The influence of construction measurement and structure storey on seismic performance of masonry structure

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Abstract. The damage of masonry structures in earthquakes is generally more severe than other structures. Through the analysis of two typical earthquake damage buildings in the Wenchuan earthquake in Xuankou middle school, we found that the number of storeys and the construction measures had great influence on the seismic performance of masonry structures. This paper takes a teachers' dormitory in Xuankou middle school as an example, selected the structure arrangement and storey number as two independent variables to design working conditions. Finally we researched on the seismic performance difference of masonry structure under two variables by finite element analysis method.

1 Introduction
Earthquake is one of the world’s largest natural disasters that endangers human life and property, and China is one of the countries in the world with a frequent occurrence of earthquakes, there are more than 600 times six and above magnitude earthquake occurred in the Twentieth Century in China. The Wenchuan earthquake in May 12, 2008 was the most serious earthquake since the Tangshan earthquake in 1976, which had wide range of seismic impact and highly destructive.

In this earthquake, the earthquake damage on the teachers’ dormitories were different, the destruction of middle school teachers’ dormitory in the northwest corner of school, students dormitories and the teaching building appeared different seismic performance. This was caused by the difference between the design and construction and the arrangement of the structural measures. In this paper, we selected the five storeys Xuankou middle school teachers’ dormitory as an example to study on the influence of the arrangement of structural measures and the number of storeys on the seismic performance of masonry structures and calculated the percentage of amplitude effect.

2 Xuankou middle school teachers’ dormitory earthquake damage
Yingxiu town was located in Sichuan, Wenchuan Province, which was the epicenter of the Wenchuan earthquake. Xuankou middle school was located in strong earthquake area of 11 seismic intensity degrees. The case with different storeys and structural measures in the earthquake were reflected more obvious than before, there were two buildings which had the same design drawings, the only difference was one building was five storeys and another was four. The comparison of the two earthquakes damage case was shown as follows:
Figure 1. The earthquake damage of Xuankou five storeys middle school teachers’ dormitory.

Figure 2. The earthquake damage of Xuankou four storeys middle school teachers’ dormitory.

Figure 3. The earthquake damage of Xuankou middle school students’ dormitory.

Figure 4. The earthquake damage of Xuankou middle school teaching building.

Figure one had five storeys, the underlying had serious damage and cross gable crack that extended to the vertical walls. In the upper storeys, the wall under the windows and the wall between windows had cross damage too. The bottom of the vertical wall had serious damage in figure two, but did not lose the carrying capacity of the structure. The structure in figure three had been obviously collapsed with cross wall damage of each storey. The bottom storey had been collapsed too, the weak area in each storey collapsed and lack of storey yield. Figure four was teaching building, the seismic damage was characterized by the complete collapse of the bottom. In addition, the foundation and the structure had been collapsed.

The case above was not special, many earthquake damage examples also proved that the degree of damage in masonry structure was proportional to the number of storeys and the area of equal intensity. The higher the number of storeys, the more serious the damage. In addition, the stronger the structural measures, the higher the seismic intensity decreases was. Therefore, this paper studied the two parameters which affected the seismic performance of masonry structure and obtained the regularity results.

3 The designed working conditions based on the structure of teachers’ dormitory

Most of Xuankou middle school buildings were designed and constructed in 2006 according to the GB50011-2001 version of “code for seismic design of buildings”. The earthquake caused a large number of casualties [1] because the intensity of this earthquake was 11 degrees. Although this model...
we selected was designed based on the seven degree fortification, but the evaluation of the actual seismic structural measures and the seismic fortification condition had achieved 9 degrees, this was one of the reasons for the smaller damage. The following figure was the single unit of the structure plan of the layout of the teachers’ dormitory, the red part was the constructional column position.

