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Research Article

Study on Analogy Calculation Method for Seismic Vulnerability of Earth-Wood Structure Houses

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Earth-wood structure houses often cause large casualties and economic losses in historical earthquakes. Therefore, it is estimated that the seismic vulnerability of civil structures in areas that have not experienced earthquakes is of great significance for earthquake prevention and disaster reduction. In this paper, an analogy calculation method was proposed for calculating the seismic vulnerability of earth-wood structure houses in unknown regions from the seismic vulnerability of earth-wood structure houses in known regions. Firstly, the main factors affecting the seismic capacity of earth-wood structure houses were determined, and the weights of influence of influencing factors on the overall seismic capacities of buildings under different seismic intensities were determined by using the fuzzy analytical hierarchy approach; secondly, the relative seismic capacities of the main influencing factors are analogically scored by considering the differences in influencing factors in different regions. Finally, based on the vulnerability matrix of earth-wood structure houses in existing regions and comprehensive evaluation of relative seismic capacities of earth-wood structures, the vulnerability matrix of unknown earth-wood structures was calculated by analogy. The results of trial calculation showed that this method has higher reliability and effectiveness. At the end of the article, the vulnerability analysis of earth-wood structure houses in Shigatse, Tibet, was carried out using this method, and the vulnerability curve was initially given.

1. Introduction

The seismic vulnerability of buildings is to estimate the degree of damage that may occur when buildings are affected by a certain intensity earthquake [1]. The seismic disaster of a region or city can be effectively reduced through correctly and reasonably analyzing the seismic vulnerability of all kinds of building structures and taking measures such as seismic reinforcement and reconstruction to improve the seismic performance of building structures that do not meet the requirements of seismic fortification [2].

Although with the continuous development of social economy and the gradual reconstruction of houses in rural areas in China, the number of earth-wood structure houses is decreasing year by year in rural areas in China, and there are still more earth-wood structure houses in rural areas in economically backward regions and ethnic minority autonomous regions in China. Due to the fact that seismic fortification is not considered in these earth-wood structure houses and the building age is old, it is extremely easy for them to be damaged under the action of earthquakes, and their seismic resistances are poor. Therefore, it is still very important to study the seismic vulnerability of earth-wood structure houses to effectively carry out the work of earthquake prevention and disaster reduction [3].

Western China is an earthquake-prone area in China; multiple earthquakes of magnitude 7 and above have occurred in history, including the Wenchuan earthquake ($M \geq 0.8$, May 12, 2008) and the Yushu earthquake ($M \geq 7.1$, April 14, 2010). There are a large number of earth-wood structure houses in rural areas in western China, which have been severely damaged by earthquakes in the past [4]. The vulnerability matrix of earth-wood structure houses has been obtained from the actual earthquake damage investigation in some western regions where the earthquake occurred. However, due to the lack of experiment and numerical simulation study on earth-wood structures, the vulnerability matrix of earth-wood structure houses cannot be established, and accurate vulnerability evaluation of earth-wood structures cannot be carried out in the regions where no earthquake has occurred. Therefore, this paper proposed a calculation method for seismic vulnerability of earth-wood structure houses, that is, based on the vulnerability matrix of earth-wood structures obtained from seismic damage statistics in some regions of western China, considering the effects of the differences in structural components of earth-wood structure houses in different regions on seismic vulnerability, through comprehensive evaluation of seismic capacities of earth-wood structures in different regions, inverse distance weighted interpolation and beta distribution were used to calculate and fit the seismic vulnerability matrix of earth-wood structure houses in the region where no earthquake has occurred.

After field investigations, it was found that earth-wood structure houses were widely distributed in rural areas of Shigatse, Tibet. According to the structural characteristics of earth-wood structure houses in Shigatse, Tibet, this paper uses the method to analyze the vulnerability of earth-wood structure houses in this area.

