Vulnerability Analysis Based on Ground Motion Intensity Parameters

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Abstract. Based on the ground motion intensity parameters PGA and Sa, this paper conducts a comparative analysis of the vulnerability of the Guangyue building's wooden structure. The results show that under the same earthquake intensity, the existence of a high platform will increase the probability of damage to the Guangyue building's wooden structure; PGA is used as an earthquake When evaluating dynamic strength parameters, the probability of evaluating the structure to reach each limit state is large, that is, the possibility of the structure exceeding various limit states is large, and the result is conservative, which is more conducive to ensuring the safety of the structure.

Keywords. Earthquake, intensity parameters, vulnerability.

1. Introduction
Guangyue Tower is located in the center of the ancient city of Liaocheng City, Shandong Province. It was completed in the 7th year of Hongwu in the Ming Dynasty (AD 1374). It was named the three famous buildings in China along with Yueyang Tower and Yellow Crane Tower. Guangyue Tower was rated as "National Key Cultural Relics Protection Unit". The Guangyue Tower is a four-fold eaves Xieshan cross-ridge cross-street pavilion, which is composed of a high platform base and an upper wooden structure.

Based on this theory, Gang Lu [1-4] studied the seismic vulnerability of steel frame structures and reinforced concrete frame structures, and proposed a series of analysis theories for related fields. Pan Yi [5] and others analyzed the anti-seismic capacity of ancient buildings and established a fuzzy relationship to predict the possible damage. Chen Ping [6] took Xi’an Bell Tower as an example and proposed a method for quantitative assessment of seismic risk of ancient buildings with wooden structures. Gao Dafeng [7-8] established the finite element model of the arrow tower based on the shaking table test of the Yongningmen arrow tower model in Xi'an, and conducted research and analysis on the vulnerability of multi-story timber structure ancient buildings under multiple earthquake intensity parameters.

At present, the research on the seismic performance of ancient building wooden structures is mainly based on experimental methods to quantitatively study its dynamic characteristics and seismic response. There is little analysis of the damage probability of ancient building wooden structures and the post-earthquake loss of cultural relics. The earthquake risk of ancient building wooden structures The evaluation system is not perfect. This paper takes Guangyue Building in Liaocheng City as the research object, analyzes the vulnerability of the structure under different earthquake intensity parameters, discusses the strength parameters suitable for the vulnerability analysis of Guangyue
Building’s wooden structure, and considers the impact of high platform foundation on the vulnerability of wooden structures.

2. Vulnerability Analysis Based on $Sa$ Ground Motion Intensity Parameters

Based on the linear regression analysis of all discrete points obtained in [9], the vulnerability curve of the structure when $Sa$ is used as the ground motion intensity parameter is drawn. The wooden structure is shown in figure 1(a), and the overall structure is shown in figure 1(b). As shown. The numbers 1~5 indicate the five structural failure states: basically intact, slightly damaged, moderately damaged, severely damaged, and collapsed; The OP, IO, LS and CP curves respectively represent the probability curves of exceeding the structure with slight damage, medium damage, severe damage and collapse.

![Seismic vulnerability curve of wooden structure](image1a)

![Seismic vulnerability curve of overall structure](image1b)

**Figure 1.** Vulnerability curve of structure under $Sa$ parameter.

It can be seen from figure 1(a) that in the interval of $0 \leq Sa \leq 0.25$ g, the wood structure of Guangyue Tower mainly suffers slight damage. When $0.25$ g$\leq Sa \leq 0.75$ g, the probability of moderate damage to the wood structure gradually increases to $Sa=0.1$ g. The probability of serious damage to the wooden structure at 0.1g is still less than 20%. When the $Sa$ peak value increases to 2.0 g, the probability of exceeding the CP curve, that is, the wooden structure collapsing, is almost zero; for figure 1(b), the same earthquake. The probability of damage to the wood structure under dynamic strength increases. When $Sa=0.25$ g, the probability of minor damage exceeds 40%, and when $Sa=1.0$g, the probability of serious damage to the structure exceeds 50%.

In the vulnerability curve of the wood structure and the overall structure considering the high platform foundation, the exceeding probability of each limit state increases with the increase of the ground motion intensity, but under the same $Sa$, the exceeding probability of the overall structure is always greater than that of the wood The probability of exceeding the structure.

3. Vulnerability Analysis Based on $PGA$ Ground Motion Intensity Parameters

In the same way, the vulnerability curve is drawn for all the discrete points analyzed and calculated in the literature [9], as shown in figure 2(a), and the seismic vulnerability curve of the overall structure is shown in figure 2(b).

![Seismic vulnerability curve of overall structure](image2a)

It can be seen from figure 2 that both structures are prone to slight damage. When the $PGA$ is 0.1 g, the probability of the two structures exceeding the slight damage (OP curve) has exceeded 90%; when the $PGA$ is between 0.2 g and 0.5 g, the structure mainly has moderate damage, and the probability of other damage is small. When the $PGA$ reaches 0.5 g, the probability of serious damage to the overall structure is 30%; when the $PGA$ is between 0.5g and 0.8g, the probability of the structure exceeding the IO line has been over 90%, the structure mainly suffers moderate damage and severe damage. When the $PGA$ reaches 0.8 g, the probability of serious damage has reached 70%; the probability of
The collapse of the two structures under earthquake action is not high. When the PGA exceeds 0.8 g, the probability of structure collapse is less than 2%.