![Figure 5. The layout of the teachers’ dormitory.](image)

With considering the storey numbers and the details of Multi-storey Masonry Buildings as the two variables, we proposed storey number N from three to five, arranged the constructional column and ring-beam for Multi-storey Masonry Buildings by referring the 89 version\(^2\), 01 version\(^3\) and the 10 version\(^4\) of seismic code, combined with the above factors we designed various conditions in the following tables:

### Table 1. The constructional column layout based on 89 specifications.

| 89version (storey column numbers) | 6 degree (Ring beam arranged interstorey) | 7 degree (Ring beam arranged interstorey) | 8 degree (Ring beam arranged interstorey) | 9 degree (Ring beam arranged interstorey) |
|-----------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|
| three storeys                     | 10                                        | 26                                        | 26                                        | 57                                        |
| four storeys                      | 18                                        | 26                                        | 31                                        | 57                                        |
| five storeys                      | 18                                        | 31                                        | 47                                        |                                            |

### Table 2. The constructional column layout based on 01 specifications.

| 89version (storey column numbers) | 6 degree (Ring beam arranged each storey) | 7 degree (Ring beam arranged each storey) | 8 degree (Ring beam arranged each storey) | 9 degree (Ring beam arranged each storey) |
|-----------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|
| three storeys                     | 10                                        | 26                                        | 26                                        | 57                                        |
| four storeys                      | 18                                        | 26                                        | 31                                        | 57                                        |
| five storeys                      | 18                                        | 31                                        | 47                                        |                                            |

### Table 3. The constructional column layout based on 10 specifications.

| 89version (storey column numbers) | 6 degree (Ring beam arranged each storey) | 7 degree (Ring beam arranged each storey) | 8 degree (Ring beam arranged each storey) | 9 degree (Ring beam arranged each storey) |
|-----------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|
| three storeys                     | 22                                        | 30                                        | 35                                        | 69                                        |
| four storeys                      | 30                                        | 30                                        | 35                                        | 69                                        |
| five storeys                      | 30                                        | 35                                        | 69                                        |                                            |
In order to measure the number of constructional columns in the relative area of the structure, we proposed the concept of constructional column coefficient $\lambda$, which was defined as the ratio of the number of columns in the area per unit area.

$$\lambda = \frac{N}{\sum F_K}$$

In this formula, $N$ was the number of columns in each storey. $\sum F_K$ was effective cross-sectional area of vertical walls, this model was 492247cm$^2$.

|            | $\lambda$ based on 6 degree fortification intensity | $\lambda$ based on 7 degree fortification intensity | $\lambda$ based on 8 degree fortification intensity | $\lambda$ based on 9 degree fortification intensity |
|------------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|
| three storeys | 0.3658 | 0.5282 | 0.6095 | 0.5282 | 0.7110 | 1.1580 | 1.4017 |
| four storeys   | 0.3658 | 0.6095 | 0.5282 | 0.6095 | 0.6298 | 0.7110 | 1.1580 | 1.4017 |
| five storeys   | 0.5282 | 0.6095 | 0.6298 | 0.7110 | 0.9548 | 1.4017 |

### 4 Finite element analysis results

After working condition was designed, we used software ABAQUS6.10 to create finite element model, inputted acceleration time-history curve of El-Centro ground motion record recorded by Imperial Valley El-Centro station according to the paper “Study on the most unfavorable design ground motion” [5]. Then we adjusted ground motion amplitude according to the 6 degree acceleration amplitude 0.05g, 7 degrees 0.1g, 8 degrees 0.2g and 9 degrees 0.4g for loading and extracted the maximum storey drift angle for analysis, the results were as follows:

| $\lambda$ | 0.05g | 0.1g | 0.2g | 0.4g |
|-----------|-------|------|------|------|
| 0.05g     | 0.00024 | 0.00047 | 0.00109 | 0.001081 |
| 0.1g      | 0.000023 | 0.00033 | 0.00007 | 0.001056 |
| 0.2g      | 0.000022 | 0.00039 | 0.000062 | 0.00232 |
| 0.4g      | 0.000020 | 0.00038 | 0.000051 | 0.00169 |

Table 5. The Xuankou middle school teachers’ dormitory (three storeys) storey draft angle.

| $\lambda$ | 0.05g | 0.1g | 0.2g | 0.4g |
|-----------|-------|------|------|------|
| 0.05g     | 0.000345 | 0.000651 | 0.001128 | 0.007093 |
| 0.1g      | 0.000321 | 0.000588 | 0.001198 | 0.008893 |
| 0.2g      | 0.000345 | 0.000624 | 0.001144 | 0.003407 |
| 0.4g      | 0.000322 | 0.000628 | 0.001123 | 0.002417 |

Table 6. The Xuankou middle school teachers’ dormitory (four storeys) storey draft angle.