2. General Thinking of the Matrix Simulation Method

It was assumed that the seismic vulnerability matrix of earth-wood structure houses in n regions (benchmark regions) was known; general thinking of deriving the vulnerability matrix of earth-wood structure houses in unknown regions (target regions) from the vulnerability matrix of earth-wood structure houses in n regions was as follows: (1) the main factors affecting the seismic capacity of earth-wood structures were determined, and the fuzzy complementary judgment matrix was established by using the fuzzy analytical hierarchy approach; the influence weights of the main influencing factors on the seismic capacities of the earth-wood structure houses under different seismic intensities were calculated; (2) the seismic capacities of the main influencing factors were evaluated, and the seismic capacity scores of the earth-wood structure houses in different regions were calculated combining with the influence weights of the main influencing factors on the seismic capacities of the earth-wood structure houses under different seismic intensities; (3) the expected values and standard deviations of the seismic damage indexes of the target region were calculated by referring to the expected values, standard deviations, and seismic capacity scores of the seismic damage indexes under different seismic intensities on the basis of the vulnerability matrix in the benchmark region through inverse distance weighted interpolation, the expected values and standard deviations of the seismic damage indexes of the target region were taken as parameters, and the beta distribution function was used to fit the vulnerability matrix of the earth-wood structure houses; and (4) the rationality and accuracy of this method were verified by example calculation and error analysis.

3. Selection and Weight Definition of the Main Influencing Factors

3.1. Selection of the Main Influencing Factors. As no seismic fortification measures are taken, earth-wood structure houses will suffer obvious seismic damages such as cracks in walls and destroyed internal supporting structures when the seismic intensity is above 6° [5]. For the same type of structure, there are many factors that affect its seismic performance. For example, based on the comprehensive consideration of structural characteristics, seismic damage analysis results, and structural mechanical model, the influencing factors of seismic damage of multistory masonry structures can be summarized as 14 articles in the following: fortification standard, construction age, bearing wall thickness, mortar strength grade, number of floors, usage, roof type, roof weight, floor type, masonry method, horizontal and vertical regularization, housing status, building site, and site soil type [6]. In view of the above influencing factors, based on the study and analysis of the actual seismic damage of historical earth-wood structure houses [7] and referring to the existing study results, as shown in Table 1, the number of floors, bearing walls, and internal supporting structures were determined as the main factors affecting the seismic capacity of earth-wood structure houses in this paper.

3.2. Determination of Weights of Influencing Factors under Different Seismic Intensities. Through the study of the previous actual seismic damage data of earth-wood structures, it was found that the influences of influencing factors on the seismic capacities were different under different seismic intensities. For example, when the seismic intensity was 6°, the seismic damage of the earth-wood structure houses was mainly the damage of the wall, and the damage grade was mainly affected by the condition of the wall; however, when the seismic intensity was 8° or above, whether overall earth-wood structure houses collapsed was mainly determined by the supporting strength of the internal supporting structures, and the damage grade was mainly affected by the internal supporting structures. In order to determine the influences of the main factors on the seismic capacities under different intensities, the fuzzy analytical hierarchy approach was used in this paper to construct the fuzzy judgment matrix and determine the influence weights of the main factors on the seismic capacities under different seismic intensities.

Fuzzy analytical hierarchy approach [8, 9] is used to combine the ideas and methods of fuzzy mathematics with the analytic hierarchy process to obtain the fuzzy judgment matrix according to the importance degree of one factor to another when different factors are compared and judged. In order to quantitatively describe the importance degree of the pairwise comparison between two factors, the scale method in Table 2 is usually used to quantify it [10].

Table 1: Main influencing factors of seismic damage of earth-wood structure houses.

No.	X_1	X_2	X_3
Influencing factors	Number of floors	Load bearing wall	Internal support structure

Table 2: Scale value and meaning of the fuzzy judgment matrix.

Scale value	Meaning	Notes
0.5	Equally important	Two factors are compared; two factors are equally important
0.6	Slightly more important	Two factors are compared; one factor is slightly more important than the other one
0.7	Obviously more important	Two factors are compared; one factor is obviously more important than the other one
0.8	Much more important	Two factors are compared; one factor is much more important than the other one
0.9	Extremely important	Two factors are compared; one factor is extremely important than the other one
0.1, 0.2, 0.3, 0.4	Converse comparison	If the judgment a_{ij} is obtained by comparing factor X_i with factor X_j, then the judgment $a_j = 1 - a_{ij}$ is obtained by comparing factor X_i with factor X_i

Thereby, the judgment matrix of the evaluation index is constructed as A:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}. \tag{1}$$

The fuzzy judgment matrix of the main influencing factors under different seismic intensities is shown in Tables 3–6, among which the selection of the comparison coefficient was mainly referred to the literature studies of seismic engineering experts such as Yin et al. [5, 11–13]; meanwhile, this was referred to a large number of actual seismic damage examples and the judgment of experts in the same field by means of questionnaire scoring.

