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Seismic Performance Analysis of RC Frame Teaching Building in Lushan Middle School

Baitao Sun[1,2] , Zhou Huang[1, 2, a] and Peilei Yan[1,2]
[1] Institute of Engineering Mechanics, China Earthquake Administration, Harbin 150080, China;
[2] Key Laboratory of Earthquake Engineering and Engineering Vibration,
China Earthquake Administration,Harbin150080, China.
[a]iem2014@126.com

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Abstract. This study analyzes the time–history subject to the teaching buildings who had the framework structures in Lushan middle school. The main parts of the framework structures suffered a little damage but their infilled walls were damaged severely in Lushan Earthquake. The study introduces the general background information of Lushan middle school as well as the method of modeling, at the same time we select the constitutive relation of the structure and input ground motions which is used to analyze. Then the average tension damage of the infilled walls on every floor and their storey drifts were calculated. It shows that the main body of teaching buildings which was built according to the new specifications after Wenchuan earthquake have the good seismic performance, however their infilled walls which were built by the specifications would be damaged severely.

Introduction

Reinforced concrete frame is characteristic of flexible arrangement of columns and easy construction which is widely used as teaching buildings, residential buildings and marketplaces. However, in the previous earthquakes, reinforced concrete frame is one of the building types which is severely damaged due to easily stress concentration, lateral rigidity shortage and low bearing capacity. A large number of casualties will occur once these buildings are badly damaged in earthquakes because that they are highly populated places as a result of their functions. Moreover, teaching places are often used as places for earthquake relief. It will have a bad effect on earthquake relief if they are damaged.

After Wenchuan earthquake in 2008, the rebuilt reinforced concrete frame buildings were built in accordance with the new seismic fortification standards, whose aseismic capacity increased compared with those before. And Lushan earthquake occurred on April 20, 2013 with the magnitude 7.0 who was a test about the anti-seismic ability of the rebuilt buildings. It can provide basis for further study to failure mechanism and seismic capacity of reinforced concrete frame by summarizing its failure characteristics.

This paper studied the seismic performance of the teaching building in Lushan middle school by time history method. In this article, the finite element model was built, then ground motions with different intensity were input to find characteristic performance of the teaching building so as to provide reference for structure design and further research

Introduction to the teaching building in Lushan middle school

Basic information. Lushan middle school is located in Lushan County, Sichuan Province, who was built in July 2009. The teaching building has 4 floors, and the height of each floor is 4.2 meters. The building is 48.9 meters long and 9.9 meters wide, and it has 10 spans along the long side and 2 spans along the short side. Each floor of the teaching building has a bathroom and 4 classrooms, while the staircase is located in the corner of the building and the bathroom is just next to the staircase, which is shown in Fig. 1.

