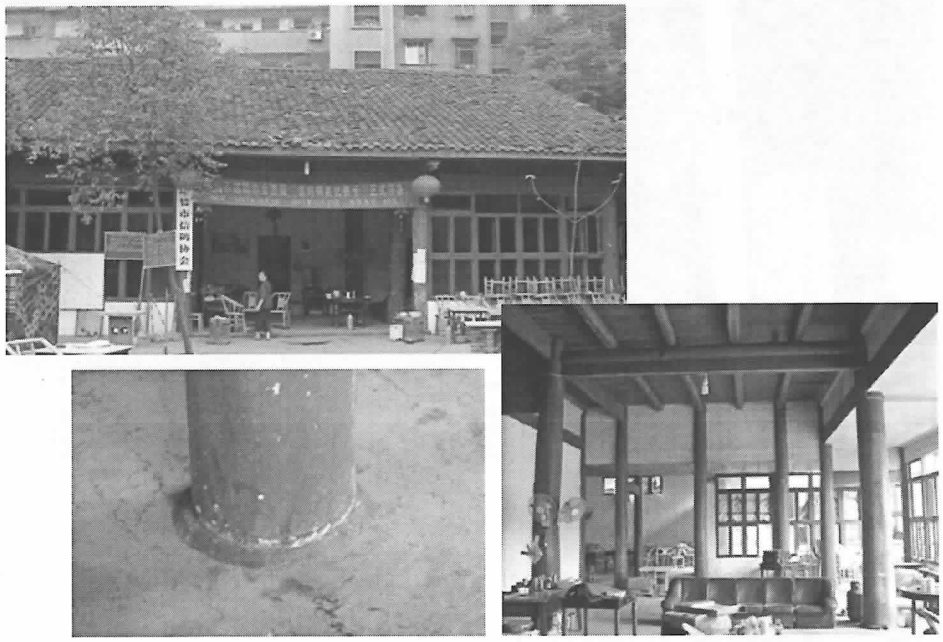

Fig.44. Column displacement of wooden structure in Mianzhu

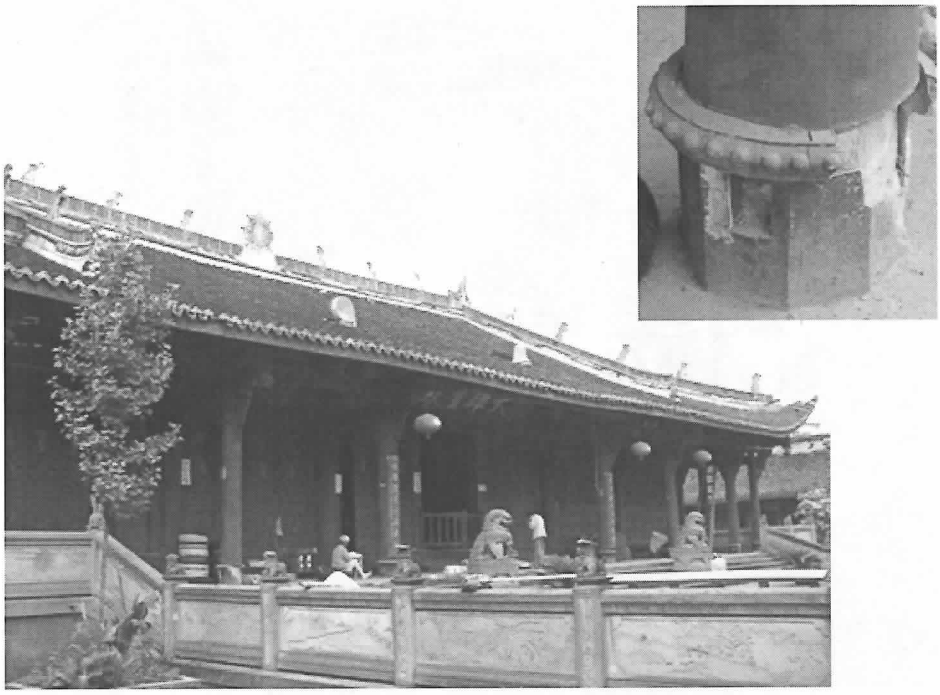

Fig.45. Column displacement of wooden structure in Mianzhu

Fig.46. Column displacement of wooden structure in Mianzhu

Fig.47. Damage of wooden structure in Dujiangyan

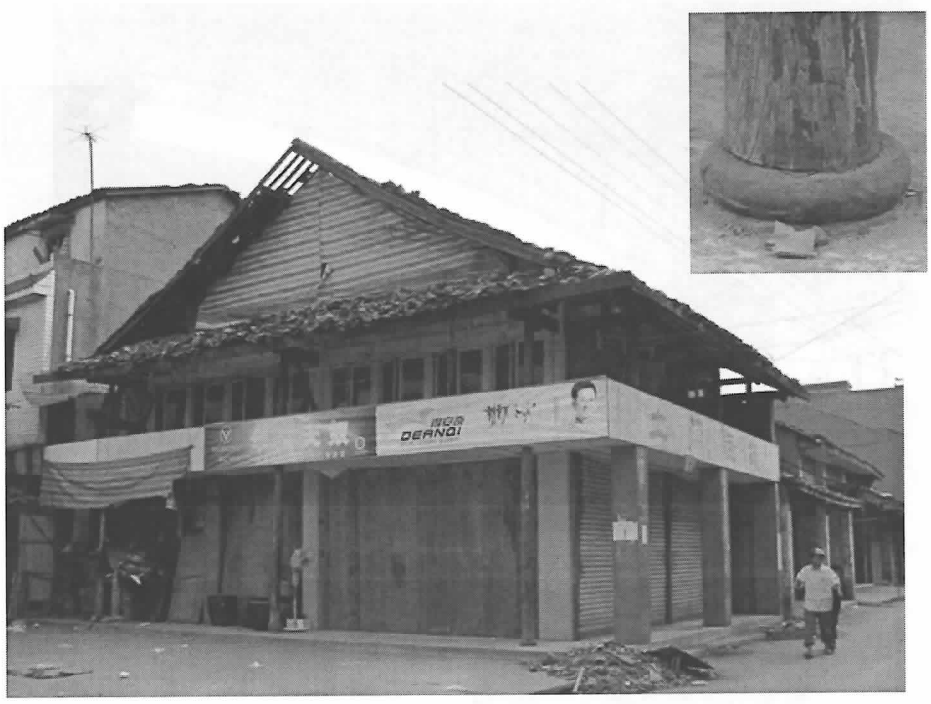

Fig.48. Damage of wooden structure in Tumen

3.2.5 Space truss structures

Space truss structures are not many in Mianzhu, but in this earthquake, since a reasonable structure, the damage is not serious.

Fig.49. Support of space truss structure in Mianzhu

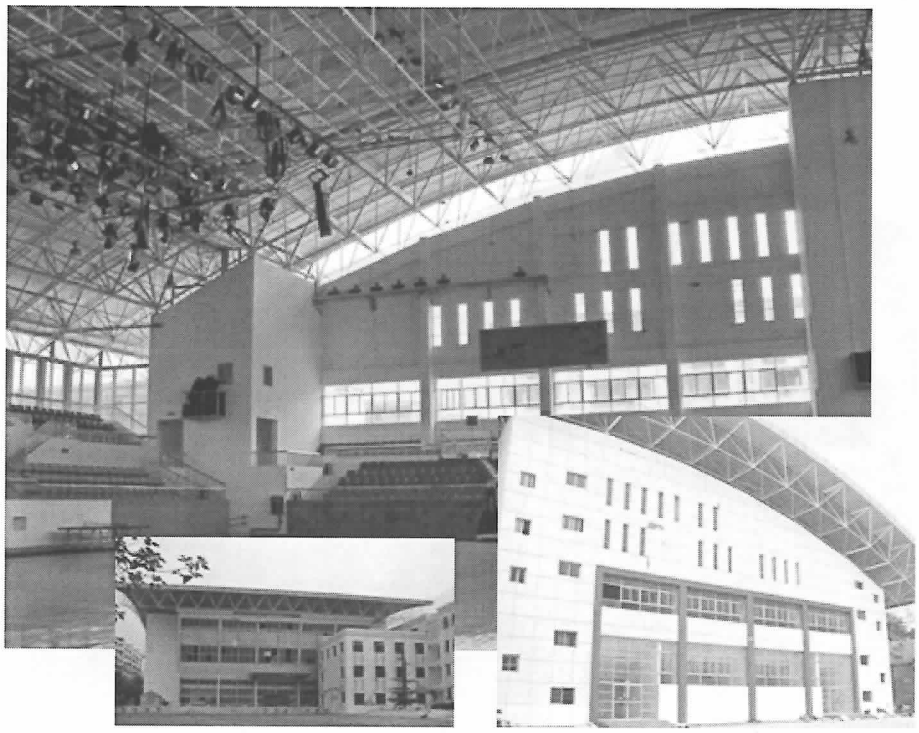

Fig.50. Space truss structure in Hanwang

3.2.6 High-rise buildings

Frame-shear wall structure and wall structure are the normal sorts of high-rise buildings. These structures have usually good seismic performance, and often be designed and constructed strictly.

Fig.51. High-rise building in Mianzhu

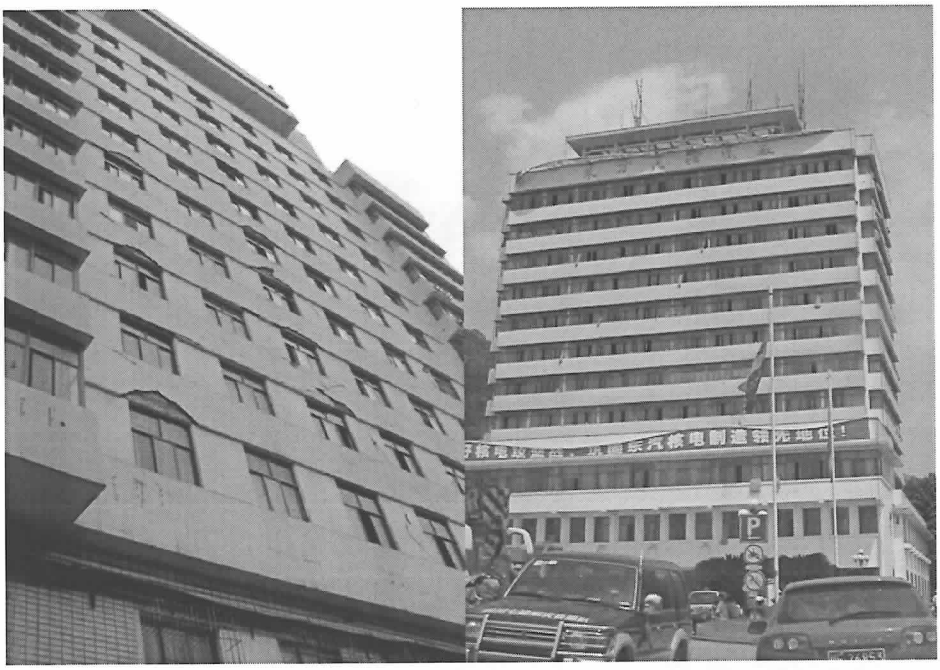

Fig.52. High-rise building in Hangwang

3.2.6 Township construction

Because most of the towns and rural housings are built by residents their own, not through rational design, therefore, in this earthquake damage is very serious.