According to the obtained fuzzy judgment matrix, the general formula to solve the weight of the fuzzy judgment matrix proposed by Xu [8] was used to calculate the influence weights of the main influencing factors on the seismic capacities of earth-wood structure houses under different intensities. The specific solution formula is as follows:

$$\omega_i = \frac{\sum_{j=1}^{n} a_{ij} + ((n/2) - 1)}{n(n-1)}, \quad i = 1, 2, \cdots n. \tag{2}$$

In formula (2), ω_i is the influence weight of the i-th main influencing factor.

The calculation results are shown in Table 7.

Whether the weight value calculated by the above formula is reasonable still needs to be checked for consistency. In this paper, according to the compatibility of the fuzzy judgment matrix [14], the consistency of weight was checked by the judgment matrix and its characteristic matrix. Characteristic matrix B is

$$b_{ij} = \frac{\omega_i}{\omega_i + \omega_j}, \quad (\forall i, j = 1, 2, \cdots n), \tag{3}$$

$$B = \left(b_{ij}\right)_{n\times n}. \tag{4}$$

Then, the weight compatibility index is

Table 3: Fuzzy judgment matrix of the main seismic damage factors when the intensity was 6°.

Influencing factor	X_1	X_2	X_3
X_1	0.5	0.4	0.6
X_2	0.6	0.5	0.8
X_3	0.4	0.2	0.5

Table 4: Fuzzy judgment matrix of the main seismic damage factors when the intensity was 7°.

Influencing factor	X_1	X_2	X_3
X_1	0.5	0.4	0.5
X_2	0.6	0.5	0.6
X_3	0.5	0.4	0.5

Table 5: Fuzzy judgment matrix of the main seismic damage factors when the intensity was 8°.

Influencing factor	X_1	X_2	X_3
X_1	0.5	0.6	0.4
X_2	0.4	0.5	0.4
X_3	0.6	0.6	0.5

Table 6: Fuzzy judgment matrix of the main seismic damage factors when the intensity was 9–10°.

Influencing factor	X_1	X_2	X_3
X_1	0.5	0.7	0.3
X_2	0.3	0.5	0.2
X_3	0.7	0.8	0.5

Table 7: Weights of various influencing factors under different seismic intensities.

	Grade VI	Grade VII	Grade VIII	Grade IX	Grade X
X_1	0.333	0.317	0.333	0.333	0.333
X_2	0.400	0.367	0.300	0.300	0.250
X_3	0.266	0.317	0.367	0.367	0.417

$$I(A,B)=\frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n}\left|a_{ij}-b_{ij}\right|. \tag{5}$$

When the compatibility index $I(A,B)$ was less than or equal to the attitude T of the decision maker, it was considered that the judgment matrix satisfied the consistency. The smaller T was, the higher the requirement of the decision maker for the consistency of the fuzzy judgment matrix was; generally, $T=0.1$ was taken.

In this paper, formulas (7), (8), and (9) were used to check whether the weight values in Table 7 were reasonable. The calculation results are shown in Table 8.

All compatibility indexes of the weights of the main influencing factors under different intensities were less than 0.1, so it was considered that the fuzzy judgment matrices of the influencing factors under different intensities were consistent, and the distribution of the weights was reasonable.

