Field Test of Damaged Building Structures in China Yushu Ms7.1 Earthquake

Junwu DAI, Yongqiang YANG and Haibo WANG
Key Laboratory of Earthquake Engineering and Engineering Vibration, China Earthquake Administration, China

SUMMARY:
Immediately after the 2010 China Yushu Ms7.1 earthquake, in the field investigation, 20 damaged buildings with different structures, 6 RC frame buildings, 6 concrete-block-masonry buildings, 3 clay brick masonry buildings, 4 inner-wood-frame buildings and 1 bottom-RC-frame-supported building, were selected by the authors to carry out the field test in the most seriously damaged epicenter Jiegu town. The natural frequency of each building was tested by using the ambient vibration test method. Both of the test results of the natural frequency for each building as well as its' damage pattern were described and simply analyzed in this paper. The relationship between the frequency tested, the structural damage level as well as the damage mechanism is also analyzed. The investigation results provide benchmark cases for nonlinear numerical analysis, design and retrofitting of RC frame, concrete block/ clay brick masonry, inner-wood-frame and bottom-frame-supported masonry building structures.

Key words: Yushu Ms7.1 earthquake, damaged building, natural frequency, field test

1. BACKGROUND

Many field investigation test researches have been done for most types of exist building structures in the past years, the evaluation of the natural frequency of a building structure has been used in the preliminary design for a new building or in the calculation of the earthquake response by using the vibration-mode-decomposition response spectrum method. But in the retrofitting design for those lightly or moderately damaged buildings in earthquake events, engineers usually hope to know the damage level of the damaged structures quantitatively. The experiences and the statistic equation for non-damaged building structures are not suitable any more. In fact, in the 2008 Ms.8.0 Wenchuan Earthquake field investigation, the author already obtained series of structural responses of 3 RC frame and shear wall buildings to the aftershocks. It should be the first time in China, the structural response of “real” buildings under earthquakes was recorded. It provides preliminary understanding about the characteristics of damaged building structures. Based on the situation of the knowledge shortage about the quantitative change of the vibration characteristics of seismic damaged building structures, the authors of this paper organize a research team to carry out the field test immediately after the Ms.7.1 Yushu Earthquake happened in April 14, 2010 in northwest China. By using the micro-ambient-vibration method, the natural vibration characteristics of totally 20 selected seismic damaged building structures were tested and the damage details of these buildings were investigated simultaneously. This paper provides the test data as well as the damage descriptions obtained in the field investigation.

2. OVERVIEW OF THE 20 DAMAGED BUILDINGS TESTED

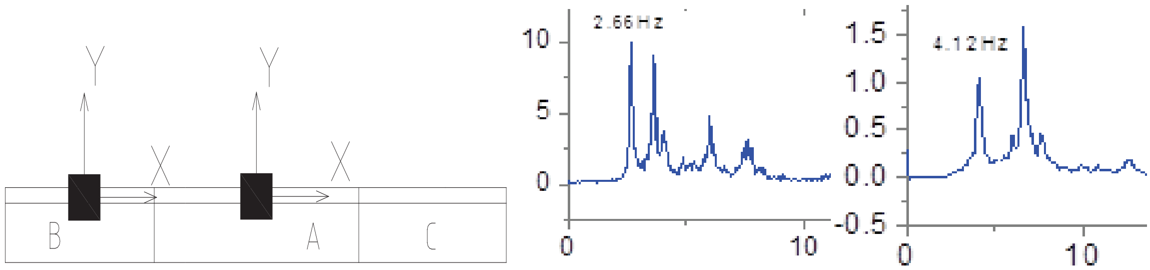
In the selected 20 earthquake damaged buildings, including 6 light concrete block confined masonry (LCBCM) structures which is very popular local structural type, 3 clay brick confined masonry (CBCM) structures, 6 RC frame (RCF) structures, 4 inner wood frame and 1 inner R/C frame with surround masonry wall (IFSMW) structures which is a kind of old traditional building type, and 1 bottom R/C shear wall frame supported masonry (BSWFSM) structure which is also famous for its' bad behavior and caused numerous casualties in 2008 Ms8.0 Wenchuan Earthquake.