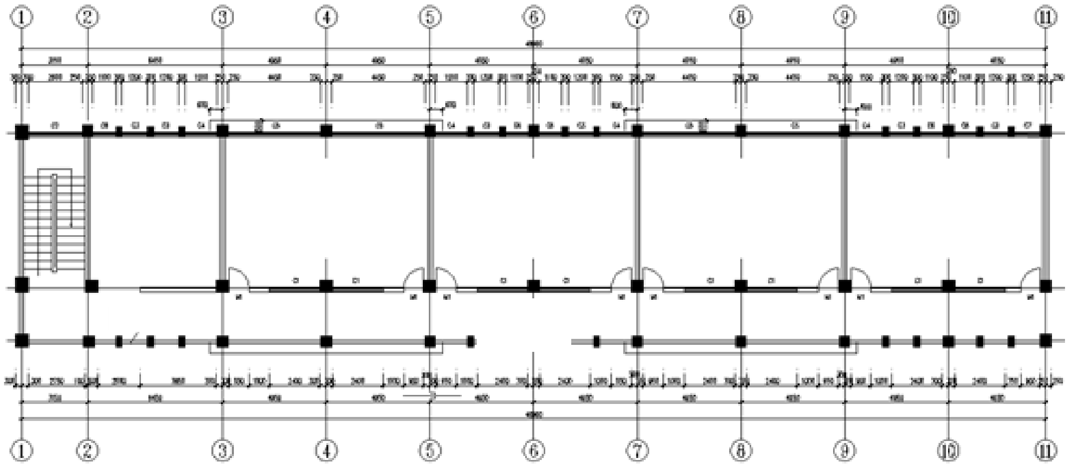

Fig. 1 Typical floor of teaching building in Lushan middle school

Building materials. The main body of the reinforced concrete frame was built with C30, while the longitudinal reinforcement of the beams and columns used HRB400 and the stirrups used HRB335 and HPB300. The floor was made of C30 and CRB550, and the infilled wall was made of perforated brick of shale with MU10 in strength, while composite mortar were used to make bricks together.

Seismic damage. Lushan middle school was in the intensity area of VIII degree in Lushan earthquake while minor damage happened to the main structure of the building, and severe damage to the infilled walls with oblique cracks, cross-slope cracks, and even plane collapse [1]. As is seen in Fig. 2.

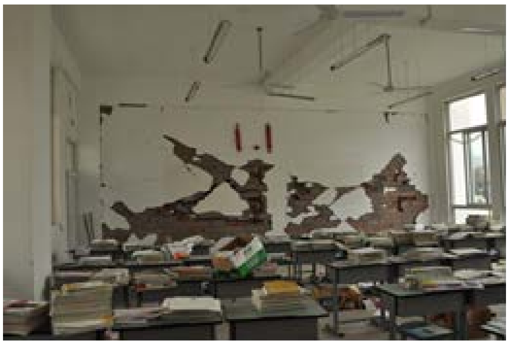

Fig. 2 Seismic damage of the teaching building in Lushan middle school

Numerical modeling and time-history analysis

Dimension. This paper uses International System of Units when using the software ABAQUS to build the finite element model of the teaching building, which is shown in Table 1.

Table 1 Dimension for ABAQUS modeling

Unit	Length	Time	Force	mass
Dimension	Meter(m)	Second(s)	Newton(N)	Kilogram(kg)

Element types and connection modes. The finite element model of this paper is established according to the actual structure. The element types of each component in the model is shown in Table 2. The connections of each component is shown in Table 3.

Table 2 Element types of components in the model

Element types		Components
Solid	C3D8R	Beams and columns
Shell	S4R	Floors and filler walls
Surface	SFM3D4	Rebar

Table 3 Connection modes of components in the model

Parts	Way of connecting
Main body structure and floors	Tie
Main body structure and filler walls	Coupling
Main body structure and raber	Embedded

Constitutive relation. The constitutive relation of concrete and steel used in the analysis is mainly from the appendix 3 of Code for Design of Concrete Structures (GB50010-2010) [2]. The mathematical model of the constitutive relationship is authoritative because it is based on the statistical analysis of experiment and theoretical research. This paper uses integral model which joins bricks and mortar together to simulate the infilled walls with the masonry constitutive relation propose by Professor Guiqiu Liu [3].

Ground motion. The ground motion for input is directly affect the result of time-history analysis. Academician Xie Lili and others put forward the concept of the severest design ground motions which used comprehensive estimation about damage potential of ground motion. Base on the research results of the severest design ground motions, 4 short-period ground motion records were selected from the literature [4], as is shown in Table 4. The ground motions is shortened as Northridge, El79, El40 and Westmorland. And the 4 records are input to the model for time-history analysis in order to select the one that has the greatest impact on the structure.

Table 4 Details of the ground motion records

Site type	Time	Name	Station	Component
I	1994	Northridge	LA - Griffith Park Observatory	270 and 360
II	1979	Imperial Valley	El Centro Array #10	50 and 320
III	1940	Imperial Valley	El Centro Array #9	EW and NS
IV	1981	Westmorland	Westmorland Fire Station	90 and 180

According to the standards, the range of 15 seconds is taken from each ground motion record [5] [6]. It can be seen that the intercepted ground motions can reflect the characteristics of the original ground motions by comparing the acceleration response spectrums of the intercepted ground motions and the original ground motions. The intercepted ground motions are input to the model along the two perpendicular directions in the horizontal plane. The amplitudes of the intercepted ground motions were adjusted 0.15g, and the ratio of the peaks of the two directional components is 1: 0.85 for each ground motions [5].

