# Seismic Response Analysis of Typical Rammed Earth House in Disaster Areas of Chinese Wenchuan Ms8.0 Earthquake using Finite Element Method

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**SUMMARY:**
Rammed earth houses widely distribute in rural region of Wudu city located in southern Gansu province of China. Because the city is near Sichuan province, these kinds of houses were seriously destroyed during 2008 Wenchuan Ms8.0 earthquake. The author, here, analyzed the seismic response of the typical wrecked house by means of finite element method. We found that contrast with other parts of the house, partition walls consist of adobes are easily destroyed by the horizontal shear force and displacement due to seismic loading, whereas the damage of corner and cross walls are caused by the shear force and acceleration. These damage features might have relations with the weak joints between rammed layers and different functional walls, the dangers which might cause are seldom considered carefully in traditional constructions of rammed earth houses. The numerical analysis results approve this point and provide a reasonable answer to why the houses have experienced a serious damage.

*Keywords: rammed earth house, Wenchuan earthquake, finite element method, damage*

## 1. INTRODUCTION

The straight-line distance between Wudu city and Wenchuan county is about 250km. During 2008 Wenchuan Ms8.0 earthquake, many people died and a lot of property were lost in Wudu city of Gansu province. Typical rural rammed earth houses of Gansu province mainly distributed this city, were destroyed seriously during the earthquake and collapse of these houses is the direct reason why so many people died (Xu et al, 2011).

According to results after Wang et al (2006), the great majority of strong earthquakes happened in rural region of China. Unfortunately, a large number of rammed earth houses widely distribute in the north-western region, even many new types of houses were built by government instead of these humble houses without any anti-seismic measure due to destructive earthquakes before 2008.

Based on the linear analysis of seismic response of typical wrecked houses in Wudu county of China by means of finite element method, here, we discussed the direct reason why those rammed earth houses are easy to be destroyed during this earthquake. The result is better references for the reinforcement of these rammed earth houses which still exist in the serious region and would be helpful to reduce the similar destructive damage.

## 2. DAMAGE OF RAMMED EARTH HOUSES DURING WENCHUAN EARTHQUAKE

Damage characteristics of typical rammed houses and pictures within different intensity regions of Wudu city during Wenchuan earthquake are shown as the follow.
In the region of intensity V, the crack of wall body and dropping of mud skin of earth wall are obviously caught. Although these damages could not cause rammed earth house collapsed and the

people died, the house has lost its function of use in a safe condition (see Fig. 2.1).

(a) Tiny cracks of wall (b) Mud skin dropped

**Figure 2.1.** Destruction of rammed earth house in intensity V region

In the case of intensity VI region, heavy vertical cracks appeared within wall and at joints between walls, even when these cracks crossed whole wall medium or more serious damages would happen. Some pictures of destruction with rammed earth houses in Wudu city taken just after the Wenchuan Ms8.0 earthquake are shown in Fig. 2.2.

(a) (b)

**Figure 2.2.** Vertical cracks within wall in intensity VI region

For those rammed earth houses located in the region of intensity VII, one typical example is gable wall separating from the structure of the house (see Fig. 2.3).

(a) (b)

**Figure 2.3.** Damage of rammed earth house in intensity VII region

In some special local-areas, e.g. the top of hill, the intensity could reach VIII or even IX due to field effect of ground motion. Consequently, the rammed earth house met serious damage. The field survey shows that rammed earth walls collapsed, broken and even whole house collapsed in those special areas (see Fig. 2.4).

(a) Rammed earth walls collapsed (b) Whole rammed earth house collapsed

**Figure 2.4.** Damage of rammed earth house over intensity VIII

The site survey disclosed the situation of rammed earth wall structure of interlayer contacts in Wudu city. Generally, the weak positions obviously distribute in the earth wall due to the traditional building methods (see Fig. 2.5). That might be the direct reason why rammed earth walls tend to broken into bricks in the region of intensity VIII (see Fig. 2.4b).

**Figure 2.5.** Interlayer contacts of the typical rammed earth wall in Wudu city

## 3. NUMERICAL ANALYSIS AGAINST EARTHQUAKE OF TYPICAL RAMMED EARTH HOUSE IN WUDU CITY

### 3.1. Model and parameters

The model of rammed earth house has the length, width and height of 11.6m, 3.6m and 3.6m respectively. According to the real structure of typical rammed earth houses in Wudu city, three rooms were adopted here for this computational model, in which both sides are 3.3m width and the middle is 3.6m width. Meanwhile, enclosing walls of the house model were designed as 0.5m width whereas partition walls as 0.2m (see Fig. 3.1). The roof vertical loading, 37000N/m$^2$, is evenly loaded on the top of walls. The parameters of wall are shown in Tab. 3.1.