Fig.53. Damage of rural housings in Jiulong

Fig.54. Damage of rural housings in Hanwang

Fig.55. Damage of rural housings in Tumen

Fig.56. Damage of rural housings in Tumen

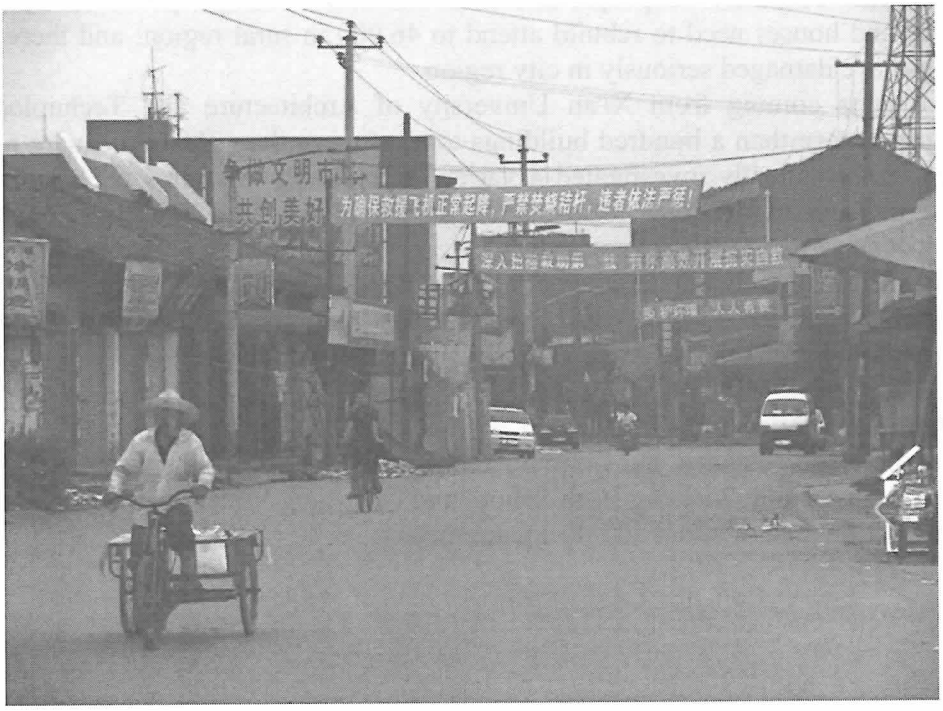

Fig.57. Rural housings in Yuquan

Fig.58. Comparison of rural housings before and after earthquake in Zundao [10]

4. Investigation in Baoji

Baoji region is suffered serious damage after the Wenchuan earthquake and the series of afterstocks. There are 32 people had been killed, and 392 people were injured. The collapsed and houses need to rebuild attend to 46,000 in rural region; and there are 580 buildings have damaged seriously in city region.

The experts coming from Xi'an University of Architecture and Technology have investigated more than a hundred buildings total of more than 300,000 square meters in the area. Systematically investigated a variety of building structures in this earthquake suffered damage in different forms, and gave technical advice to the people about building damage and repair acknowledges.

In the following, the different sorts of buildings divided by using categories are introduced which are school, rural house, office building, industrial building, tower building, shopping mall, residential and ancient architecture separately.

4.1 School buildings

The experts investigated the building damage of Weiyang High School, Chencang Chezhan High School, Xicheng High School and Chencang Vocational Education Center, the construction area of about 20,000 square meters.