2.1. Observations on Damaged Light Concrete Block Confined Masonry (LCBCM) Structures

Due to the high altitude and corresponding lower air pressure of the local climate condition, it's hard to manufacture the clay bricks with enough strength fit for seismic resistant building construction. So, the light concrete block becomes the main substitute construction materials to the clay brick which is very popular even in other seismic areas of China. And the light concrete block (sometime with hollows) confined masonry (LCBCM) structure becomes the most popular local structural type. In the 2010 Yushu Ms7.1 earthquake event, most of this kind of building structures without seismic design and construction were severely damaged or collapsed due to the lack of seismic restrain measures and unreasonable construction. For those seismically designed and constructed LCBCM structures, they showed advantages of seismic design. But it's obvious that the damage pattern and severity is highly related with the building height, room space or distance between transversal walls and distribution of the confine R/C columns and beams in masonry walls. The seismically designed 2-story LCBCM building showed better performance than those 4-story ones. And the residential buildings with relative smaller rooms showed higher seismic resistance than those office building and school buildings with relative larger rooms. Typically, the damage mostly concentrated in the walls of first story with lower shear capacity not enough to satisfy the earthquake demand. 6 of the damaged LCBCM building structures were selected to be tested in the field investigation. The ambient vibration of each of the 6 buildings was tested by orthogonally installing 2 accelerometers on the roof central of each building respectively. As results of the ambient vibration test, the natural frequency of each building structure along its' 2 orthogonal main axes were calculated with FFT analyses, fig.1~5.

a) overview b) wall damage in 1st story c) roof colliding

Figure 1. Typical damage of a 4-story LCBCM school building



a) measurement points b) NF in y-D-2.66Hz c) NF in x-D-4.12Hz

Figure 2. Natural frequency test for the seismic damaged LCBCM school building

Figure 3. Seismic damage of a 4-story LCBCM office building and its' NF (1.75 Hz) tested

a) overview b) damage of wall under window c) NF tested (3.71Hz)

Figure 4. Typical damage of a 4-story LCBCM residential building and its' NF (3.71 Hz) tested

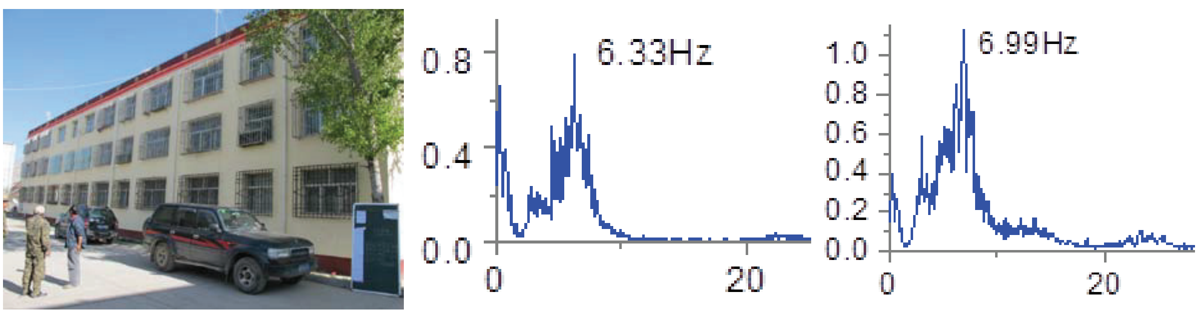


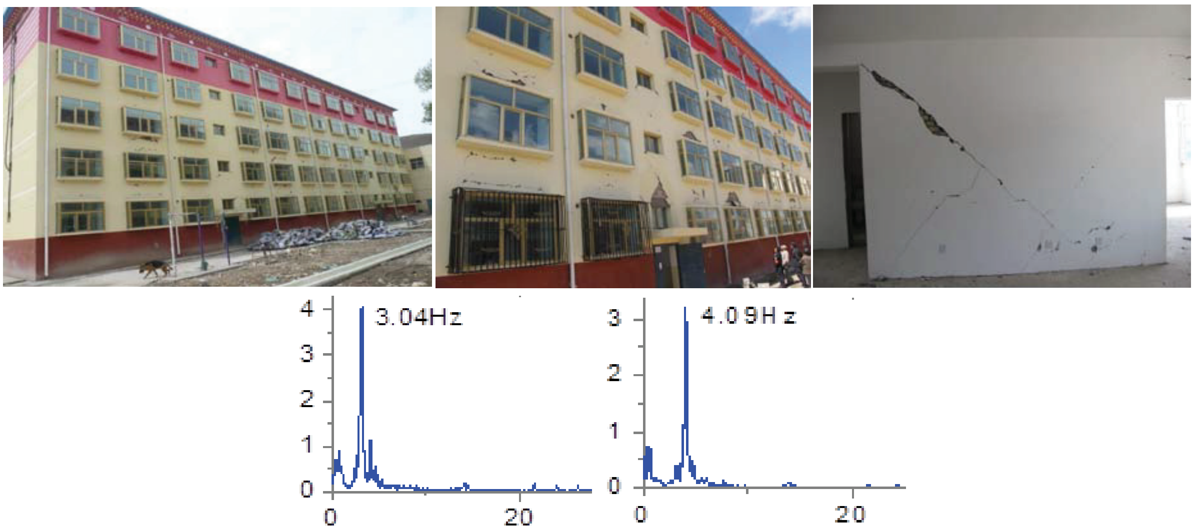
Figure 5. A 3-story LCBCM residential building without any damage and its' NF (6.33Hz) tested