Computational model of finite element method (FEM) was meshed by 39,500 elements with 50,076 nodes, and all elements are hexahedron with 8 nodes. Considering the complexity of dynamic response of rammed earth under earthquake, the author adopted linear method in this analysis. Analysis works of numeral calculation were completed by using of ANSYS software of Institute of Engineering Mechanics, China Earthquake Administration.

**Table 3.1.** Parameters of wall in computational model

| Materials | Density (kg/m$^3$) | Dynamic elastic modulus (Pa) | Poisson's ratio | Coherent strength (Pa) | Internal friction angle(°) |
|---|---|---|---|---|---|
| Rammed earth wall | 1485 | $1.125*10^8$ | 0.35 | $1.88*10^5$ | 14 |

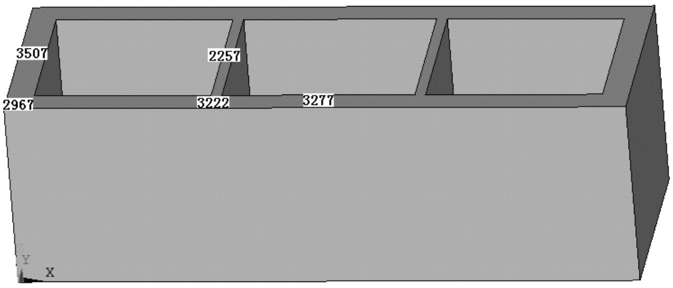
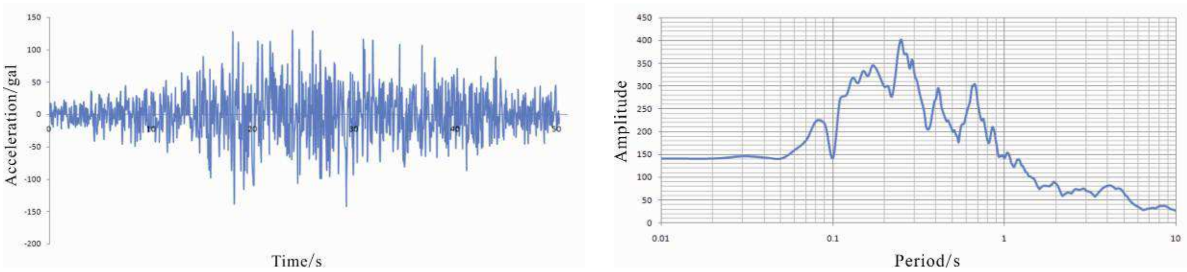



**Figure 3.1.** Computational model of FEM of typical rammed earth house in Wudu city and nedes for output acceleration record

### 3.2. Seismic loading input

During the analysis process, we adopted a real time-history of Wenchuan earthquake recorded in Wenxian county as the input loading (see Fig. 3.2a). For the target ground motion, the maximum acceleration is about 141gal and predominant period is around 0.25s (see Fig. 3.2b).



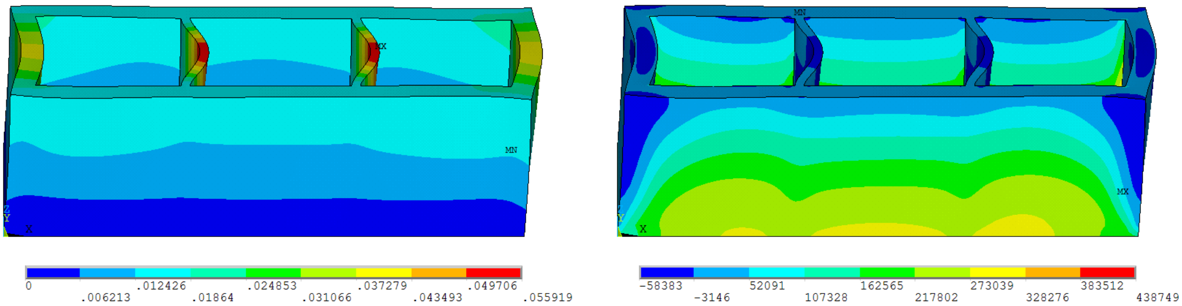

(a) Time history (b) Response spectrum

**Figure 3.2.** The record of Wenchuan earthquake in Wenxian county

### 3.3. Analysis results

*3.3.1. Response of displacement*

The analysis result discloses that all rammed earth walls move back and forth on horizontal plane and whole building structure appears shear motion response to seismic loading. Moreover, the displacement variation shows that the top of the earth wall could experience a larger deformation than the bottom, and the maximum displacement of partition walls is about 5.59cm (see Fig. 3.3a).