The calculation results of three storeys and four storeys structure shown that when the PGA was 0.05g, 0.1g and 0.2g, the structure storey drift angle was changing in a linear fashion. After the material entered the plastic section, the storey drift angle increased abruptly. Because the deformation of plastic section was more meaningful for analysis, so we just picked PGA0.3g, 0.4g, 0.8g for loading when we calculated the five storeys structure, the results were shown as follows:
Table 7. The Xuankou middle school teachers’ dormitory (five storeys) story drift angle.

| λ (g) | 0.3658 | 0.5282 | 0.9548 | 1.1580 | 0.4469 | 0.7110 | 1.0564 | 1.4017 |
|-------|---------|---------|---------|---------|---------|---------|---------|---------|
| 0.3g   | 0.012003 | 0.011653 | 0.00591 | 0.003669 | 0.007923 | 0.008953 | 0.001331 | 0.001188 |
| 0.4g   | 0.014513 | 0.013211 | 0.012561 | 0.007543 | 0.01504  | 0.011896 | 0.002798 | 0.001463 |
| 0.8g   | 0.098647 | 0.049018 | 0.094292 | 0.012561 | 0.03097  | 0.005706 | 0.00549  |         |

The following figures were the story drift angle under various working conditions:

**Figure 6.** Three storeys structure story drift angle.

**Figure 7.** Four storeys structure story drift angle.

**Figure 8.** Five storeys structure story drift angle.

**Figure 9.** The story drift angle in different storeys under different working conditions.

As shown in the above chart and figures, with the peak ground acceleration (PGA) increased, story drift angle increased too. The structure was in elastic state before the PGA reached to 0.3g, when PGA reached to 0.4g or higher, the structure was moderately or severely damaged, almost all of the low fortification condition achieved the collapse limit values of the story drift angle in this condition. The result of different storeys with same PGA also shown that the influence of the number of storeys on the story drift angle was small in the elastic range, basically in the same story drift angle performance level, when PGA was 0.4g, the maximum story drift angle in three storeys was 0.010813, the four was 0.011773, and the five was 0.014513, the growth rates were 8.87% and 23.17%, respectively. More information was shown in the following table 8:
Table 8. The increase of storey draft angle in different storeys.

| λ    | 0.3658 | 0.4469 | 0.5282 | 0.711 | 0.9548 | 1.0564 | 1.158 | 1.4017 |
|------|--------|--------|--------|-------|--------|--------|-------|--------|
| Storey four to three |       |        |        |       |        |        |       |        |
|       | -34.40% | -31.76% | -15.78% | 14.29%  | 46.43%  | 46.89%  | 42.76% | 44.42%  |
| Storey five to four | 104.61% | 178.09% | 48.55% | 95.75% | 268.71% | 41.55% | 212.11% | 9.20% |

5 Summary
This article analysed the time history of different construction measures and different storeys of the masonry structure by using ABAQUS finite element software, obtained the data of storey drift angle and the percentage difference of the storey drift angle under different storeys. Through the above research, the conclusion was summarized as follows:

In the elastic deformation stage of the masonry structure, the impact of the construction measures on the seismic performance of the structure was negligible. Because of the large stiffness of the Fortified masonry, the self-oscillation period was small, so the structure self-oscillation period was the same as the peak of the reaction spectrum, which exacerbated the impact of the earthquake damage. This phenomenon caused the reduction coefficient of the constructional column coefficient was varies abide by concave function in different peak acceleration condition.

With the same number of storey and the same PGA, in the elastic section of the structure, the influence of the number of storeys on the storey draft angle was small and basically in the same storey angle performance level. When the structure entered the plastic deformation segment, the higher the storey, the more rapidly increased of the storey draft angle and it was at different levels of damage performance. When the PGA reached to 0.4g, the maximum value of the storey draft angle was 0.010813, the four storey was 0.011773, and the storey five was 0.014513, which increased by 8.87% and 23.17%, respectively.

With the construction measures in the same storey increased, the storey draft angle increased too, we can see that the higher the storey, the more serious the seismic performance of masonry structure. The storey factor had greater influence on the seismic performance of masonry structure when the seismic fortification was low and when the PGA of ground motion was more than 0.4g.

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