Fig.59. Teaching building of Weiyang High School

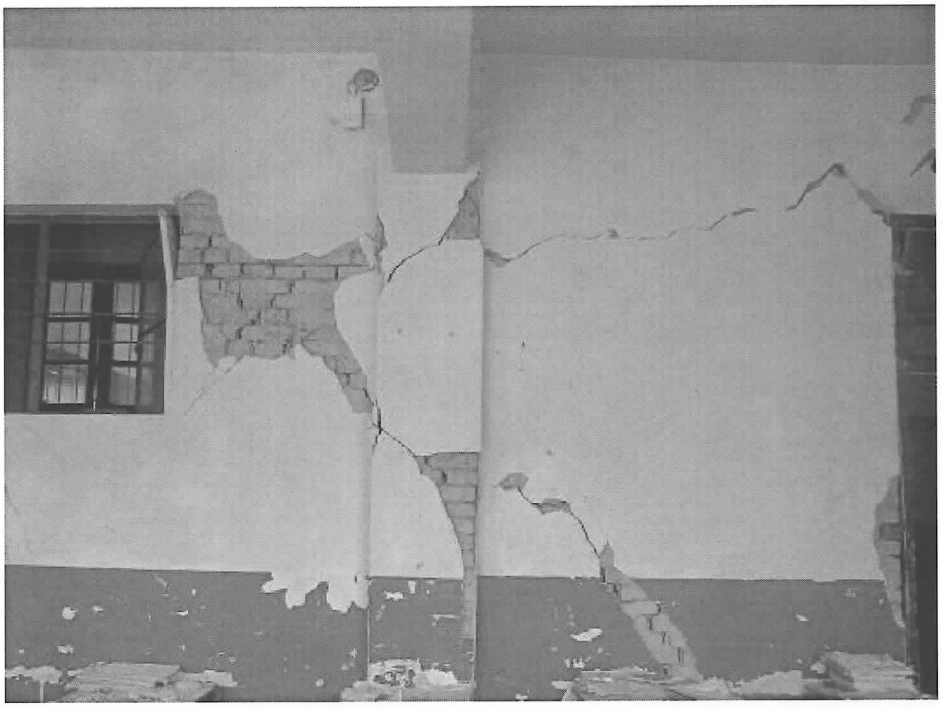

Fig.60. Destruction of brick columns under the beam

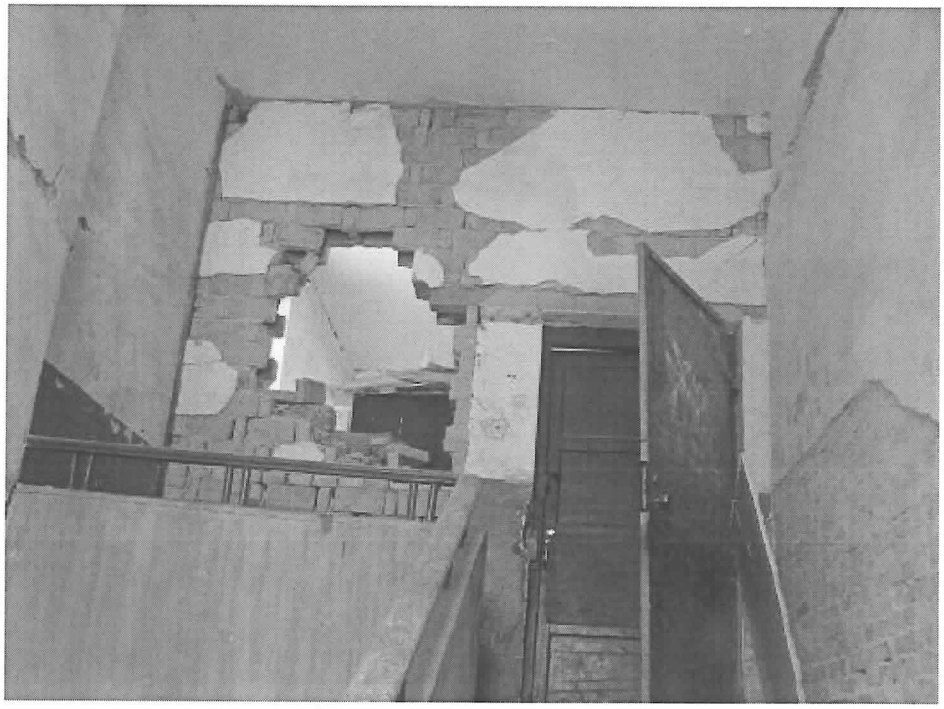

Fig.61. Damage of filled wall

Fig.62. Teaching building of Chencang Chezhan High School

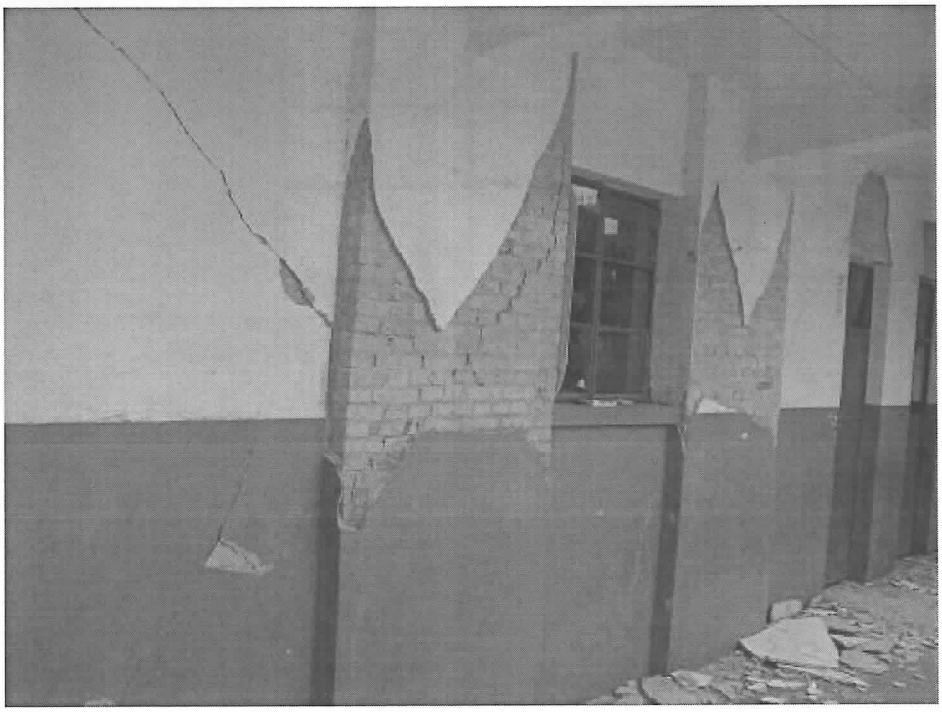

Fig.63. Destruction of brick columns under the beam

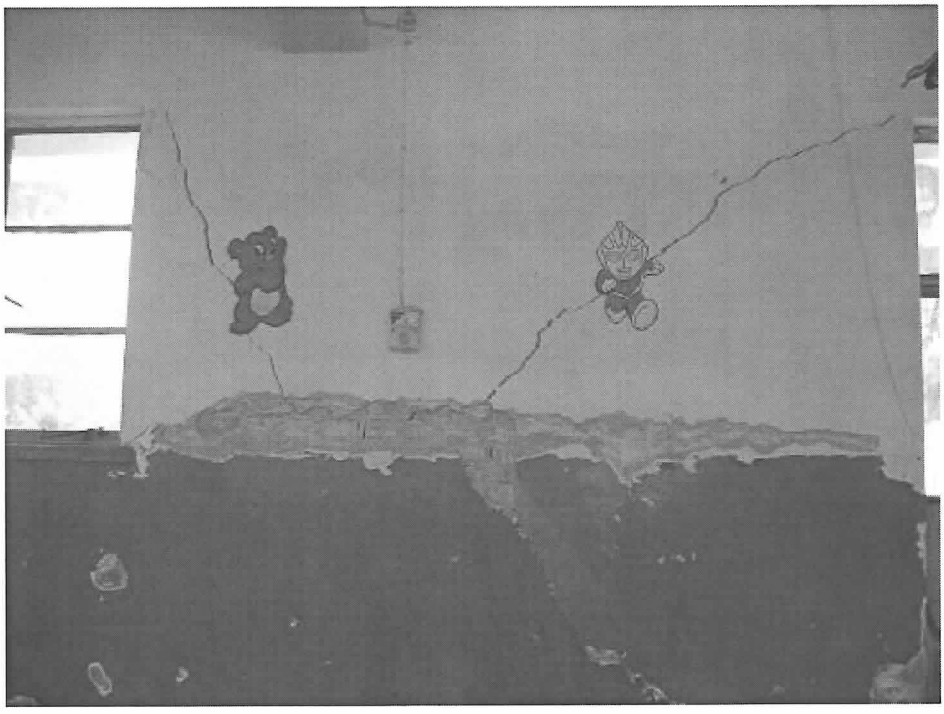

Fig.64. Destruction of inside wall

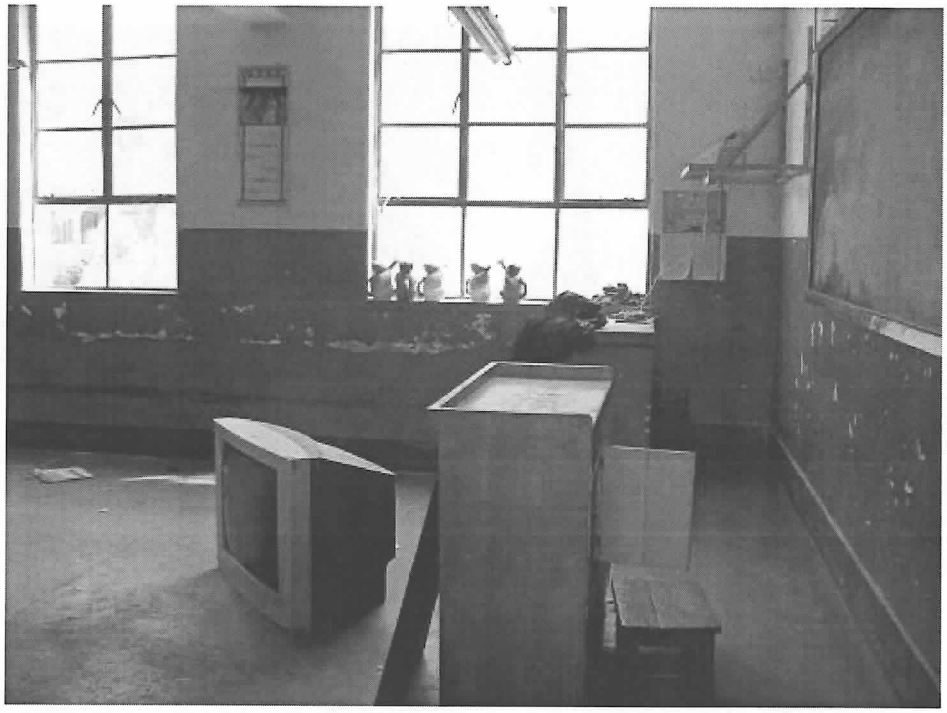

Fig.65. TV set was thrown down by the earthquake

Fig.66. Teaching building of Chencang Chezhan High School

Fig.67. Damage of seismic joint

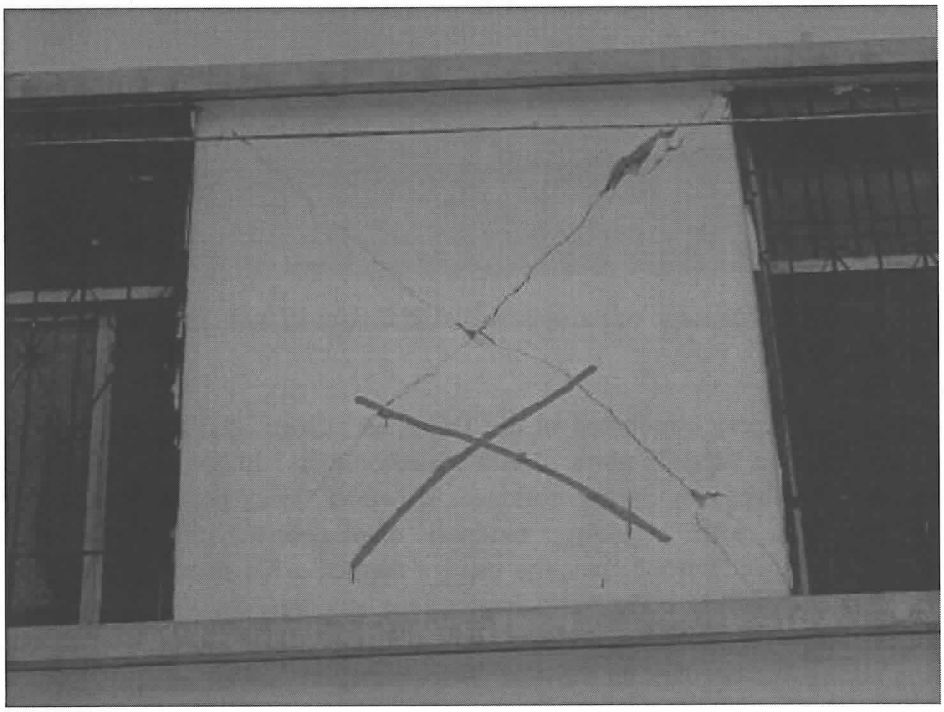

Fig.68. Damage of wall between windows

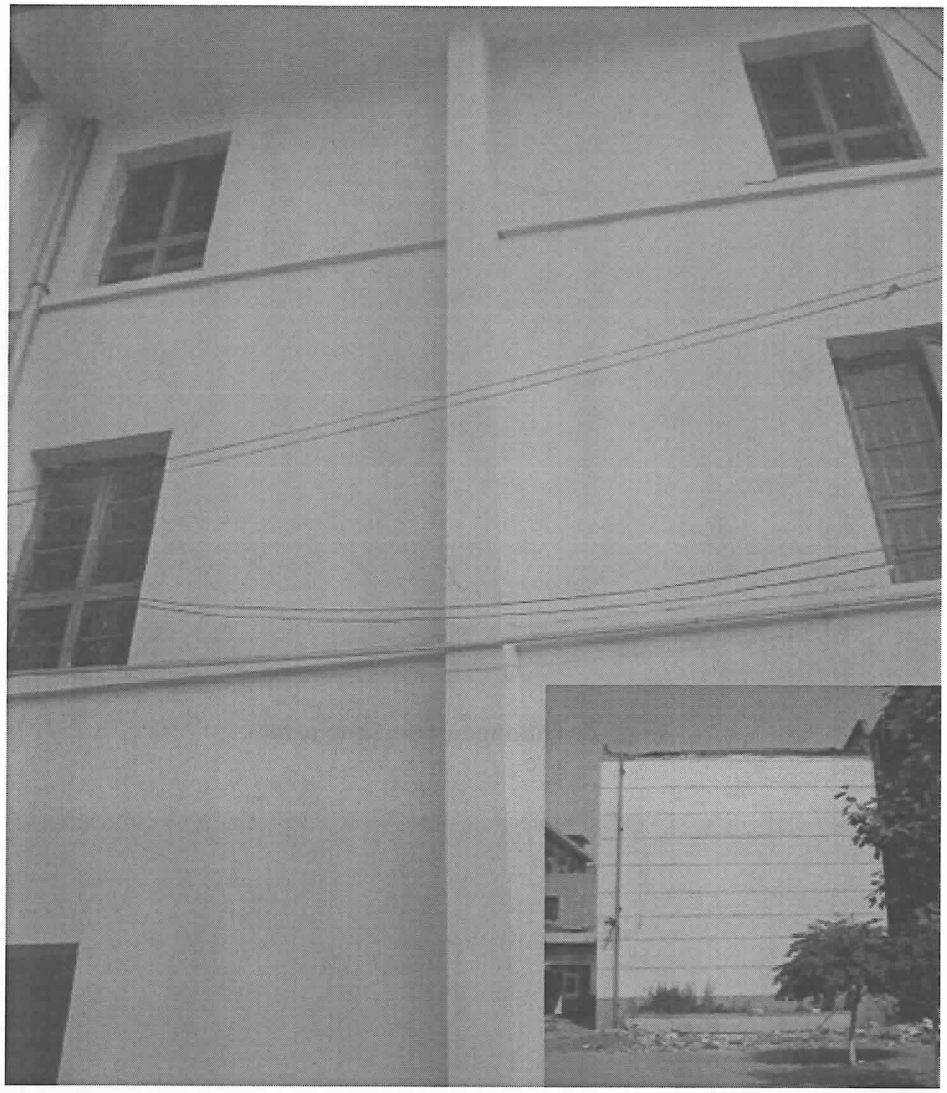

Fig.69. Damage of parapet wall and cracks in wall and column

4.2 Rural houses

The residential survey conducted in the Dongbao village of Guo town , a total of 16 surveys, construction area of about 4,000 square meters. In the village, adobe house occurred in the collapse or partial collapse. However, brick-concrete structure houses only appeared the wall cracking, external displacement, there are no collapse phenomenons. It is understood that, the village formed a construction company earlier, and have civil engineering correspondence college students, the villagers have a certain degree of architectural expertise, and are more affluent villages, most of the construction of housing taking into account the seismic performance.