(a) Displacement (b) Shear stress

**Figure 3.3.** Analysis results of displacement and shear stress

*3.3.2. Response of stress*

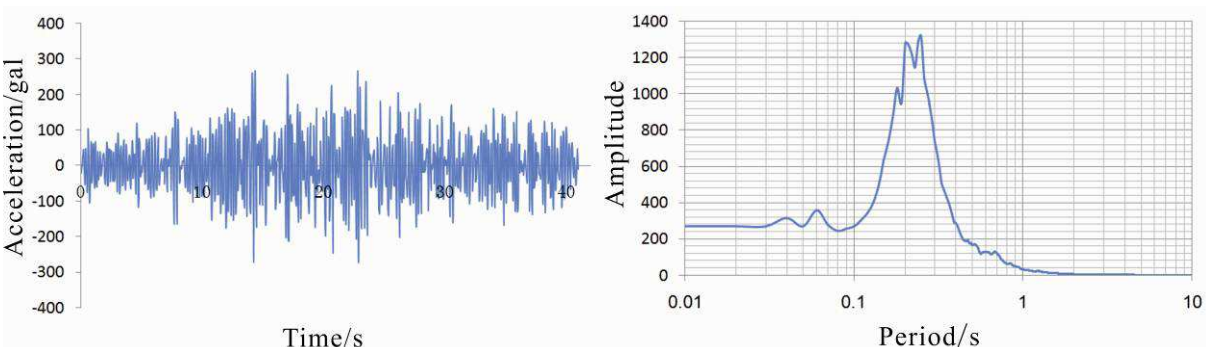
The maximum shear stress could reach 0.43MPa at the bottom of the model when whole rammed earth house experience shear movement. For partition walls, the topper is the maximum position of shear stress and for whole model, the bottom and the corners are the most dangerous places (see Fig. 3.3b).

*3.3.3. Response of acceleration*

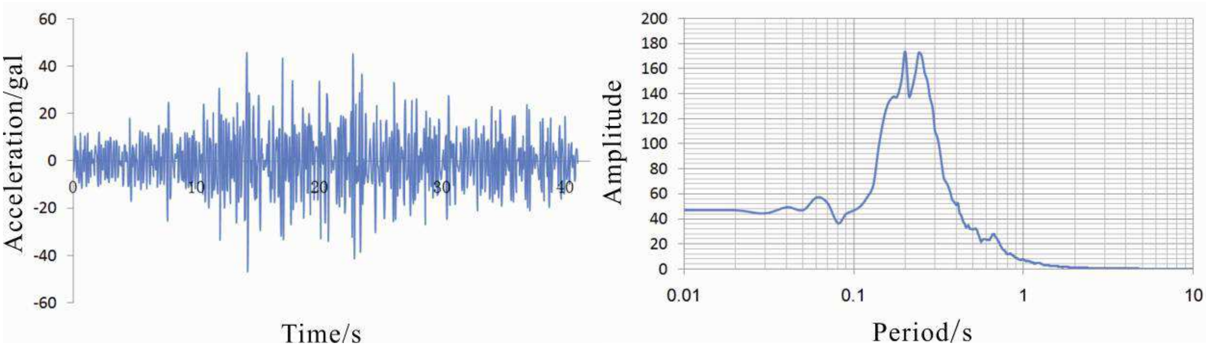
The nodes of 2257, 2967, 3222 and 3507 are acceleration record positions and respectively for the partition wall, corner wall, longitudinal wall and cross walls (see Fig. 3.1). Computational results show horizontal acceleration at the top of walls is larger than input seismic loading. According to the peak ground acceleration (PGA) records, the cross walls are more dangerous than the longitudinal walls; partition walls are more dangerous than the cross walls; and the corners are more dangerous than others (see Tab. 3.2). For acceleration spectrum, the output bandwidth become narrow, about 5Hz, compared to the input bandwidth from 1Hz to 10Hz (see Fig. 3.4). This result may have relation with the reduction of the seismic energy absorbed by the wall and in the situation the rammed earth wall works as a filter.

**Table 3.2.** PGA and predominant period of the nodes

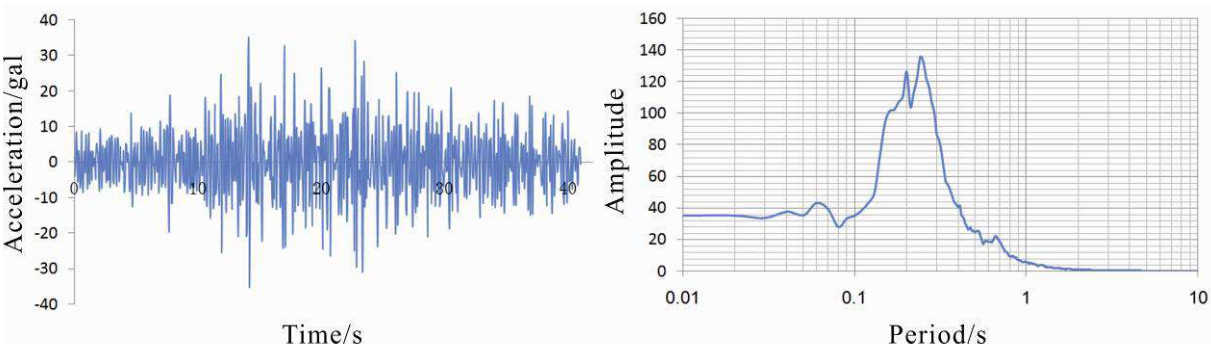
| Nodes | 2257 | 2967 | 3222 | 3277 | 3507 |
|---|---|---|---|---|---|
| PGA/Gal | 270.5119 | 46.72106 | 35.313442 | 33.07341 | 162.484681 |
| Tg/s | 0.25 | 0.2 | 0.24 | 0.2 | 0.2 |