4. Comprehensive Evaluation of Seismic Capacities of Earth-Wood Structures

Because there are some differences in the specific conditions of the main factors affecting the seismic capacities in different regions, for example, the thickness of the walls is different among some regions, the seismic capacities of earth-wood structure houses in different regions are different. According to the actual situation of the main influencing factors, the relative seismic capacities of the main influencing factors are determined by using the expert scoring method. Experts participating in scoring mainly come from the fields of structural engineering, earthquake engineering, and disaster prevention and mitigation engineering and have extensive experience in earthquake site inspections. In this paper, the relative seismic capacities of the main influencing factors were divided into five grades, and the better the relative seismic capacity was, the higher the score given by relevant experts was. For example, if the damage grade of the earth-wood structure with thick walls is lower than that of the earth-wood structure with thin walls during the earthquake [15], the expert score is higher; if the damage grade of the double-floor earth-wood structure is higher than that of the single-floor earth-wood structure during the earthquake, the expert score is lower. The scoring standard for the relative seismic capacity of each influencing factor is shown in Table 9.

According to the housing census data, we could understand the specific situations such as the number of floors of earth-wood structures, bearing walls, and internal supporting structures in a certain region. Based on the specific conditions of the main influencing factors of earth-wood structures, relevant experts were consulted for evaluating the relative seismic capacities of the main influencing factors. According to the influence weights of the main influencing factors on the seismic capacities of the building under different intensities, the comprehensive scores of the relative seismic capacities of the earth-wood structures in a certain region under different intensities were obtained as follows:

$$F_j=\sum_{m=1}^{3}F_m\omega_{mj}. \tag{6}$$

In the formula, F_j is the comprehensive score of the relative seismic capacity under seismic intensity j; F_m is the score of the relative seismic capacity of the $m\backslash m$-th main influencing factor; and ω_{mj} is the comprehensive score of the relative seismic capacity of the m-th main influencing factor under seismic intensity j.

Table 8: Calculation results of compatibility indexes.

Seismic intensity	Grade VI	Grade VII	Grade VIII	Grade IX	Grade X
Compatibility index	0.066	0.028	0.044	0.099	0.099

Table 9: Scoring standard for the relative seismic capacity of each influencing factor.

Relative seismic capacity	Worse	Bad	Ordinary	Good	Better
F value	0–0.2	0.2–0.4	0.4–0.6	0.6–0.8	0.8–1

5. Seismic Damage Matrix Simulation

Seismic engineering experts such as Hu [16] put forward the concept of seismic damage indexes. The values between 0 and 1 are used to express the degree of seismic damage of the structure. Table 10 shows the corresponding seismic damage index range of five damage grades [1].

The expected value of the seismic damage index is the average value of the seismic damage indexes of buildings in a region. The dispersion of the damage grade of buildings in a region can be expressed by the standard deviation of the seismic damage index. Therefore, the expected value and standard deviation of the seismic damage index of a certain type of structure can be obtained according to its vulnerability matrix.

Based on the difference in the comprehensive score of the relative seismic capacity between earth-wood structure houses in the benchmark region and the target region, the expected values and standard deviations of the seismic damage indexes in the benchmark region under different intensities were used to calculate inverse distance weighted (IDW) interpolation [17], and thus, the expected values and standard deviations of the seismic damage index in the target region were obtained. The weighted distance is

$$d_{ij}=\left|F_{0j}-F_{ij}\right|, \tag{7}$$

and thus,

Table 10: Correlation between the seismic damage index and the seismic damage degree.

Damage grade	Basically intact	Slightly damaged	Moderately damaged	Severely damaged	Destroyed
Seismic damage index	0–0.1	0.1–0.3	0.3–0.55	0.55–0.85	0.85–1.0

$$Dr_j = \frac{\sum_{i=1}^{n}\left(Dr_{ij}/d_{ij}^2\right)}{\sum_{i=1}^{n}\left(1/d_{ij}^2\right)}, \tag{8}$$

$$\delta_j = \frac{\sum_{i=1}^{n}\left(\delta_{ij}/d_{ij}^2\right)}{\sum_{i=1}^{n}\left(1/d_{ij}^2\right)}. \tag{9}$$