Fig.70. Gable cracks

Fig.71. Cracking wall in front of the house

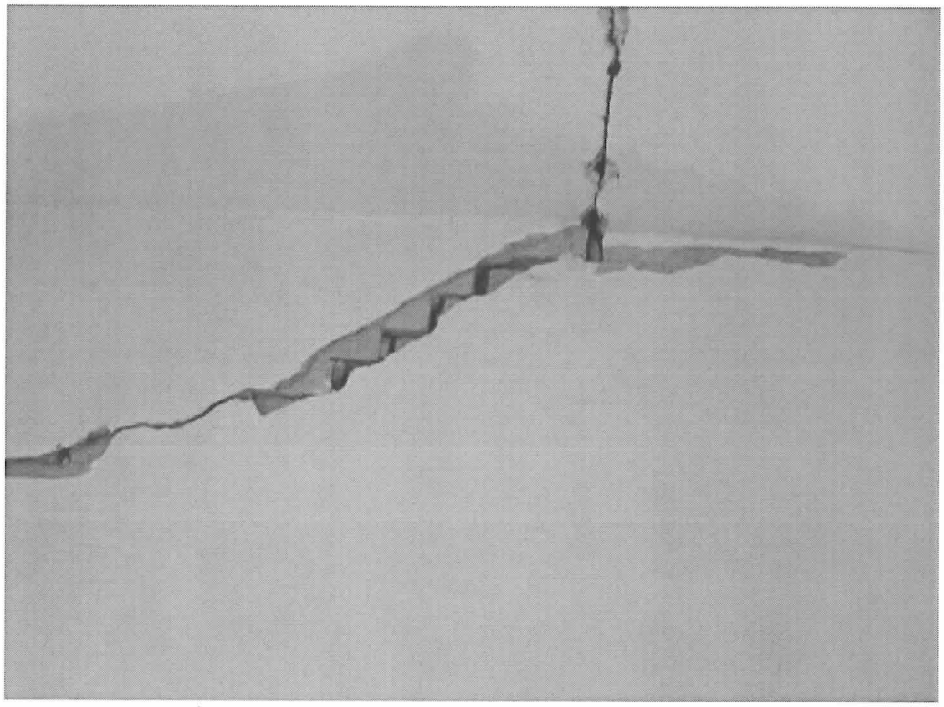

Fig.72. Cracked load-bearing wall and precast slab floor

Fig.73. Collapsed adobe house

Fig.74. Ground fissures generated by the earthquake

4.3. Office buildings

Experts surveyed five office buildings, that belong to a beer company, an inland revenue department, a district tourism bureau, an estate transactions authority and a bank, the area of them are about 29,000 square meters.

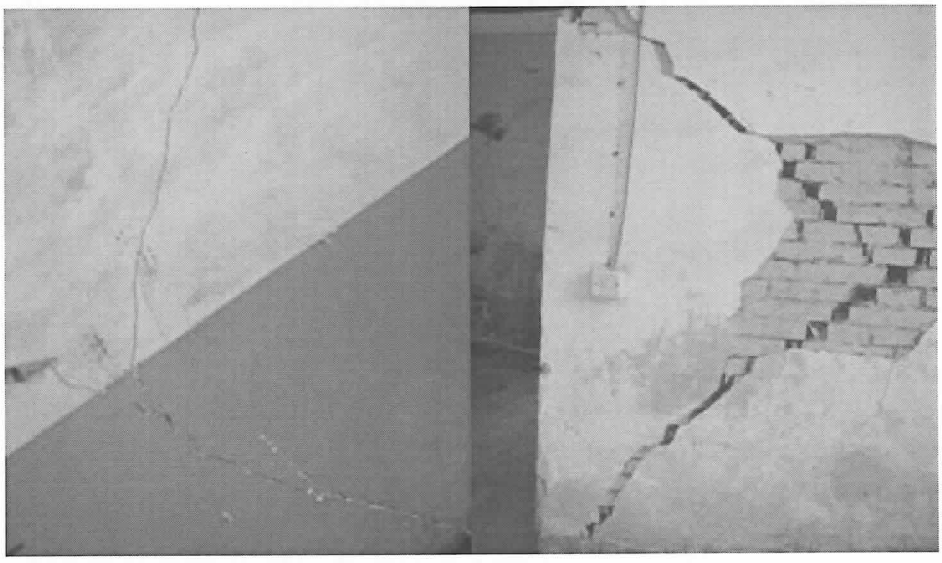

Fig.75. Longitudinal wall and cross wall cracks of the building of a beer company

Fig.76. Inner longitudinal wall cracks of an inland revenue department office building

Fig.77. Exterior wall cracks of a district tourism bureau office building

Fig.78. Bearing wall damage under beam

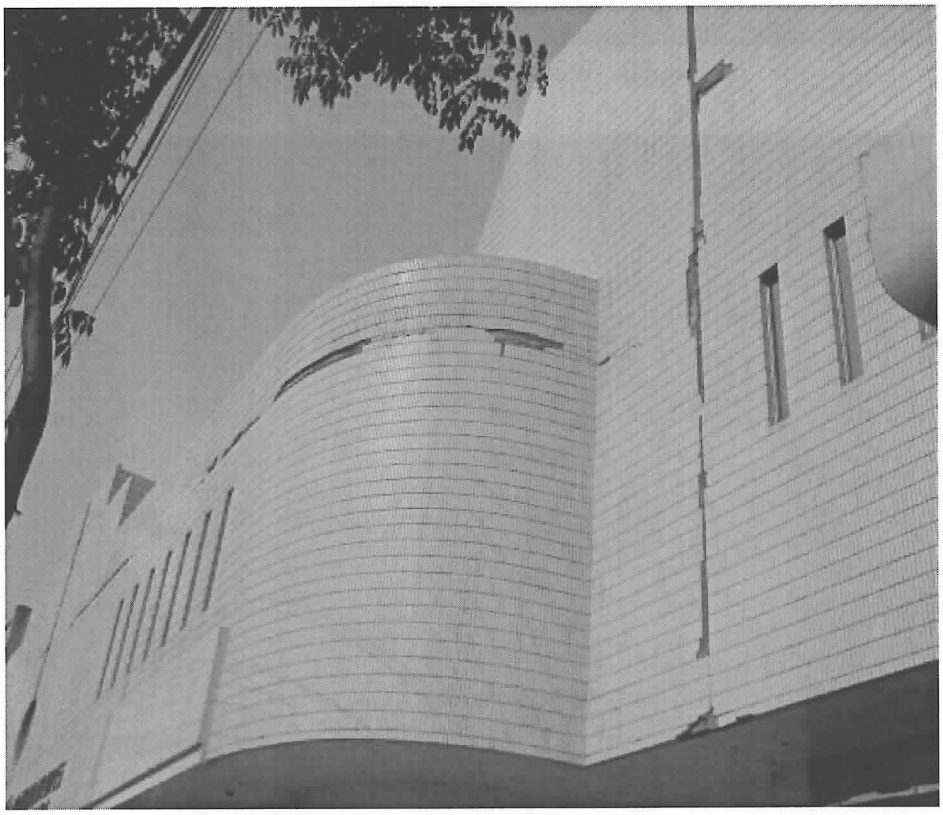

Fig.79. External wall damage of a bank office building

4.4. Industrial buildings

Three factories are investigated, which are a power factory, a beer company, a machine tool plant, construction area of them is total about 78,000 square meters.