From the natural frequency (NF) test results, shown in fig.1~5, it can be seen that the natural frequency changes with the damage severity happened to the structural walls. For the 3-story LCBCM residential building without any damage in the Yushu earthquake shown in fig.5, the NF along its' 2 main structural axes is 6.33Hz and 6.99HZ respectively, for the same type of 4-story LCBCM office building shown in fig.3, the NF value decreases to only about 1.75Hz due to the severe damage in the 2nd story walls without enough confine measurements. For after earthquake retrofitting design, it could be useful to help engineer evaluate the structural status.

2.2. Observations on Damaged Clay Brick Confined Masonry (CBCM) Structures

There are 3 clay brick confined Masonry (CBCM) building structures tested in the field investigation. Very similar to the damage phenomenon of the LCBCM building structure, the damage severity of the CBCM building is also strongly related with their height, room space or distance between transversal walls and distribution of the confine R/C columns and beams in masonry walls. The damage of school building with lager space rooms and more stories is much severer than the residential buildings with smaller rooms and lower stories. The damage in the school building is mostly concentrated in the lower story walls due to the higher earthquake shear force at the bottom level and lower overall lateral resistant capacity caused by the lack of walls and lower-strength clay bricks manufactured locally in the condition of lower air pressure. From fig.6, it can be seen that the damaged walls between windows show not only in-plane shear pattern but also out-of-plane bending pattern. Inner transversal and longitudinal walls all show obvious shear pattern damage. Fig.7 shows the overview of a damaged 5-story residential CBCM building. The damage severity is lighter than the school building shown in fig.6. Its' damage pattern belongs to a transition stage between intact and seriously damaged. The lintel walls under the windows were damaged mostly and few walls in the dining room with larger space were also damaged firstly. It expresses the damage sequences of the masonry buildings. The NF test results obtained from the FFT analyses of the ambient vibration data also roughly reflect the damage severity as well as the overall health status of the structures tested, as shown in fig.6~8.

Figure 6. Typical damage of a 4-story CBCM school building and its' NF (2.63Hz) tested



Figuer 7. Typical damage of a 5-story CBCM residential building and its' NF (3.04Hz/4.09Hz) tested

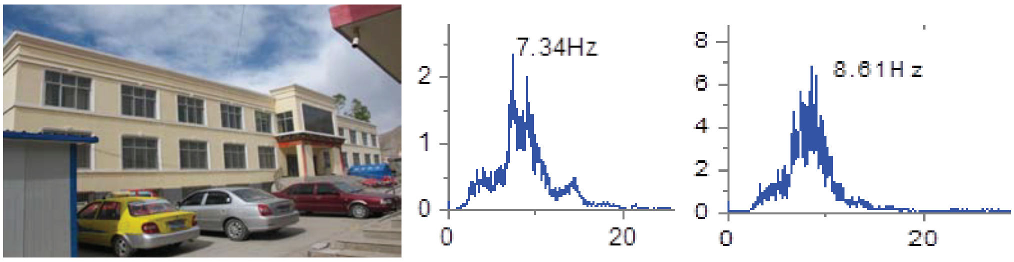


Figure 8. A 2-story CBCM residential building without damage and its' NF (7.34Hz/8.61Hz) tested