In the formula, d_{ij} is the weighted distance between the relative seismic capacities in the target region and the benchmark region under seismic intensity j; F_{0j} is the comprehensive score of the relative seismic capacity of the target region under seismic intensity j; F_{ij} is the comprehensive score of the relative seismic capacity of the i-th benchmark region under seismic intensity j; Dr_j is the expected value of the seismic damage index of the vulnerability matrix of the target region under seismic intensity j; Dr_{ij} is the expected value of the seismic damage index for the vulnerability matrix in the i-th benchmark region under seismic intensity j; δ_j is the standard deviation of the seismic damage index for the vulnerability matrix in the target region under seismic intensity j; and δ_{ij} is the standard deviation of the seismic damage index for the vulnerability matrix in the i-th benchmark region under seismic intensity j; Liu et al. [18] proposed a method for the use of the beta distribution function to fit the vulnerability matrix by taking the seismic damage index as a continuous variable and taking the expected value and the standard deviation of the seismic damage index as parameters. In this paper, this method was used to fit the vulnerability matrix of earth-wood structure houses in the benchmark region.

According to the relationship between the expected value and the standard deviation of parameters a and b of the seismic damage index, the values of parameters a_j and b_j of the beta distribution function under intensity j are calculated as follows:

$$\omega_i = \frac{\sum_{j=1}^{n} a_{ij} + ((n/2) - 1)}{n(n-1)}, \quad i = 1, 2, \cdots n, \tag{10}$$

$$b_j = \left(1 - Dr_j\right)\left(\frac{Dr_j - Dr_j^2}{\sigma_j^2} - 1\right). \tag{11}$$

Thereby, the beta probability density distribution of the seismic damage index under seismic intensity j could be obtained as follows:

$$f\left(Dr; a_j; b_j\right) = \frac{Dr^{a_j-1}(1-Dr)^{b_j-1}}{\int_0^1 t^{a_j-1}(1-t)^{b_j-1}\mathrm{d}t}, \quad 0 \le Dr \quad \le 1. \tag{12}$$

According to formula (13), the damage probabilities of the earth-wood structure houses in the target region under different damage degrades can be fitted, and finally, the vulnerability matrix of the earth-wood structure houses in the target region can be obtained.

$$p_{ij} = \int_{Dr_{i1}}^{Dr_{i2}} f\left(Dr; a_j, b_j\right)\mathrm{d}Dr. \tag{13}$$

In the formula, Dr is the continuous variable of the seismic damage index; p_{ij} is the probability of grade i damage under seismic intensity j; Dr_{i1} is the lower limiting value of the range of the seismic damage index for grade i damage; and Dr_{i2} is the upper limit value of the range of the seismic damage index for grade i damage.

6. Analysis of Examples

The vulnerability matrix of earth-wood structure houses in Gansu province was fitted using the calculation method proposed in this paper.

In this paper, Sichuan province, Xinjiang Uygur Autonomous Region, and Yunnan province in western China are selected as the benchmark regions, and the main factors affecting the seismic capacity of earth-wood structure houses in the benchmark regions and Gansu region are shown in Table 11.

According to the specific conditions of the main influencing factors in each region in Table 11, the expert scores of the main influencing factors in each region are shown in Table 12.

According to formula (6), the comprehensive scores of relative seismic capacities of earth-wood structure houses in Gansu province and the benchmark regions under different seismic intensities are calculated in Table 13.

Based on the scores and the expected values and standard deviations of the seismic damage indexes under different intensities in each benchmark region in Table 14, the expected values and standard deviations of seismic damage indexes under different intensities in the Gansu region were calculated according to formulas (8) and (9), and the calculation results are shown in Table 15.

Formulas (10) and (11) were used to calculate the beta distribution parameters under different seismic intensities, and the beta distribution function curve of continuous seismic damage index under different intensities is shown in Figure 1.

According to the beta probability density distribution of the obtained seismic damage indexes, the vulnerability matrix was fitted by using formula (13). The fitting results and the vulnerability matrix obtained through the actual seismic damage investigation are shown in Tables 16 and 17.

In order to verify the reliability and effectiveness of this method, the vulnerability results of earth-wood structure houses estimated by this method were compared with the actual vulnerability results of seismic damage investigation. As shown in Table 18, the error between the expected value of the seismic damage index obtained by simulation in

Table 11: Specific conditions of the main influencing factors in the benchmark regions and Gansu region.

