The numerical simulation on dynamic response of Tibetan traditional stone-wood structure under earthquake action

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Abstract. Based on the existing test data obtained from preliminary study, the numerical modeling work for the characteristics of Tibetan traditional Stone-wood structure was performed in this paper. The mode of vibration and frequency were researched by modal analysis method. Meanwhile, the time history curves of displacement at different parts of structure and peak displacements were obtained after simulating the dynamic response of structure under frequent earthquakes. And the weakest parts and damage characteristics under the frequent earthquakes have been summarized. Studies showed that the shapes of displacement curves at different parts of structure were so similar that the displacement of all components reached to the peak at the same time. Finally the weakest parts of Tibetan Stone-wood structure were parapet walls with the largest peak displacement under earthquake and walls near to structural opening were easier to be destroyed than others.

1 Introduction

Because of the unique geographical position, religious culture, special climates and economic conditions of Tibet, a special stone-wood structured have been formed there [1]. The building structure is mainly composed of yellow mud and stone. Because of the poor cohesiveness of mud, irregularity of stone, deficiency of structural measures, and stones could not be vertical and horizontal bite built, the seismic performance of the housing structure is so poor that always be damaged badly under the repeated earthquakes. At present, the seismic performance of ordinary masonry structures has been researched by scholars, and they achieved certain results. But most of the rules are appropriate for the regular brick masonry, dynamic response and failure mechanism of rubble masonry under seismic studies are rarely involved, and a more systematic stone structure theory has not been formed. Therefore, based on the numerical simulation of the Tibet Lhasa surrounding rubble structure, the modal analysis have been performed in this paper, and dynamic response of Tibetan stone-wood structure have been researched. After summarizing the seismic performance, the weakest parts of structure have been presented.

2 Numerical modeling technique

A Tibetan stone-wood structure in Lhasa was selected to be the object of study. The seismic fortification intensity is 8 degrees, the designed basic seismic acceleration value is 0.20g, and the designed earthquake is grouped into the third groups. The layout of the structure is shown in figure 1, which is rectangular and with two layers.
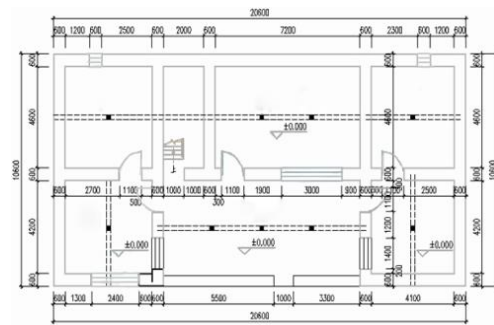
Figure 1. the floor plan of the selected stone-wood structure.

The existing constitutive relations mainly include linear type, the logarithmic function type, the polynomial type and rational fraction type [2] which are not suitable for larger rubble masonry structure. So mechanical properties data obtained from the early experimental study [3] were used in this paper. And the curve of stress-strain relationship obtained from test is shown in figure 2, of which the ascent stage is selected in modeling, shown in figure 3.
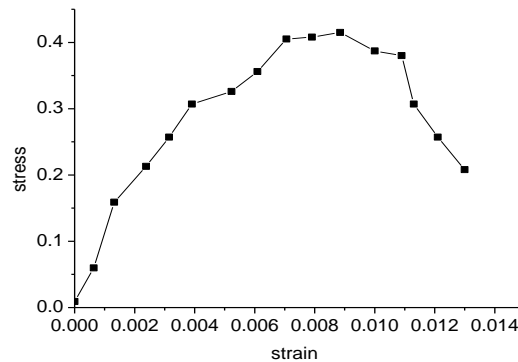

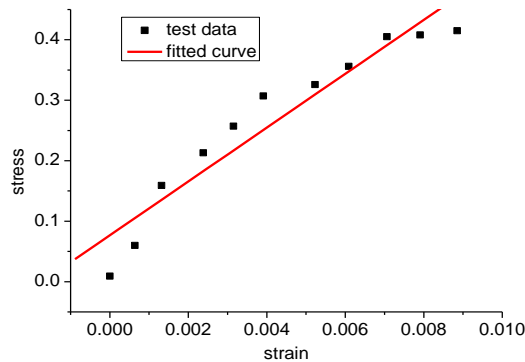Figure 2. the curve of stress-strain relationship from test.

Figure 3. the selected stress-strain relationship in modeling.