Fig.80. Workshop of a power factory

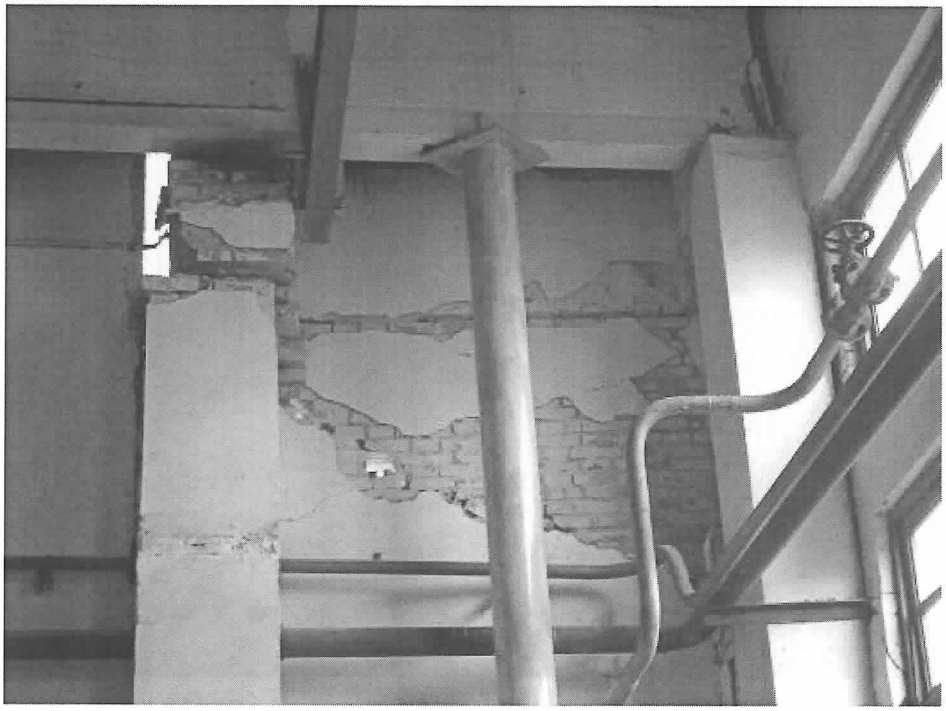

Fig.81. Crack and dislocation in top of brick column of wind resistance gable

Fig.82. Cracks of wind resistance gable

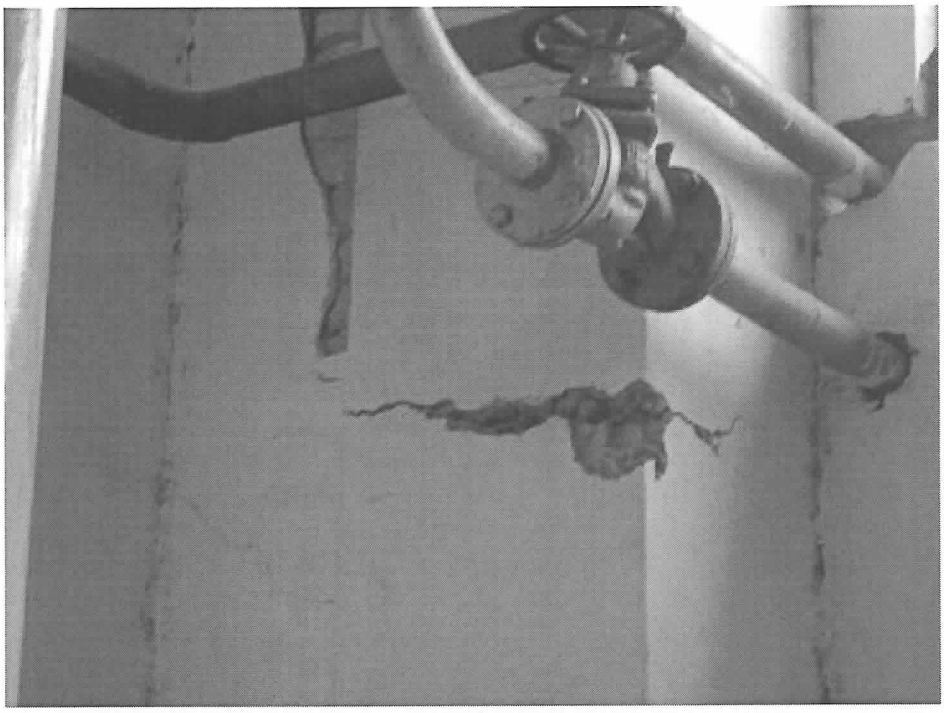

Fig.83. Damage of frame bent column

Fig.84. Frame column cracking of sunroof

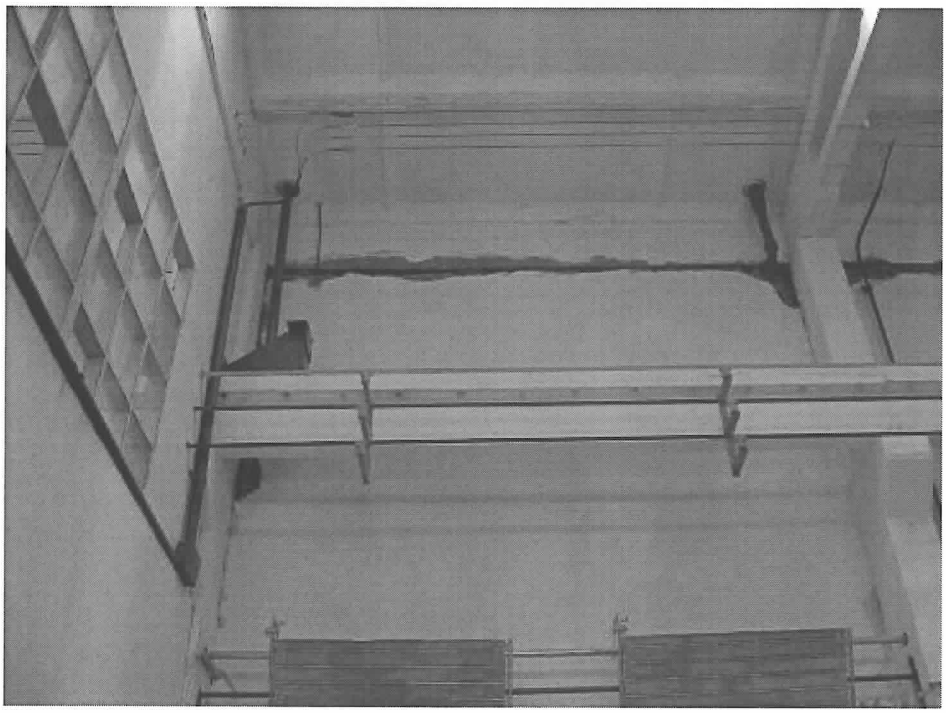

Fig.85. Horizontal crack bottom the beam of longitudinal wall

Fig.86. Support bulkling between columns of storage of coal factory buildings in a beer company

Fig.87. Short beam shear failure of a workshop

Fig.88. Vertical cracks in the gable and roof beam damage of boiler room workshop

4.4 Tower buildings

Four water storage towers and four chimneys had been checked. One of them is concrete structure and others are masonry structure.

Fig.89. Masonry structure tower is 33 meters high 15 meters circumference, 700mm of wall thickness. There are a number of circular cracks from bottom to top; interval of them is about 3 meters, crack width decrease with height, no vertical cracks.

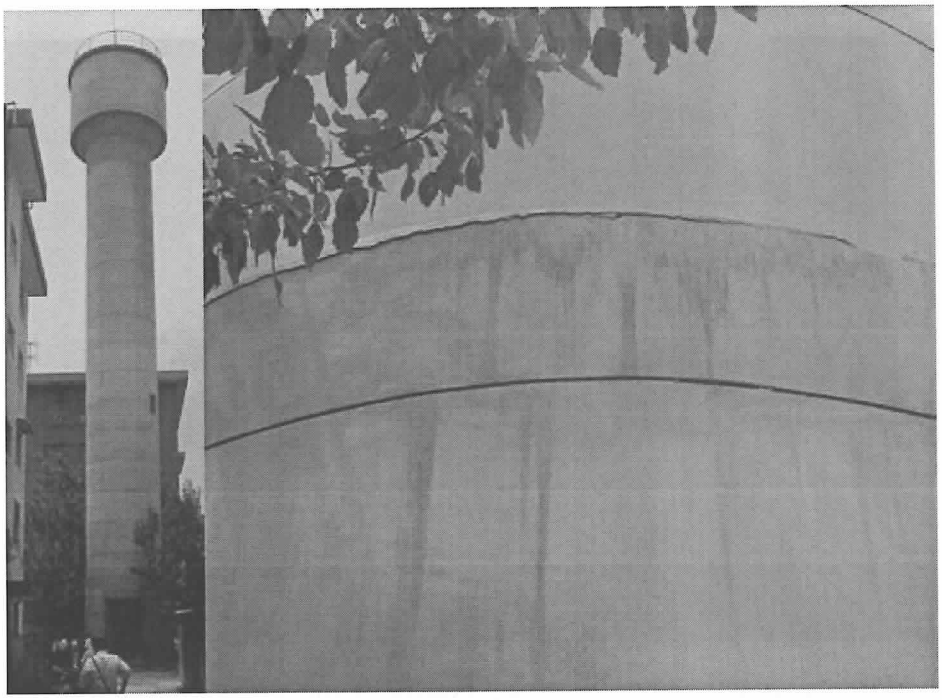

Fig.90. Masonry structure tower is 30 meters high. There is one circular cracks at the site of 6 meter from bottom.

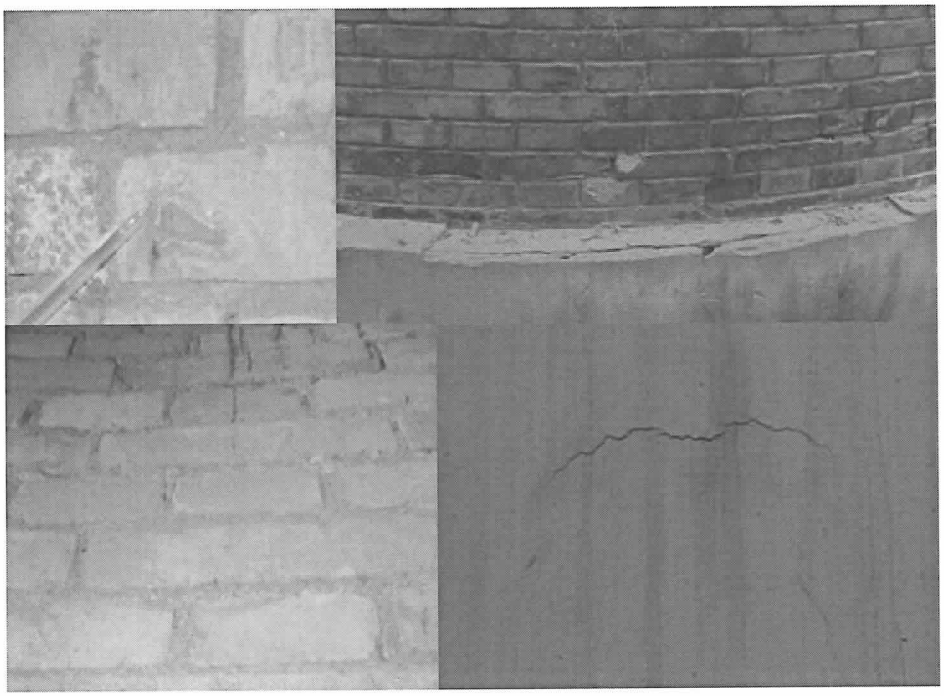

Fig.91. Masonry structure tower with 6 ring beams is 30 meters high, There is one circular cracks at the site of 1 meter from bottom, There are diagonal cracks and vertical cracks between first and second ring beam.

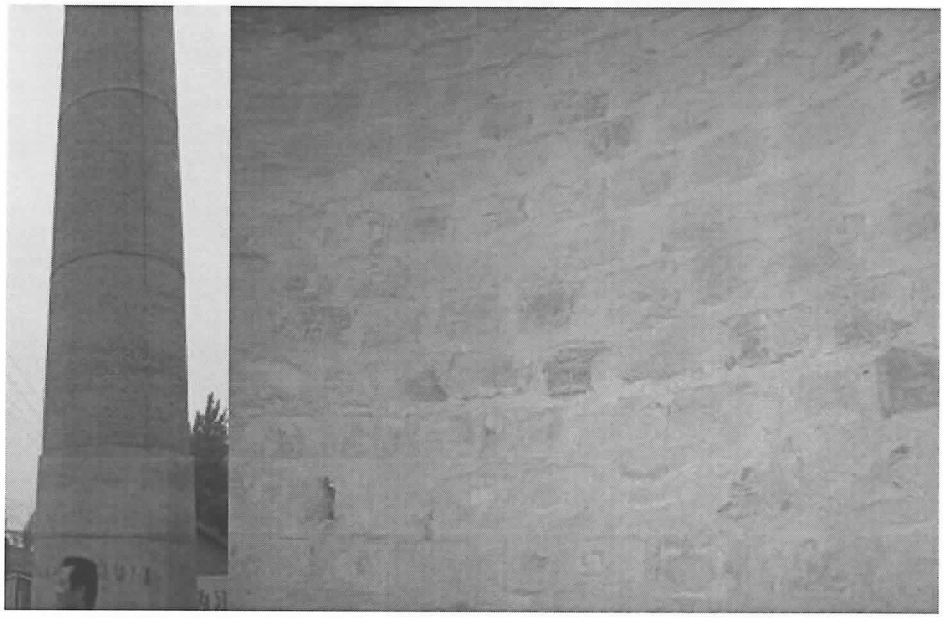

Fig.92. Masonry structure tower with ring beams, mortar strength is reduced along the height. Circumferential cracks appear at the section of the mortar strength has changed.