	Number of floors	Load bearing wall	Internal support
Sichuan province	The houses had one or two floors	The wall thickness was 30–50 cm, and the wall integrity was ordinary	Some houses had supporting structures such as wooden frames and wooden columns, and the internal supporting condition was ordinary
Xinjiang Uygur Autonomous Region	The houses mainly had one floor	The wall thickness was 30–50 cm, and the wall integrity was relatively poor	Fewer houses had internal supporting structures, and the internal supporting condition was poor
Yunnan province	Most houses had two floors, and a few houses had one floor	The wall thickness was 60–120 cm and was 80 cm in most cases, with good wall integrity	Most houses had wooden posts, wooden beams, and mortise and tenon connection between beams and columns, with better internal supporting condition
Gansu province	The houses mainly had one floor	The wall thickness was 30–50 cm, and the wall integrity was ordinary	Some houses had supporting structures such as wooden frames and wooden columns, and the internal supporting condition was good

Table 12: Scores of the main influencing factors of the benchmark regions and Gansu region.

	Number of floors	Load bearing wall	Internal supporting structure
Sichuan	0.6	0.6	0.5
Xinjiang	0.8	0.3	0.3
Yunnan	0.4	0.8	0.8
Gansu	0.8	0.4	0.7

Table 13: Comprehensive scores of relative seismic capacities of the benchmark regions and Gansu region.

	Grade VI	Grade VII	Grade VIII	Grade X
Sichuan	0.533	0.532	0.533	0.533
Xinjiang	0.467	0.458	0.467	0.467
Yunnan	0.667	0.673	0.667	0.667
Gansu	0.613	0.622	0.643	0.658

Table 14: Expected values and standard deviations of seismic damage indexes in each benchmark region.

		Grade VI	Grade VII	Grade VIII	Grade IX	Grade X
Sichuan	Expected value	0.172	0.358	0.592	0.770	0.900
	Standard deviation	0.168	0.258	0.270	0.207	0.091
Xinjiang	Expected value	0.250	0.405	0.632	0.806	0.909
	Standard deviation	0.216	0.262	0.276	0.185	0.084
Yunnan	Expected value	0.137	0.332	0.559	0.755	0.900
	Standard deviation	0.166	0.250	0.276	0.221	0.094

Table 15: Expected values and standard deviations of seismic damage indexes under different intensities in Gansu province.

	Grade VI	Grade VII	Grade VIII	Grade IX	Grade X
Expected value	0.156	0.343	0.562	0.755	0.900
Standard deviation	0.152	0.249	0.276	0.220	0.094

Table 15 and the expected value of the actual seismic damage index was relatively small, which basically met the requirements of vulnerability evaluation. The error between the simulated vulnerability matrix and the actual seismic damage vulnerability matrix basically met the expected results. Therefore, this method is feasible.

7. Vulnerability Analysis of Civil Structure Houses in Shigatse, Tibet

Through field research, it was found that the earth-wood structure houses in Shigatse, Tibet, were mainly two-story traditional Tibetan-style buildings with thick walls and good internal support structure, as shown in Figure 2.

Based on the actual situation of earth-wood structure houses in Shigatse, Tibet, the method of this paper is used to analyze the vulnerability of earth-wood structure houses in this area. Sichuan province, Xinjiang Uygur Autonomous Region, and Yunnan province in western China are selected as the benchmark regions, and the main factors affecting the seismic capacity of earth-wood structure houses in the benchmark regions and Shigatse, Tibet, are shown in Tables 11 and 19.

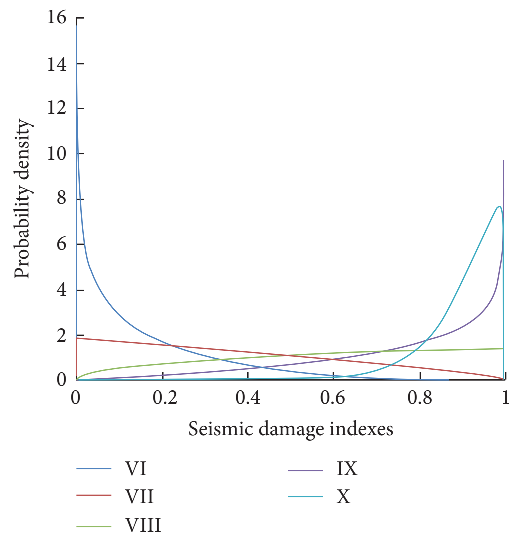

Figure 1: Probability density distribution curves of seismic damage indexes under different seismic intensities.