The stone masonry walls resist the vertical compressive stress σ_n and shear stress τ caused by earthquake. And the horizontal normal stress σ_x is so small that can be ignored in numerical modeling [4]. The failure criterion of masonry structure under pressure-shear condition presented in literature [5] was used in this paper, so the corresponding failure modes are shear sliding failure, tensile failure and compressive failure. At the same time, SOLID65 elements are selected to simulate the stone masonry walls in stone-wood structure and SOLID45 elements are used to simulate wood beams, columns and compound floor. The meshed model is shown in figure 4.
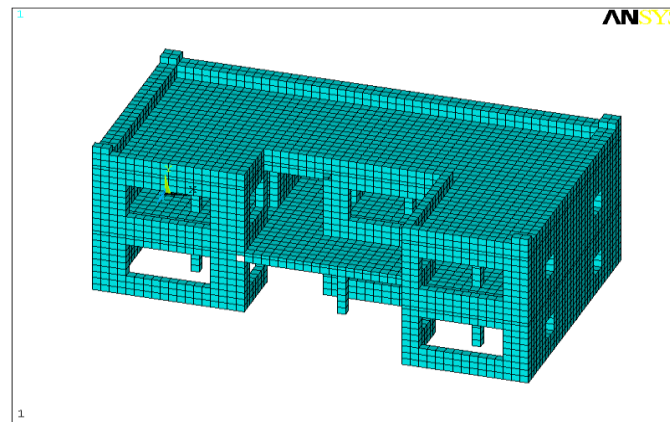
Figure 4. The meshed model.

3 Analysis of calculation results

3.1 Modal analyses

The Subspace method was chosen for the modal analysis in the paper, then the first eight orders of frequency and vibration mode of the Tibetan stone-wood structure were obtained. The first three modes as shown in figure 5 to figure 7. At the same time, the first eight vibration cycle of the Tibetan stone-wood structure are calculated and shown in table 1.

Table 1: The first eight order frequency and cycle

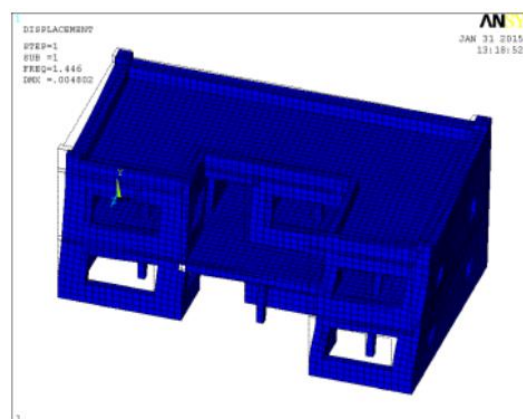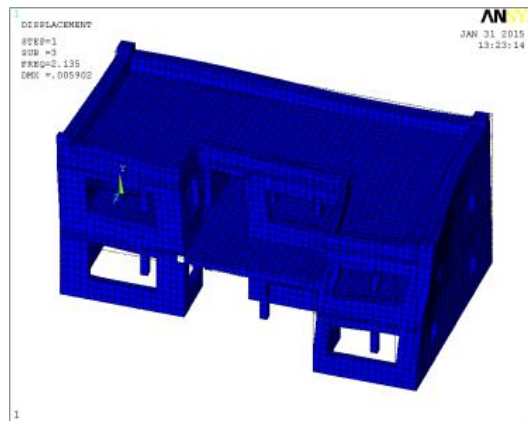| Mode of vibration	1	2	3	4	5	6	7	8
frequency	1.4458	1.7008	2.1350	2.3401	2.8540	3.3651	3.5260	3.9348
cycle	0.6917	0.5880	0.4684	0.4273	0.3504	0.2972	0.2836	0.2541

Figure 5. The first mode.
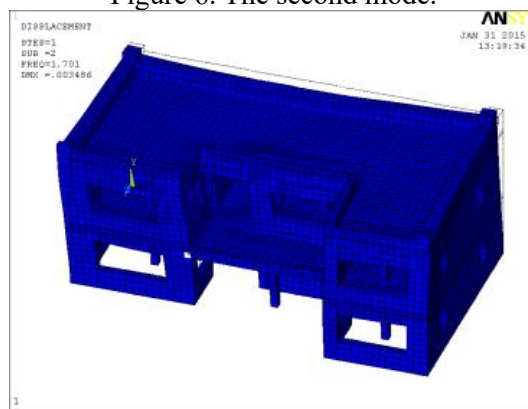
Figure 6. The second mode.

Figure 7. The third mode.

As we can see from Table 1, because the building materials and the construction technology of Tibetan stone-wood structure house are quite different from the ordinary stone masonry, the natural vibration period is 0.6917s, which differ greatly with the previous empirical formula. It can be observed from the figures that the first mode and second mode of the structure mainly translate along the X axis, from the third mode, the torsion appears, and accompanying with the vibration of the integral space. This shows that the shear deformation is still the main deformation form of the Tibetan stone-wood structure in the earthquake, accompanying with the shear deformation are the integral space vibration and torsional vibration, which are similar to the shear vibration of a cantilever beam. This is consistent with the vibration phenomenon of the common stone masonry structure obtained in the previous research. The vibration characteristics of the structure mainly depended on the stone masonry walls, so the Tibetan stone-wood structure still exhibit masonry rigidity, while the natural vibration period of the structure is relative large.

3.2 The displacement response of structure on frequent earthquake

In this paper, three standard of seismic waves were select to calculate simultaneously, such as EI-Centro wave, Taft wave and Tianjin wave, and each wave parameter is shown in table 2.