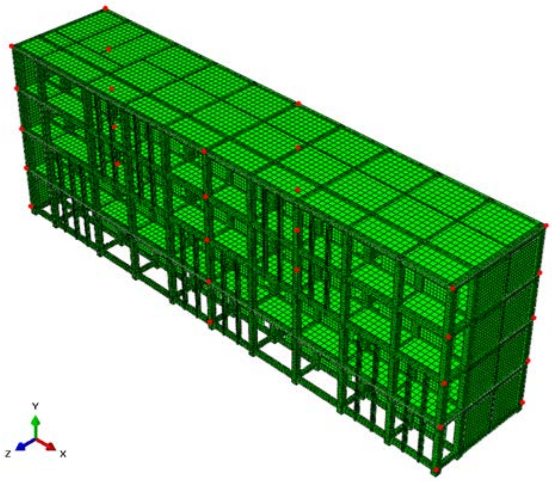

Fig. 3 Points used for extracting storey drift angle of the teaching building in Lushan Middle School

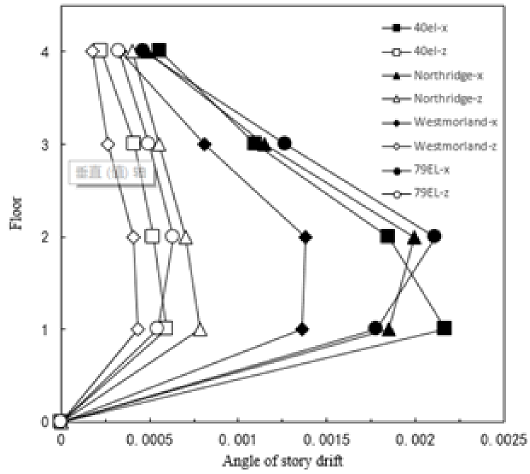

Fig. 4 Storey drift angle of X to the structure

The deformation of the structure is represented by the storey drift angle which is calculated from the displacement of the points selected on each floor as is shown in Fig. 3. And the result is shown in Fig. 4.

It can be seen that the largest seismic response of the structure occurred when the 40El ground input. Therefore, 40El is chosen as input ground motion for the following time-history analysis.

Time-history analysis. The maximum acceleration of 40El is adjusted to the peak acceleration of frequent earthquake, design earthquake, rare earthquake, super-rare earthquake corresponding to the seismic fortification intensity which can be seen in Table 5.

Table 5 Peak earthquake acceleration of input ground motions

Earthquake scale	Frequent earthquake	Design earthquake	Rare earthquake	Super-rare earthquake
Acceleration	$55\,cm/s^2$	0.15g	$310\,cm/s^2$	0.4g

The storey drift angle in both directions of X and Z are output, and the X-to-storey drift angle are much larger than that in the Z direction. Therefore, the X-storey drift angle is used to represent the damage of the structure. And the average tension damage of the infilled walls on each floor which is shown in Fig.5 is used to measure the damage of those infilled walls.