2.3. Observations on Damaged RC frame (RCF) Building Structures

Totally, 6 damaged RC frame (RCF) building structures including 4 existing buildings (1 school buildings, 1 hotel and 2 office building) and 2 buildings under construction but close to finished except for the infill walls (1 temple building and 1hospital building) are selected to be tested in the field investigation. For the 4 existing RCF buildings, the damage were mostly observed in masonry infill walls with typical shear pattern, end-corner columns with typical bending-torsion pattern, stair cases with bending-shear coupling and short-columns with shear pattern caused by incorrect construction and distribution of the masonry infill walls. These damages were caused by shear, torsion, bending and shear coupling or unexpected local shear and compression. For the 2 RCF buildings under construction, because there is no influence came from masonry infill walls, the damage pattern expresses the seismic response characteristics of the pure RCF structure. The typical design defects caused damages are still focused on not only the column end instead of beam end but also the staircase. In spite of after the 2008 Wenchuan Ms8.0 earthquake the seismic design code has been updated to try to avoid such kinds of damages.

From fig.9~14, it can be seen that the natural frequency of the damaged RCF building structure is much lower than those code-experience values for design purpose. The NF value of the 2 buildings under construction without masonry infill walls is averagely much lower than those 4 existing RCF buildings with masonry infill although damaged. It's evidence of the masonry infill walls contribute to the overall stiffness and taking the role of first defense-line in the earthquake impact.

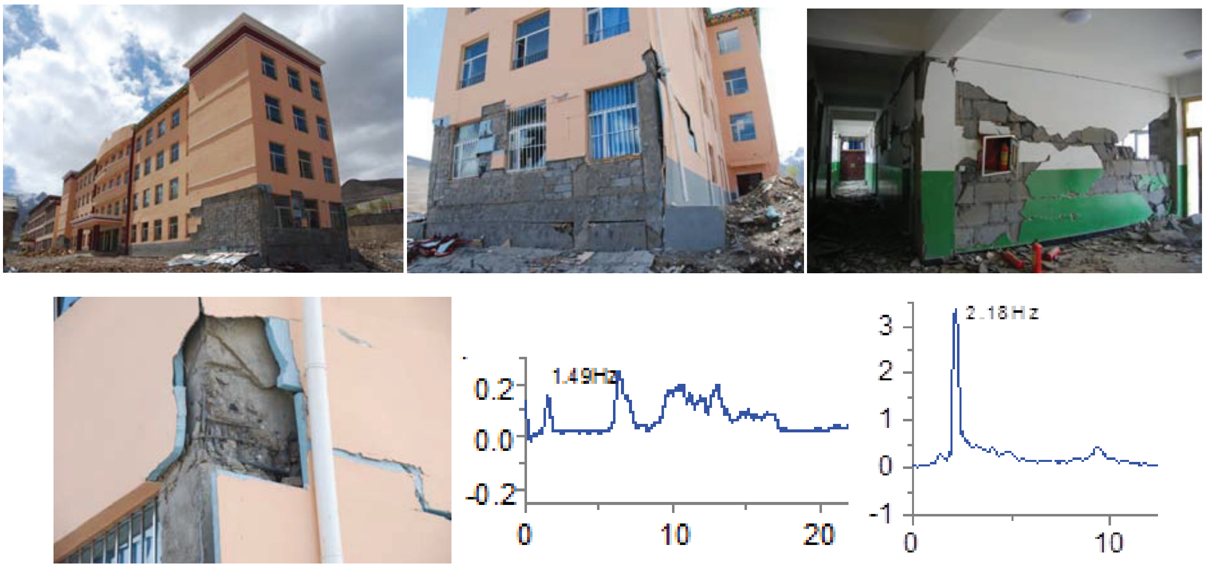


Figure 9. Damage of a 4-story RCF school building and its' NF (1.49Hz/2.18Hz) tested