![Vulnerability curve of structure under PGA parameters.](image)

(a) Seismic vulnerability curve of wooden structure  
(b) Seismic vulnerability curve of overall structure

**Figure 2.** Vulnerability curve of structure under PGA parameters.

In the vulnerability curve of the wood structure and the overall structure considering the high platform foundation, the exceeding probability of each limit state continues to increase with the increase of the ground motion intensity, but under the same PGA, the probability of exceeding the overall structure is always greater than that of the wooden structure.

4. Analysis of Vulnerability Matrix Based on Sa and PGA

According to the "Code for Seismic Design of Buildings" [10], it is known that the PGA of the structure in the 7-degree (0.15 g) area under frequent earthquakes, fortification earthquakes and rare earthquakes, the corresponding PGA values are 55 cm/s², 150 cm/s² and 310 cm/s²; The horizontal earthquake influence coefficient corresponding to the 7 degree (0.15 g) area in the code is drawn. The horizontal earthquake influence coefficient curve of the 7 degree (0.15 g) area frequently encountered earthquakes, fortified earthquakes and rare earthquakes is drawn, as shown in figure 3, and three corresponding peak values of Sa under the level of seismic fortification requirements are 0.087 g, 0.254 g and 0.541 g respectively.

![Earthquake influence coefficient curve.](image)

**Figure 3.** Earthquake influence coefficient curve.
According to the vulnerability curve, we can find out the probability of exceeding the three earthquake levels of the structure, and compare the vulnerability matrix represented by the two parameters, as shown in table 1.

**Table 1.** Vulnerability matrix based on $Sa$ and $PGA$ for the structure of 7 degree (0.15g) area.

| Structure          | Earthquake level | $Sa$ (g) | Limit state | $PGA$ (g) | Limit state |
|--------------------|------------------|---------|-------------|-----------|-------------|
|                    |                  | OP      | IO          | LS        | CP          | OP      | IO          | LS        | CP          |
| Wood structure     | Encounter        | 0.087   | 50.4%       | 0.20%     | 0.00%       | 0.055   | 60.3%       | 0.25%     | 0.00%       |
|                    | Fortify          | 0.254   | 97.0%       | 24.9%     | 0.00%       | 0.150   | 97.5%       | 31.6%     | 0.00%       |
|                    | Rare encounter   | 0.541   | 99.2%       | 89.7%     | 0.00%       | 0.310   | 99.4%       | 90.2%     | 0.00%       |
| The whole frame    | Encounter        | 0.087   | 68.2%       | 4.87%     | 0.00%       | 0.055   | 83.9%       | 12.5%     | 0.00%       |
|                    | Fortify          | 0.254   | 99.2%       | 74.9%     | 0.00%       | 0.150   | 99.4%       | 75.2%     | 0.00%       |
|                    | Rare encounter   | 0.541   | 99.6%       | 97.4%     | 0.12%       | 0.310   | 99.8%       | 98.2%     | 0.20%       |

It can be seen from table 1 that based on the $PGA$ ground motion intensity parameters: under the action of frequent earthquakes, the probability of the Guangyue building wood structure exceeding the service limit state (OP) is 60.3%, which is 9.9% higher than the probability of exceeding the wood structure under the $Sa$ parameter, the existence of high platform base increases the probability of wood structure exceeding the normal service limit state (OP) by 23.6%, reaching 83.9%, which is 15.7% higher than the probability of exceeding the overall structure under the $Sa$ parameter. The probability of occurrence of the remaining limit states is basically is 0; under the action of the fortification earthquake, the structure has basically exceeded the normal service limit state (OP). For the wooden structure, the probability of exceeding the usable limit state after repair is 31.6%, which is higher than that of the $Sa$ parameter. The probability of exceeding has increased by 6.7%. The existence of high platform bases has increased the probability of exceeding the wooden structure by 43.6% to 75.2%, which is 0.3% higher than that of the overall structure under the $Sa$ parameter, and the life safety limit state and collapse limit state will occur, the probability is 0; Under the action of rare earthquakes, the structure exceeding the life safety limit state and collapse limit state is still very small, but the probability of exceeding with $PGA$ as a ground motion intensity parameter is still higher than $Sa$.

In contrast, when $PGA$ is used as the ground motion intensity parameter, the probability of evaluating the structure to reach each limit state is greater, that is, the possibility of the structure exceeding various limit states is high, and the result is conservative, which is more conducive to ensuring the safety of the structure, when assessing the earthquake risk of Guangyue Tower, it is suitable to select $PGA$ as the ground motion intensity parameter for analysis.

**5. Conclusion**

(1) Under the same earthquake intensity, the existence of high base will increase the probability of damage to the wooden structure of Guangyue Tower.

(2) When $PGA$ is used as the ground motion intensity parameter, the probability of exceeding the three levels of the Guangyue Tower is greater than that when $Sa$ is used as the ground motion intensity parameter.
parameter. This shows that when PGA is used as the ground motion intensity parameter, the evaluation structure reaches each limit state. The probability should be large, the possibility of the structure exceeding various limit states is large, and the result is conservative, which is more conducive to ensuring the safety of the structure.

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