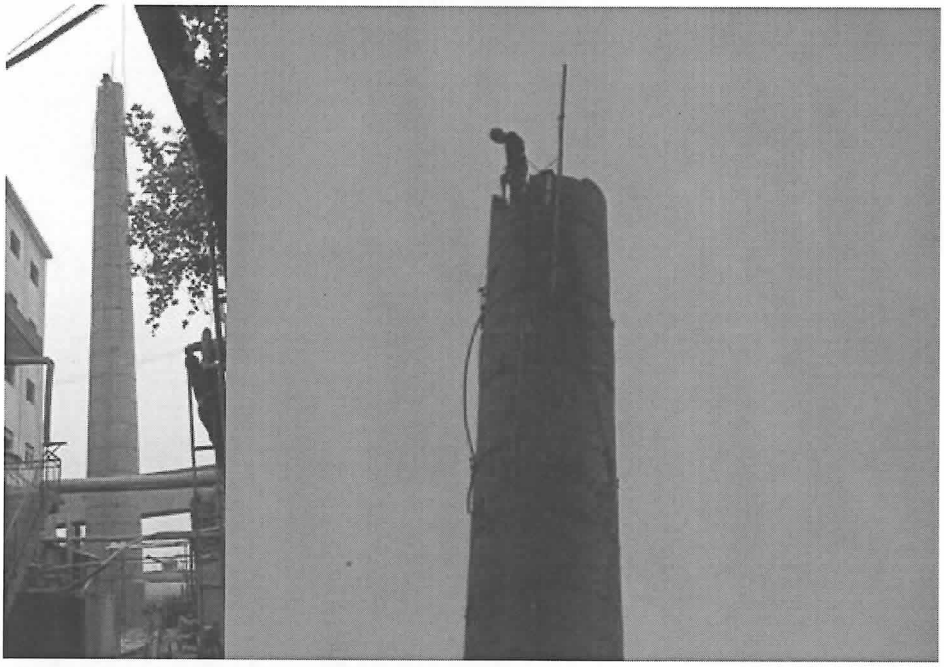

Fig.93. Masonry structure chimney is 35 meters high, 4.5 meters diameter. There is one circular crack with 1 meter distance from top. The crack is wide, and brick body is dislocated. It is being dismantled shown in the photo.

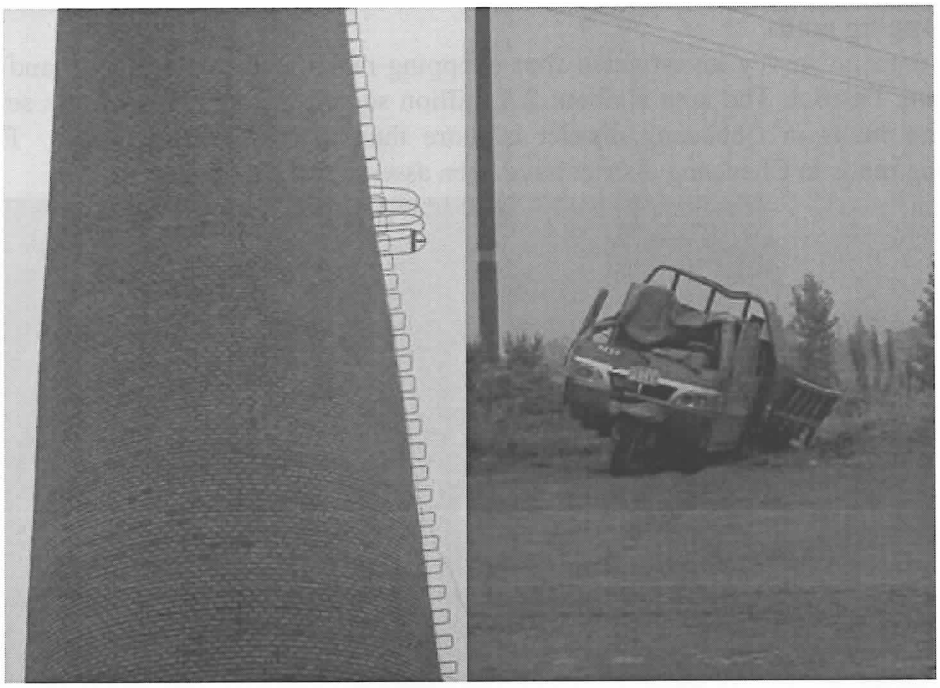

Fig.94. Brickfield masonry structure chimney is 58 meters high. 15 meters long at the top fell down and damage the tractor parting beside it. Remainder has vertical permeability cracks of 20 meters long from the top.

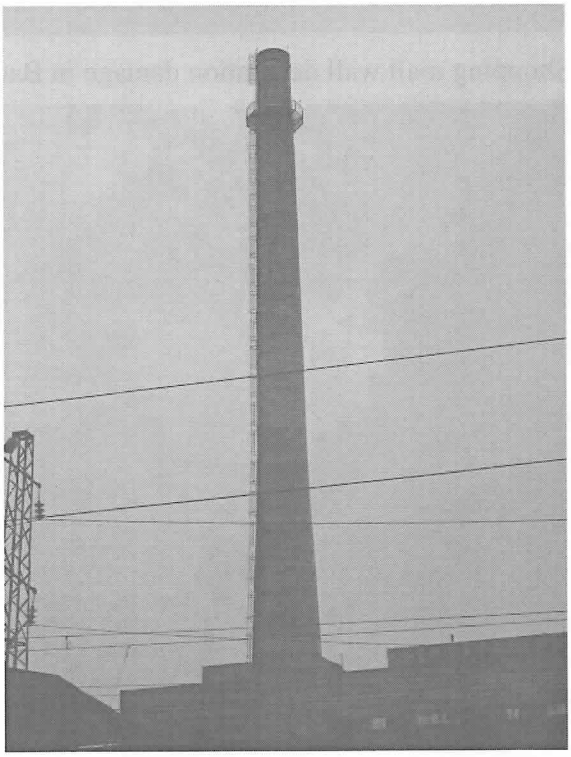

Fig.95. RC structure chimney of a bear company is 45 meters high, and is no obvious damage.

4.5 Shopping malls

The damage survey investigated four shopping malls, one of Baoji City and three of Chencang District. The area is about 2.4 million square meters. The distress severity of shopping malls in Chencang district is more than that of in Baoji city. The three shopping malls in Chencang district have been assessed as dangerous.

Fig.96. Shopping mall wall decoration damage in Baoji city

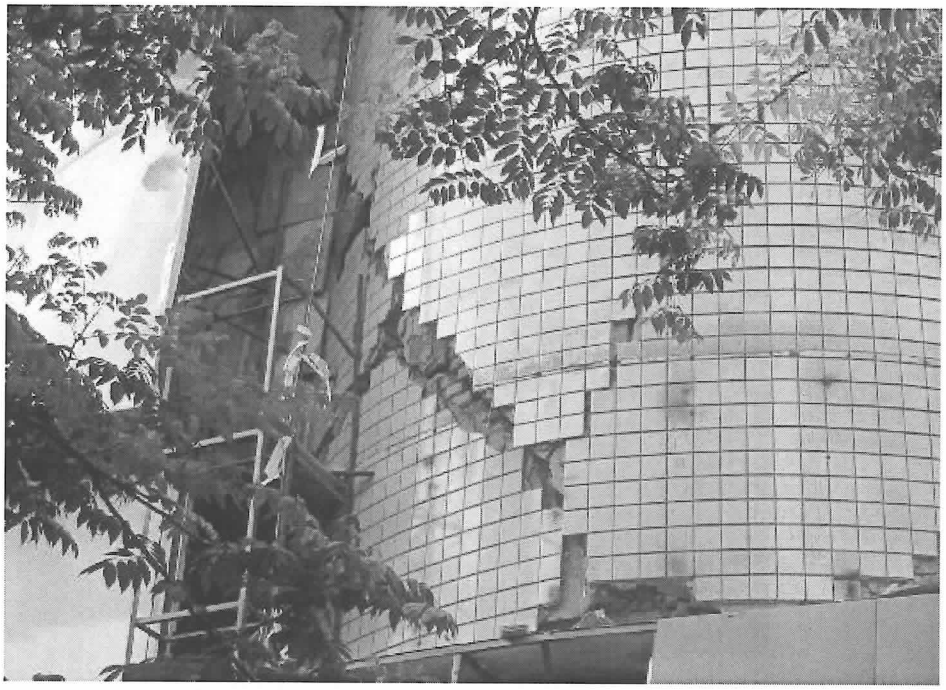

Fig.97. Stair hall arc wall damage of a shop in Chencang district

Fig.98. Column yield near node zone, steel drums outside, and has been out of work.