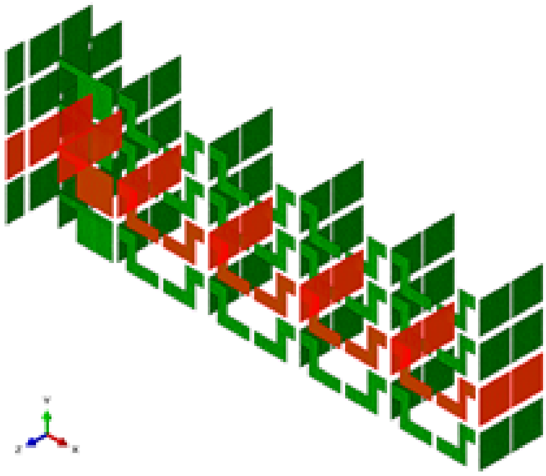

Fig. 5 Infilled walls used to calculate the average tension damage of each floor

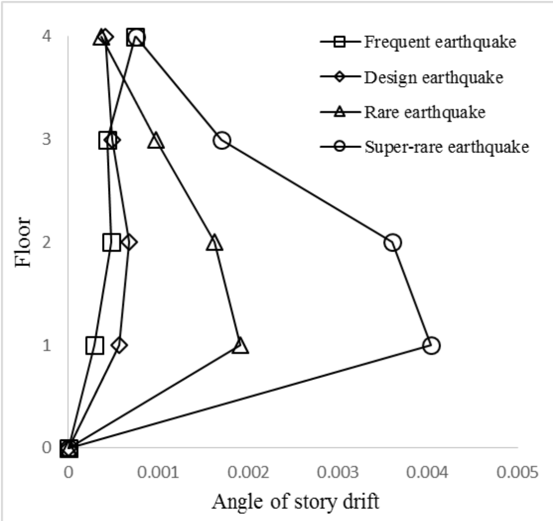

Fig. 6 Storey drift angle

Results. The results of the time history analysis are shown in Fig. 6 and Fig. 7. The result in Fig. 6 shows that in the event of frequent earthquakes and design earthquakes, the deformation of the main structure is small. While in the event of rare earthquakes and super-rare earthquakes, the deformation of the main structure increased greatly, but still within the limit.

The result in Fig. 7 shows that the maximum value of the tension damage of the infilled is 0.138 in the case of frequent earthquake. When design earthquake occurs, the maximum value is 0.276. When the structure is subjected to rare earthquake, the tension damage of the infilled walls obviously increased, and the maximum value reaches 0.680. When the structure encounters super-rare earthquakes, the maximum value of tension damage reaches 0.798.

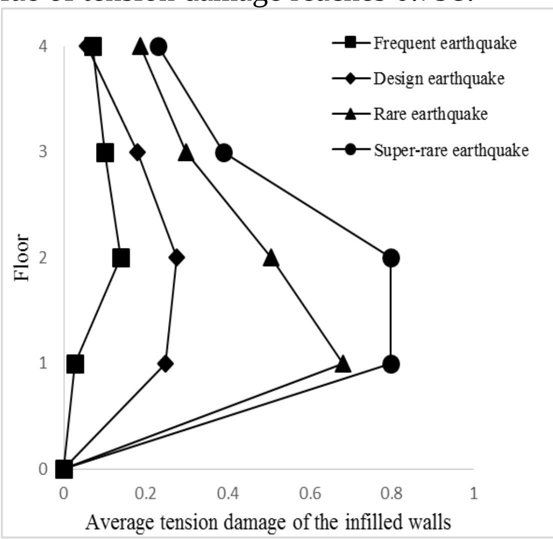

Fig. 7 Average tension damage of filler walls in each floor

Moreover, the infilled wall on second floor would damage more seriously than those on first floor if frequent earthquake and design earthquake happen, while those on first floor would damage most seriously if rare earthquake and super-rare earthquake encounter.

The filling walls built with perforated bricks are damaged slightly in the event of frequent earthquakes and design earthquakes, while those are seriously damaged or even completely destroyed in the event of rare earthquakes and super-rare earthquakes.

Summary

The analysis about the seismic performance of the teaching building in Lushan middle school shows that the main structure of the reinforced concrete frame built according to new standards has good seismic performance, which can withstand even the rare earthquakes and super-rare earthquakes, but the infilled walls of the building are so weak that being severely damaged and even destroyed.

In addition to the function of enclosure and interval, the infilled wall who is an important part of the framework, is part of seismic fortification lines for consuming the energy of earthquakes. Besides serious damage to the wall can affect the normal use of the building, resulting in a great loss of property or even casualties. Therefore, a reasonable setting of the filling wall can not only protect the main body of the frame, but also to minimize the damage of itself. Further research for reasonably setting of the infilled walls is needed.

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