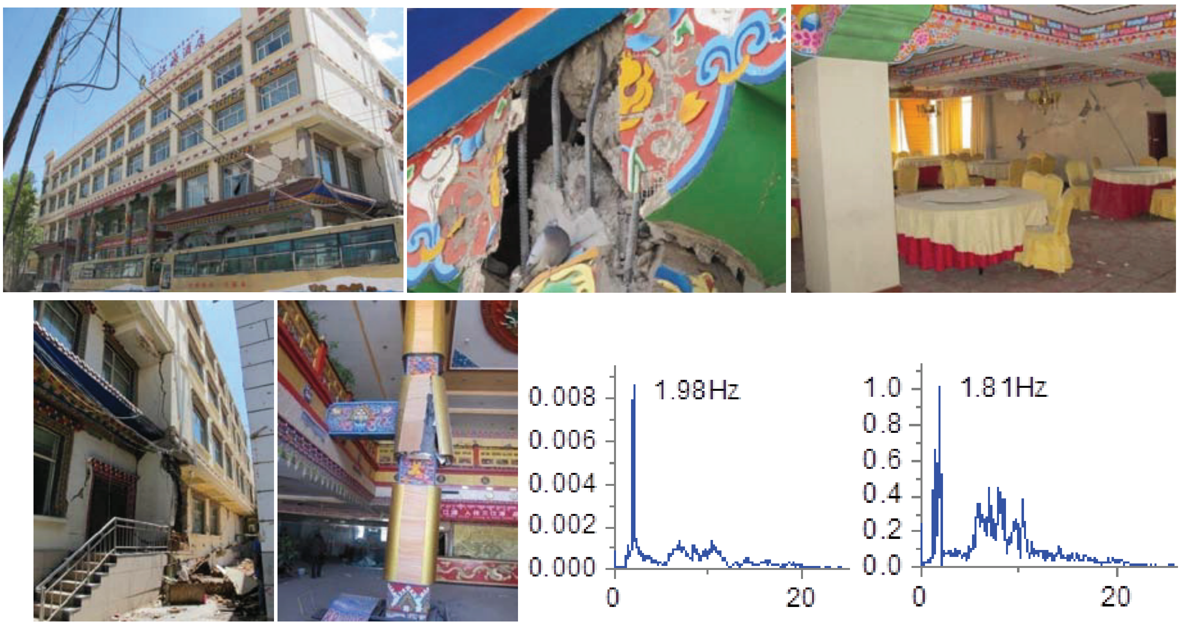


Figure 10. Damage of a 4-story RCF hotel building and its' NF (1.81Hz/1.98Hz) tested