Table 2: The parameters of the seismic wave input.

Name of the earthquake	Seismic waves	magnitude	The epicenter(km)	Site category	PGA(gal)	The response spectral predominant period(s)
Imperial Valley	EL-Centro	6.3	22	II—III	341.7	0.55

| Taft Lincoln School | Taft | 7.7 | 47 | II | 175.9 | 0.44 |
| Tianjin Ninghe | Tianjin | 6.9 | 67 | III—IV | 145.8 | 0.90 |

Table 3: The displacement response of the structure under seismic wave.

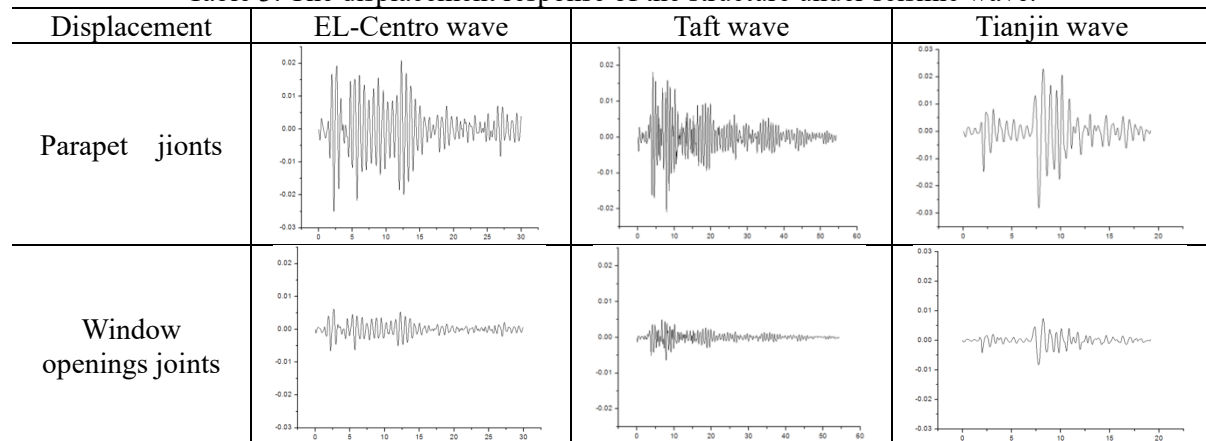| Displacement	EL-Centro wave	Taft wave	Tianjin wave
Parapet jionts			
Window openings joints			

Table 4: Maximum displacement under different seismic wave function(mm).

Displacement response	EL-Centro wave	Taft wave	Tianjin wave
First floor column joints	7.38	5.72	9.35
Second column joints	15.20	12.21	18.10
Parapet's nodes	25.00	20.88	28.00
Window openings joints	6.56	6.39	8.33
Wall between window joints	5.34	5.40	6.96

The time-displacement curves of several nodes of Tibetan-style stone-wood structure under the action of the EL-Centro, Taft, and Tianjin seismic waves were gotten in this paper, and the displacement curves of parapets and opening for windows are shown in table 3. By comparison, all parts of structure under the same seismic wave reach to the maximum displacement at the same time, and various parts of time-displacement curves roughly show the same shape. And this indicates that Tibetan stone-wood structure under seismic waves moves in one direction without tearing occurs because the movement of each component direction is inconsistent, which can be beneficial to its earthquake resistance.

Meanwhile, the maximum displacement under seismic waves are shown in table 4. The table 4 shows that the peak value of displacement of the structure under the action of Tianjin wave is the biggest one. It indicates that the displacement response of Tibetan stone-wood structures present a big difference under the action of seismic waves with the same peak acceleration and different seismic spectrum characteristics. Because the predominant periods of seismic waves are different, and the frequency of Tianjin seismic wave is the nearest to the fundamental frequency of structure, and resonating may be occurred easily, followed by EL-Centro wave and the Taft wave that their structures are not sensitive. Additionally, it can be found that the peak value of displacement appears on the parapet, presenting extreme fragile under the action of earthquakes. Opening for window walls have a slightly larger displacement than the displacement of the walls between windows at the same height. It shows that the opening for window wall is easily damaged than others at the same height. Therefore, parapets and opening for window walls belong to the weak parts of walls, which are

consistent with survey of the results of seismic damage.

4 Conclusion

This paper presents the results of the numerical modeling for the characteristics of Tibetan traditional Stone-wood structure. Based on these results and those of previous studies, the following conclusions can be drawn from this study. The numerical model used in this paper could simulate the dynamic response characteristics of Tibetan traditional stone-wood structure on the earthquake effectively. And the oscillation phenomenon of Tibetan stone-wood structure is shear oscillation, which is similar to the ordinary stone masonry structure, but the natural period of vibration is much larger. Furthermore, parapets and opening for window walls are the weak parts of walls, which should be reinforced to improve the seismic performance of Tibetan traditional Stone-wood structures.

Acknowledgements

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