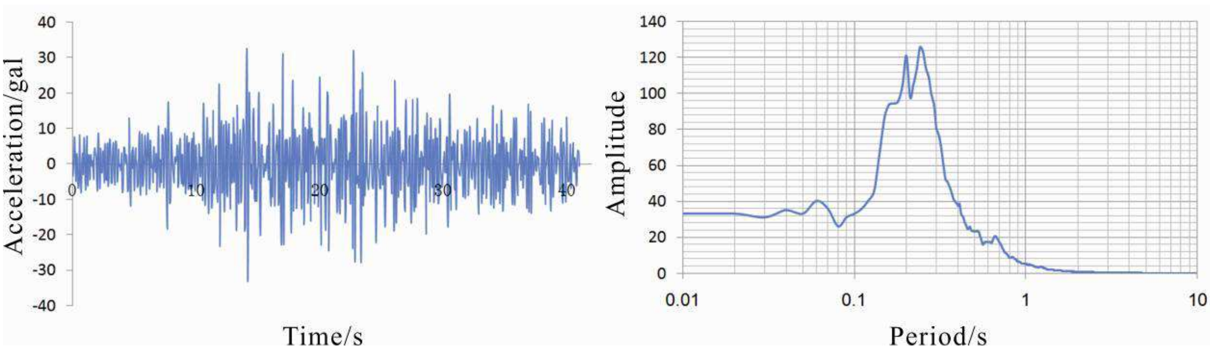

(a) Node 2257



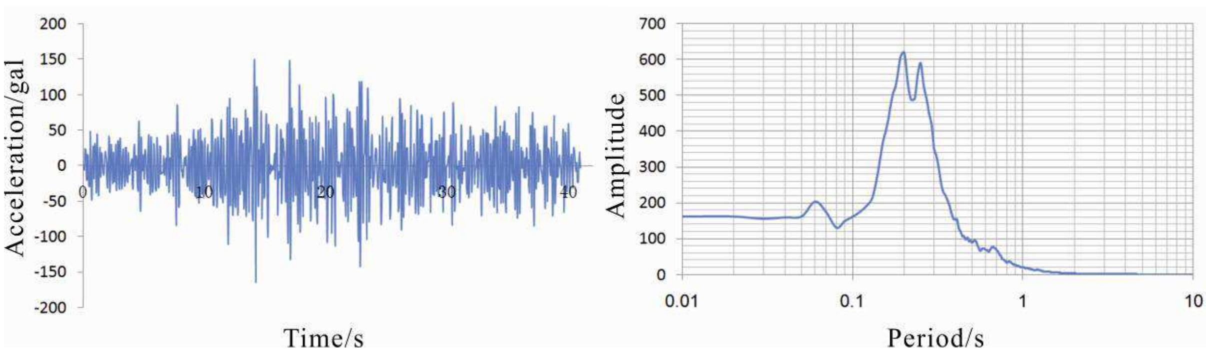

(b) Node 2967




(c) Node 3222




(d) Node 3277




(e) Node 3507

**Figure 3.4.** Time history of acceleration and spectrum at the nodes

## 4. CONCLUSIONS

The weak contacts in rammed earth wall caused by traditional constructure method are the mainly reason why whole wall broken into bricks when strong earthquake happens.
By means of numerical analysis, it is easy to understand that the top of partition walls are suffered the maximum of displacement, shear stress and acceleration. Moreover, traditional partition walls are designed thinner and destroyed seriously than other walls according to site survey. The partition walls are positions to be easily destroyed.
The corners of walls are easy to be destroyed under a moderate earthquake. More larger displacement, shear stress and acceleration are founded at the corners in analysis model. There are no contacts to be used for reiforcement at the corners between two walls in traditional construction method. The divorce of two walls is found out in common even a moderate earthquake occured.
The cross walls are easier to be destroyed than longtitudinal walls because the PGA on the top of cross walls is larger than longitudinal walls in computional model. This analysis coincides with the result of site survey.

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