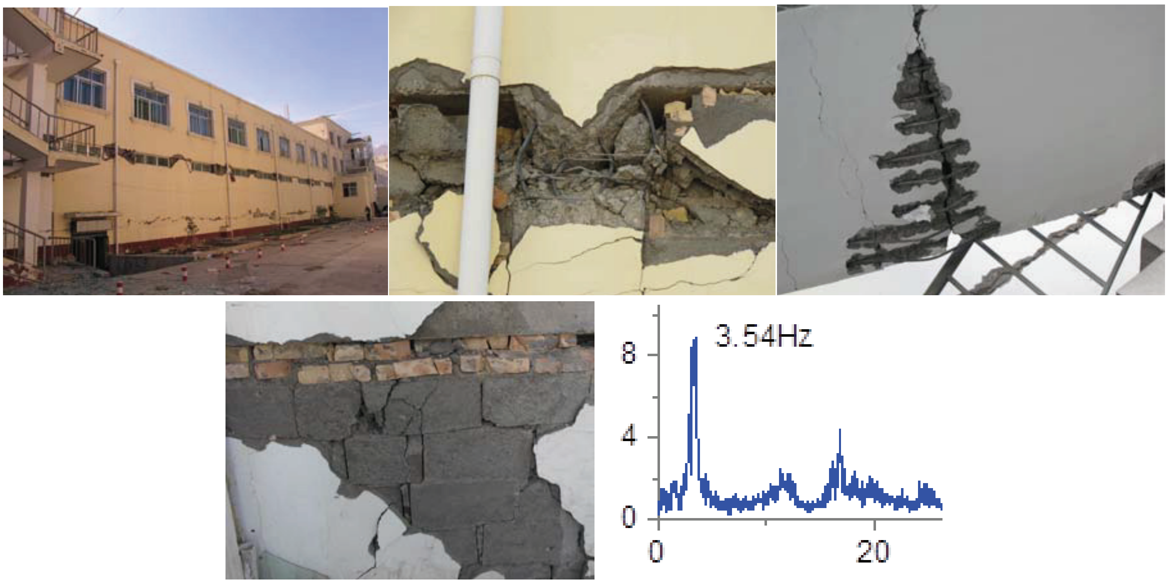


Figure 11. Damage of a 4-story RCF office building and its' NF (3.54Hz) tested

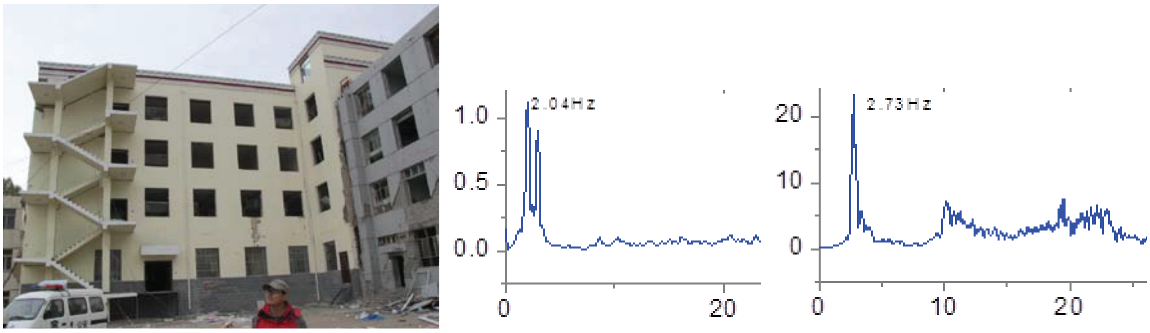


Figure12. Damage of a 4-story RCF office building and its' NF (3.54Hz) tested

Figure 13. Damage of a 5-story RCF hospital building and its' NF (1.26Hz) tested

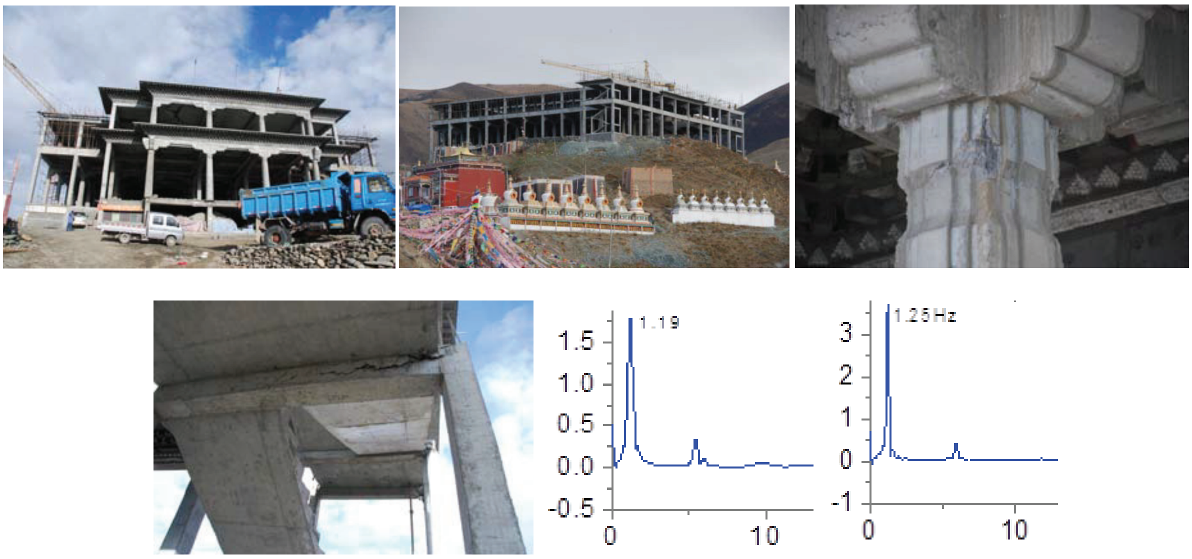


Figure 14. Damage of a 2-story RCF temple building and its' NF (1.19Hz/1.25Hz) tested

2.4. Observations on Damaged Inner Wood Frame or Inner R/C Frame with Surround Masonry Wall (IFSMW) Building Structures

The inner wood frame with surround masonry wall (IFSMW) structure is a very popular and typical local temple building type. The inner R/C frame with surround masonry walls structure is the modern version IFSMW structure. Because of the good heat preservation and service durability of the masonry walls constructed with clay, rubble, willow twigs or grass tendons mixture, the surround walls usually constructed up to 1.6 meter thick or so and lasting hundreds of years. The inner wood frame supported floors provides probable of flexible large space arrangement. Totally, there 5 IFSMW building were investigated. From fig.15~17, it is observed that the damage of these 5 IFSMW structures mostly happened at the joints of the beams and their supporting surround walls. In fact, the inner flexible wood frame and the surround stiff-brittle walls composite a very special structural system. During the shaking of earthquake, the inner wood frame can laterally deformed very large but the surround stiff-brittle walls only permit very small lateral deformation. Correspondingly, the dynamic response would be quite different with each other. As the results of this conflict, the joints between the frame and walls become the easily damaged weak points. The wood beams almost are able to move freely on the surround walls due to the damage of the joints where the surround walls support the beams.