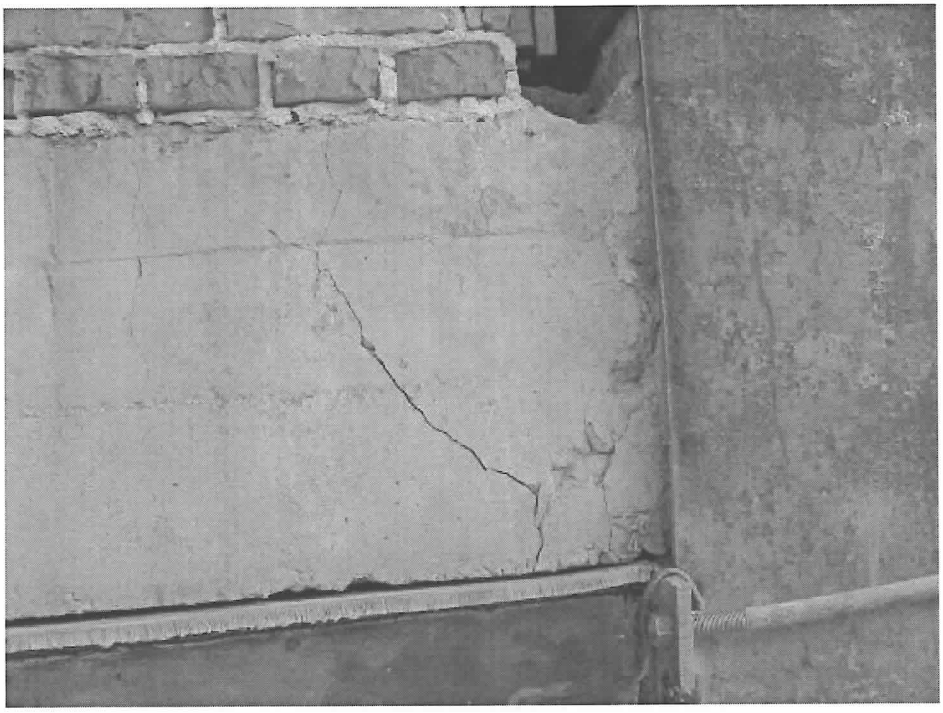

Fig.99. Shear failure at the end of beam

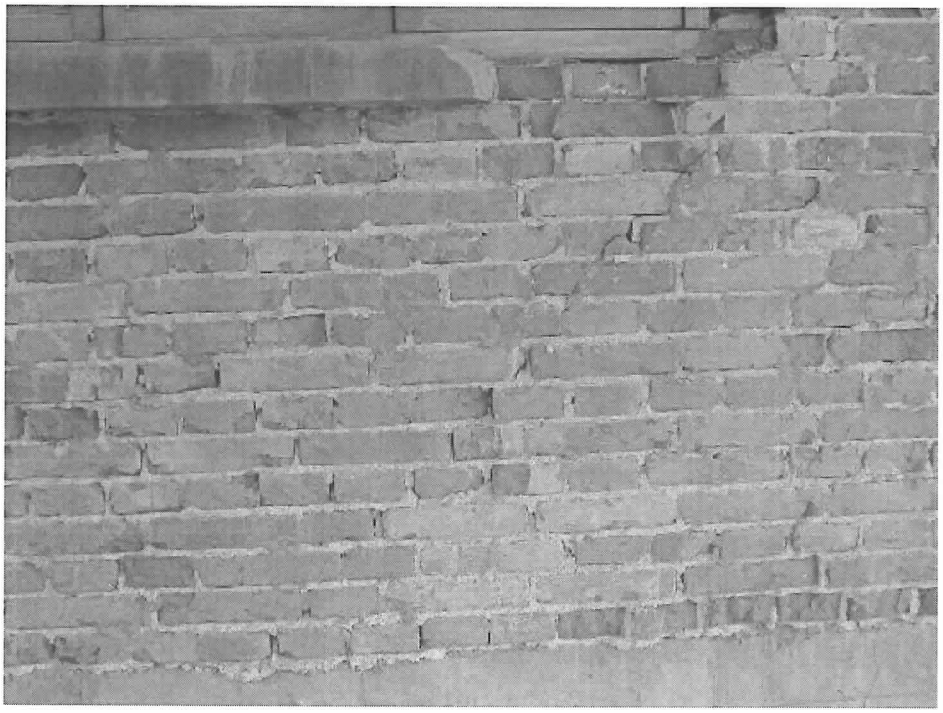

Fig.100. Filled wall crushed

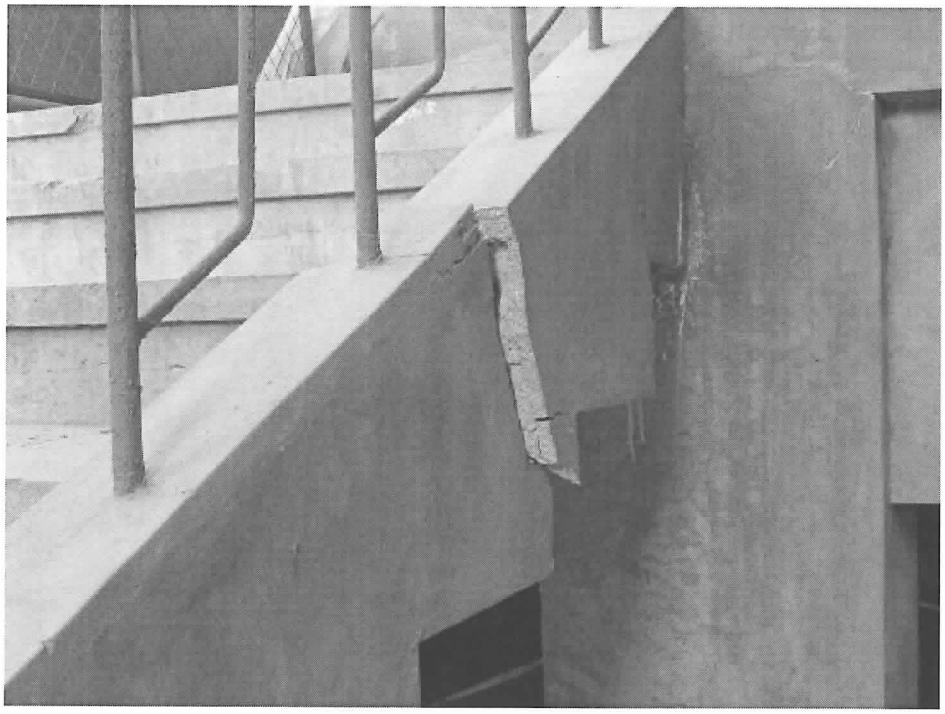

Fig.101. Snap broken of staircase

Fig.102. Snap broken at the connection between steel beam and RC beam

Fig.103. Damage of constructional column

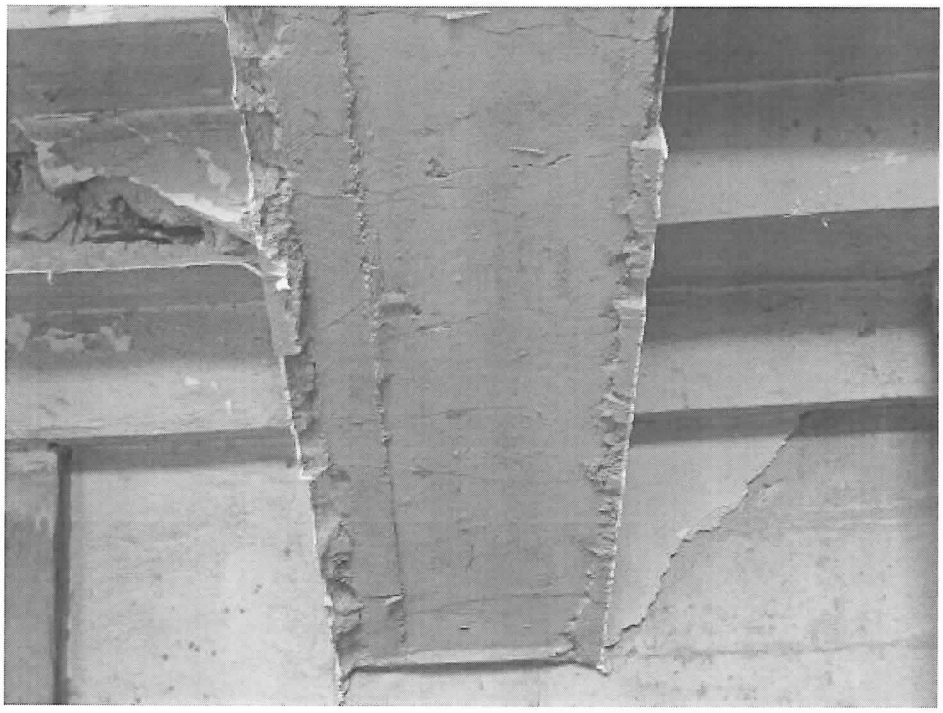

Fig.104. Many horizontal cracks appeared at the bottom of the stair beam

Fig.105. Shear failure at the stair column of the third floor

Fig.106. Inner frames and masonry mixed structure of a shopping center in Chencang district