The natural frequency test results reflect the same fact. The inner wood part has the lower NF value while the surround masonry part has a much higher NF value relatively. For the inner R/C frame with surround masonry walls structure, it's quite different with the inner wood cases, the NF value of both parts has very little difference. It shows that the R/C frame is much stiffener than the wood frame and has a better cooperation with the surround masonry walls during earthquake shock. The serious damage in the columns of the attic 3rd story discloses the fact that the inner R/C frame work well together with the surround 1.6 meter thick masonry walls in the lower 2 stories, although there are a few shear cracks can be observed in the thick surround walls.

Figure 15. Damage of a 3-story IRCFSMW temple building and its' NF (5.19Hz/5.81Hz) tested

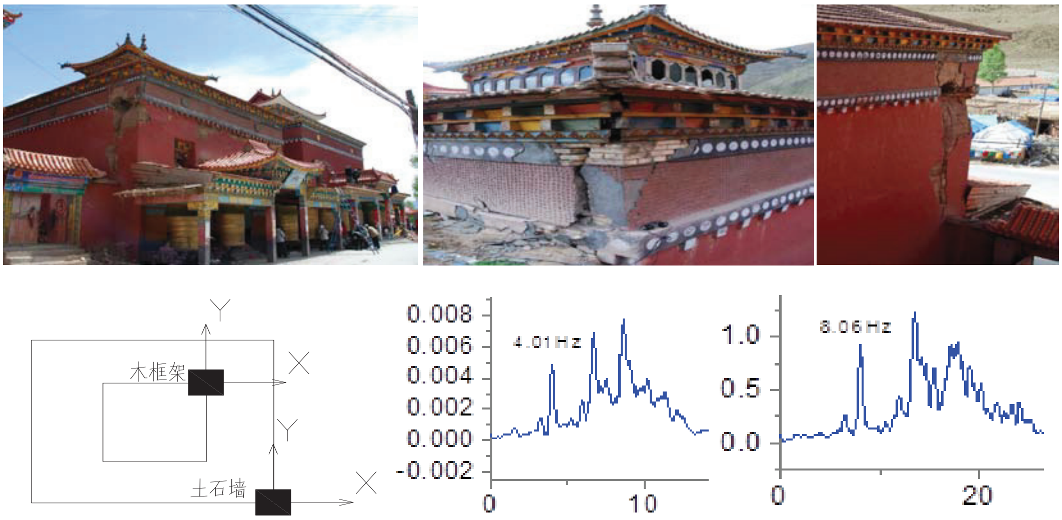


Figure 16. Damage of a 3-story IWFSMW temple building and its' NF (4.01Hz/8.06Hz) tested

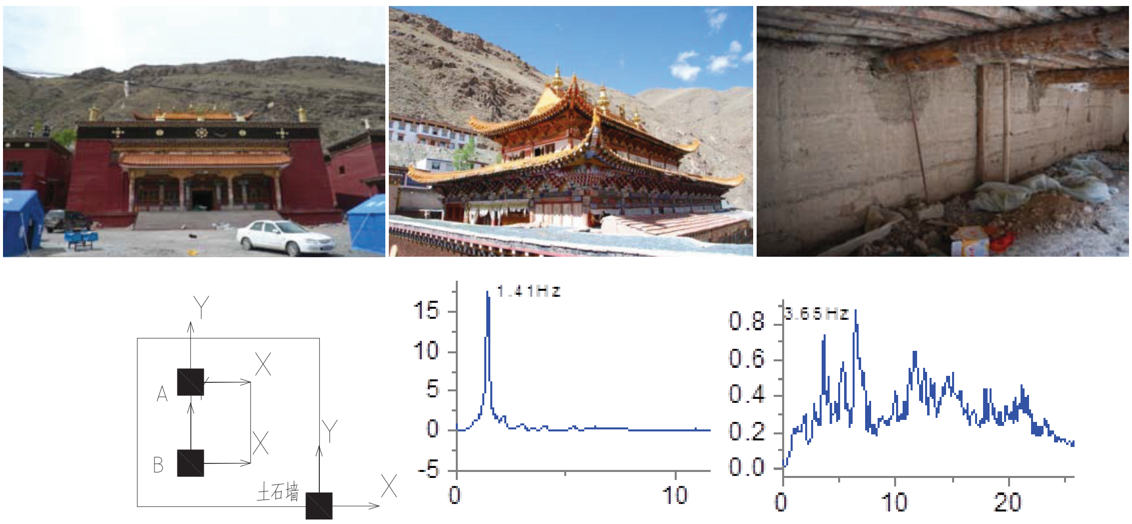


Figure 17. Damage of a 3-story IWFSMW temple building and its' NF (1.41Hz/3.65Hz) tested

2.5. Observations on Damaged Bottom R/C Shear Wall Frame Supported Masonry (BSWFSM) Building Structure

Only 1 damaged bottom R/C shear wall frame supported masonry (BSWFSM) building structure was tested in the field investigation. It's a 5-story residential building with typical characteristics of code defined BSWFSM structure. The serious shear damage is mostly concentrated in the 2 story, the code-called transition story from the bottom R/C shear wall frame to confined masonry upper stories. The damage characteristics disclose the incompatible of the lateral resistant stiffness between the first story and the transition story. The natural frequency value 2.91Hz illustrates that this building is still very stiff even with the severe damage in the 2nd story walls, as shown in fig.18.

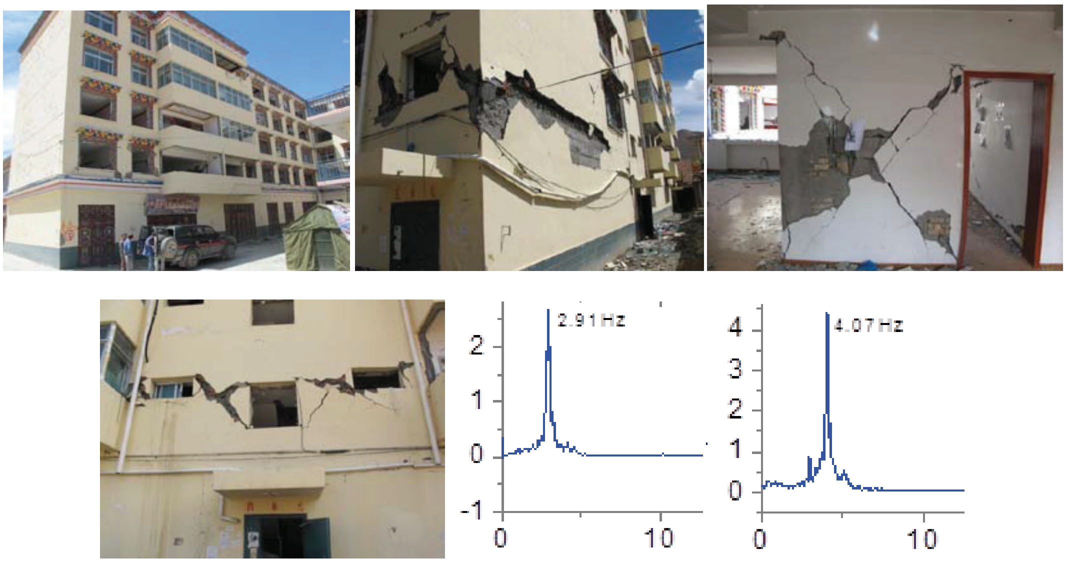


Figure 18. Damage of a 5-story BSWFSM residential building and its' NF (2.91Hz/4.07Hz) tested

3. CONCLUDING REMARKS

In summary, 5 types of building structures damaged in 2010 Yushu earthquake were tested in the field investigation. The results disclose the facts that the natural frequency testing can be used to evaluate the damage severity of the structures roughly and could be used as the basis of retrofitting design of earthquake damaged building structures. Further study also should be carried out for developing useful methods to avoid the design mistakes from the fundamental solution.

ACKNOWLEDGEMENT

The authors appreciate the financial support from the Earthquake Scientific Research Funds Program (No. 201208019) and the China National Natural Science Foundation Program (No.51078336).

REFERENCES

B. LI, W.S. LU and J.H. SHEN. (2006). Example analysis for dynamic characteristics test of high-rise buildings. *Structural Engineer,* **22(2)**, 63-66.

H.X. LIU. (1986). The Great Tangshan Earthquake Damage. Earthquake Engineering Press, Beijing, CHINA