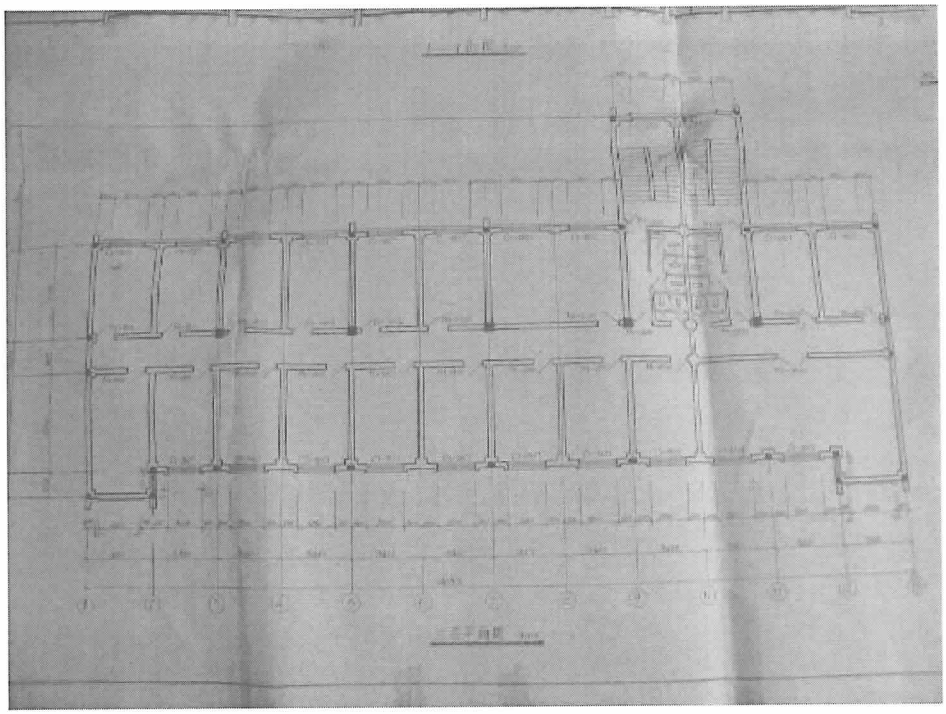

Fig.107. Structural working drawing

Fig.108. Damage of south outer wall

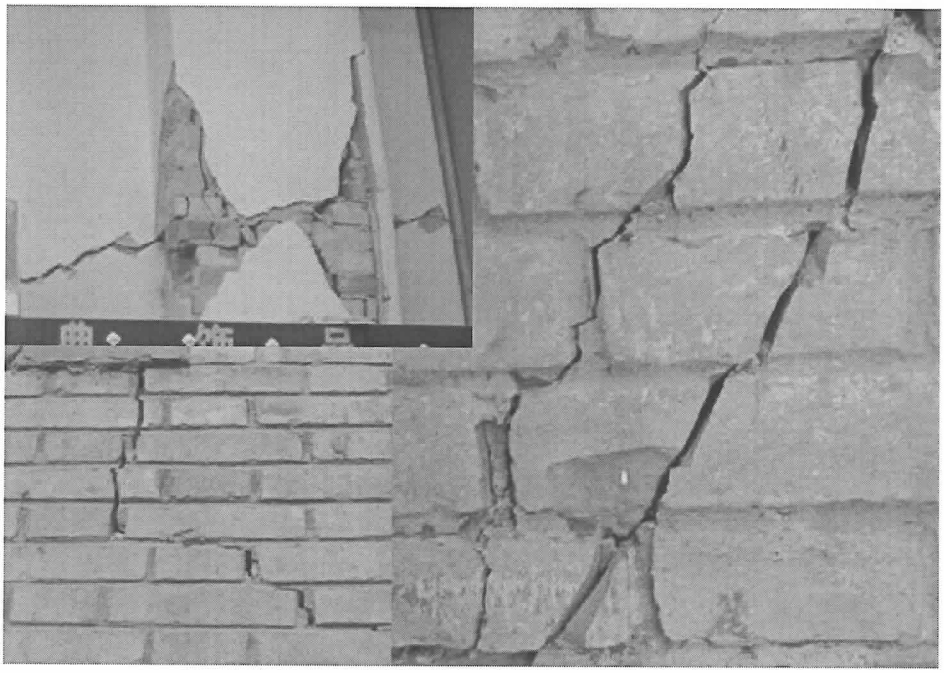

Fig.109. Damage of brick wall and column

Fig.110. Damage of brick interior wall

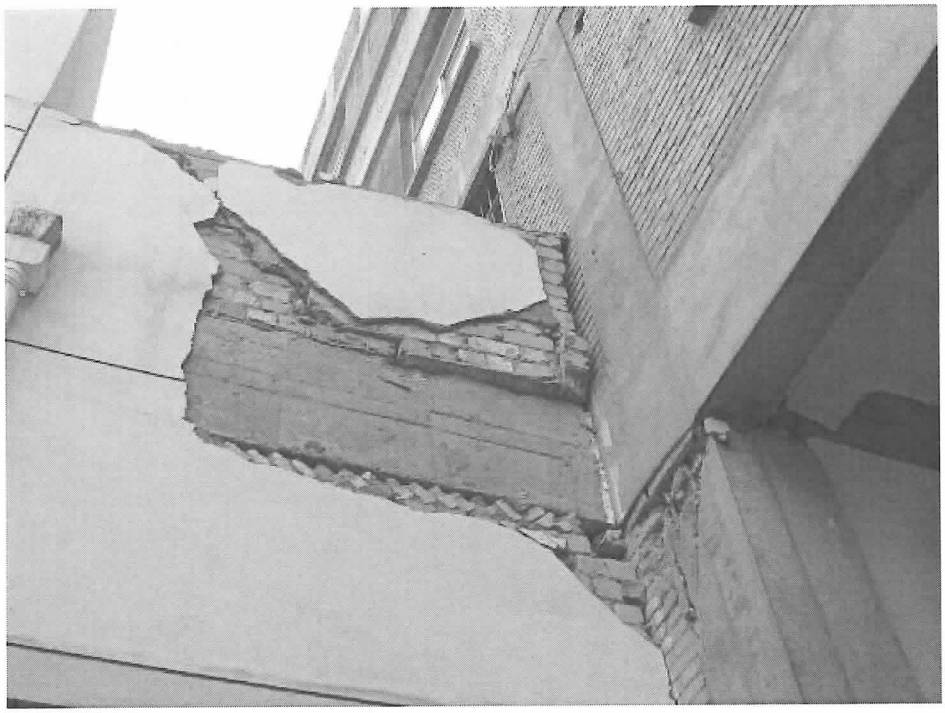

Fig.111. Frame structure damage of a restaurant in Chencang district

Fig.112. Column damage

Fig.113. Joint damage

4.6 Residential storied buildings

In order to understand the earthquake's impact on the masonry structure residential buildings, 21 residential total of 68,000 square meters had been investigated. Among them, one building which located at Weiyang road in Chencang district is the most typical damage.

Fig.114. Cracks of brick outer wall

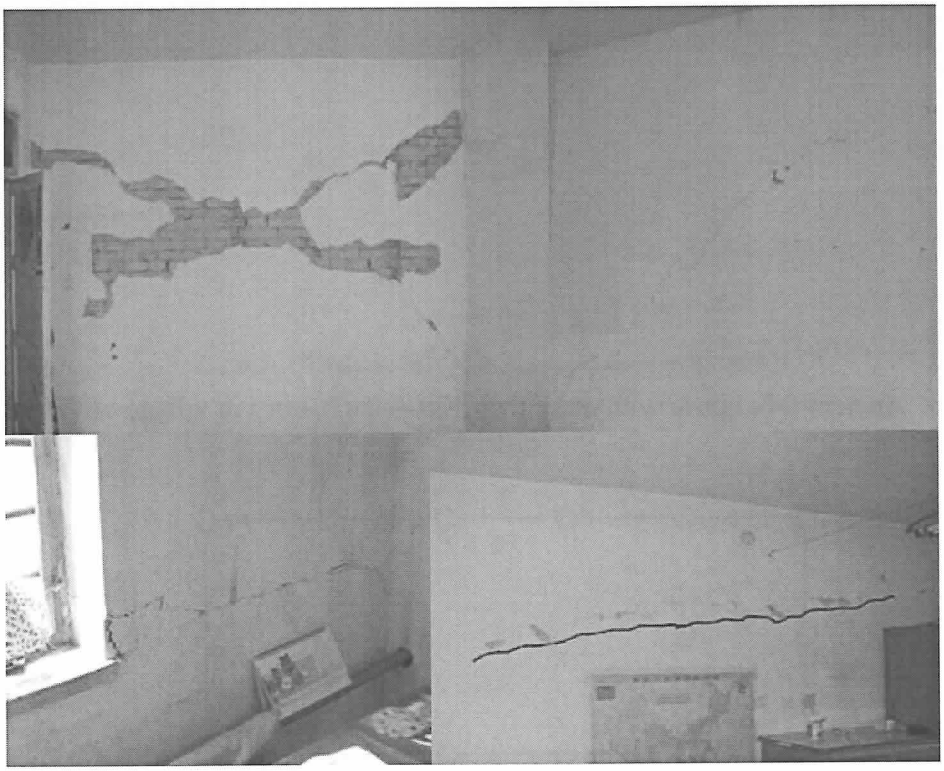

Fig.115. Cracks of brick interior wall

Through the large amount of damage survey, it can be found that the damage of masonry structure with no ring beam are very serious, there has been inclined cracks, X cracks and other damage patterns. That has proved that ring beam is very important to the building shock resistance.

4.8 Ancient architecture

In order to understand the impact of ancient architecture making by earthquake, several ancient architecture and a tombs have been investigated.

There is almost no damage in this house shown in Fig.116. The house is wood structure, is supported by 16 wooden pillars, and is surrounded by rammed earth wall mixed with wheat straw. The wall didn't support the weight of the entire roof, but 16 wood pillars bear the load. Wooden structure is a good toughness, high seismic performance of buildings.

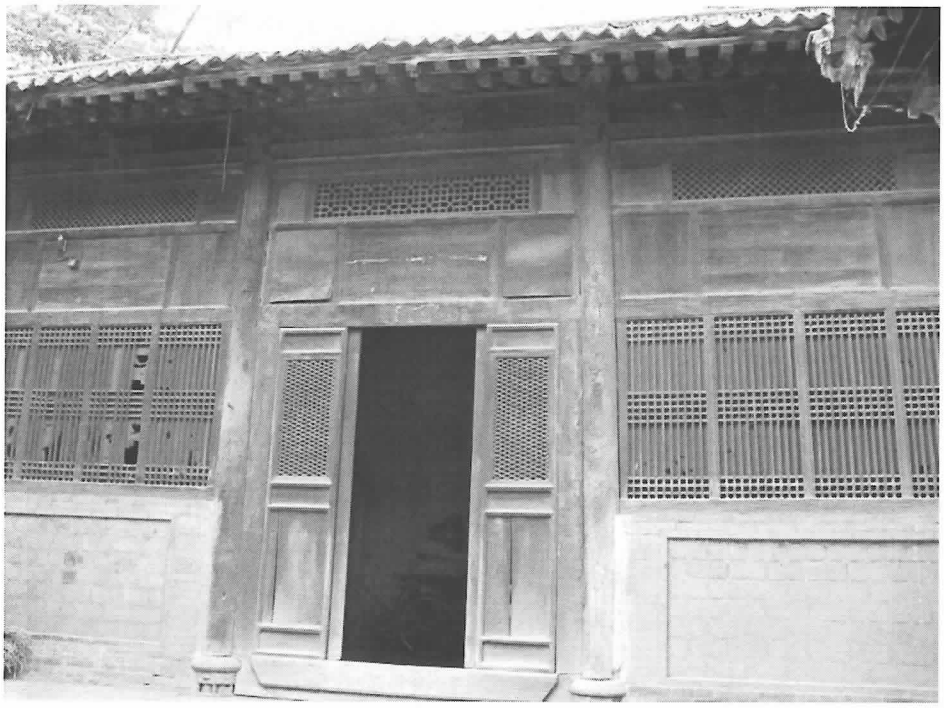

Fig.116. Ancient folk house with more than 120 years history in village of Chencang district.

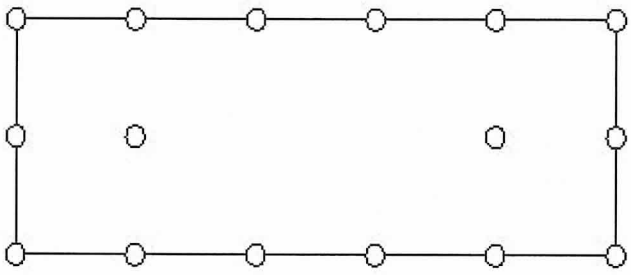

Fig.117. Schematic diagram of the column arrangement

Fig.118. A wooden structure Taoist temple main shrine

The building shown in Fig.118 is a two-story wooden structure loft, and built in 1825. It is 12 meters length, 6 meters width and 10meters height. It is also surrounded by rammed earth wall mixed with wheat straw in the first floor. The load supported by wooden structure, and the wall don't bear the weight of the wall. The whole building without any tilt, the inner wall has a vertical crack, the width is about 2mm, and there are two vertical cracks in outer wall, the width of about 2mm.

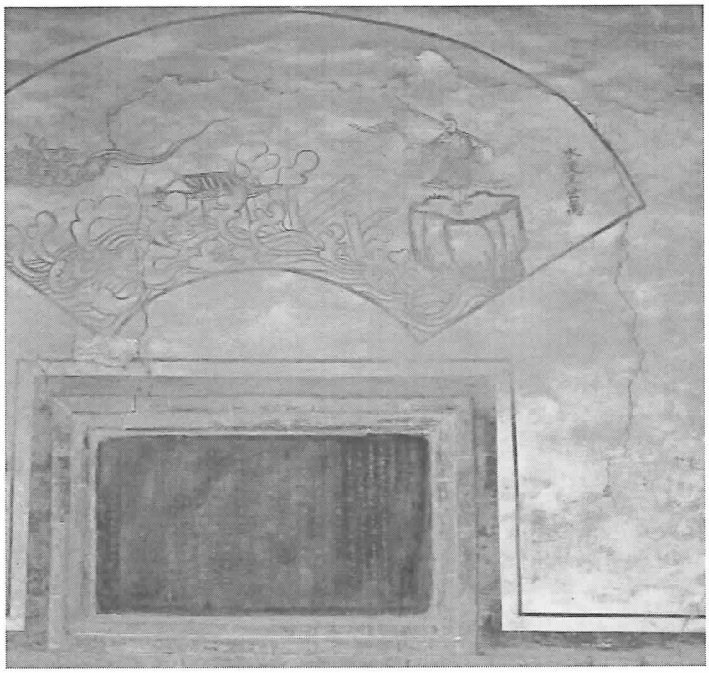

Fig.119. Vertical cracks in the inner wall

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[3] http://news.xinhuanet.com/photo/2008-05/14/content_8171817.htm (Accessed 2 January 2009)
[4] http://www.cnsphoto.com/ (Accessed 2 January 2009)
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[6] http://www.cnr.cn/2008zt/scdz/tpbd/200805/t20080517_504792634.html (Accessed 2 January 2009)
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