Table 16: Vulnerability matrix of earth-wood structure houses in Gansu province fitted by the proposed method.

	Grade VI	Grade VII	Grade VIII	Grade IX	Grade X
Basically intact	48	20	5	0	0
Slightly damaged	35	30	16	3	0
Moderately damaged	14	28	26	14	0
Severely damaged	3	19	36	41	22
Destroyed	0	3	17	42	78

Table 17: Actual seismic vulnerability matrix of earth-wood structure houses in Gansu province.

	Grade VI	Grade VII	Grade VIII	Grade IX	Grade X
Basically intact	55	18	4	0	0
Slightly damaged	30	29	10	1	0
Moderately damaged	13	32	32	18	0
Severely damaged	2	18	31	27	10
Destroyed	0	3	23	54	90

Table 18: Comparison between the expected value of the seismic damage index obtained by simulation and the expected value of the actual seismic damage index.

	Grade VI	Grade VII	Grade VIII	Grade IX	Grade X
Simulation value	0.156	0.343	0.562	0.755	0.900
Actual value	0.157	0.357	0.588	0.767	0.903
Error	0.001	0.014	0.026	0.012	0.003

According to the specific conditions of the main influencing factors in Shigatse region in Table 19, the expert scores of the main influencing factors in Shigatse region are shown in Table 20.

Based on the scores and the expected values and standard deviations of the seismic damage indexes under different intensities in each benchmark region in Table 14, the expected values and standard deviations of seismic damage indexes under different intensities in Shigatse region are calculated according to formulas (6), (8), and (9), and the calculation results are shown in Table 21.

Formulas (10) and (11) were used to calculate the beta distribution parameters under different seismic intensities and obtain the beta distribution function of continuous seismic damage index under different intensities. Finally, formula (13) is used to fit the vulnerability matrix in Table 22.

(a) (b)

Figure 2: (a) Structural appearance of earth-wood structure houses in Shigatse region. (b) Internal support structure.

Table 19: Specific conditions of the main influencing factors in Shigatse region.

	Number of floors	Load bearing wall	Internal support
Shigatse region	The houses mainly had two floors	The wall thickness was 80–100 cm, and the wall integrity was good	Most houses had wooden posts, wooden beams, and normal connection between beams and columns, with better internal supporting condition

Table 20: Scores of the main influencing factors of Shigatse region.

	Number of floors	Load bearing wall	Internal supporting structure
Shigatse region	0.4	0.9	0.6

Table 21: Expected values and standard deviations of seismic damage indexes under different intensities in Shigatse region.

	Grade VI	Grade VII	Grade VIII	Grade IX	Grade X
Expected value	0.156	0.343	0.562	0.755	0.900
Standard deviation	0.152	0.249	0.276	0.220	0.094

Table 22: Seismic vulnerability matrix of earth-wood structure houses in Shigatse region.

	Grade VI	Grade VII	Grade VIII	Grade IX	Grade X
Basically intact	54	21	4	0	0
Slightly damaged	31	31	15	4	0
Moderately damaged	12	27	26	13	0
Severely damaged	3	18	37	39	22
Destroyed	0	3	18	44	78

According to the vulnerability matrix of earth-wood structure houses in Shigatse region calculated using the method in this paper, the vulnerability curve of earth-wood structure houses in this region can be obtained, as shown in Figure 3.

The calculation results show that the moderate and above damage degree of earth-wood structure houses in Xigaze area occupied the main part when the earthquake intensity is 8°; when the earthquake intensity is 10°, the earth-wood structure houses in the area are basically destroyed. Comparing the expected values of the earthquake damage index of earth-wood structures in Shigatse and other benchmark regions, because the load bearing wall of the earth-wood structure is thicker and good overall condition in Xigaze, the expected value of the earthquake damage index of earth-wood structure houses in Xigaze is relatively low in low-intensity areas; in high-intensity areas, due to the poor internal support structure

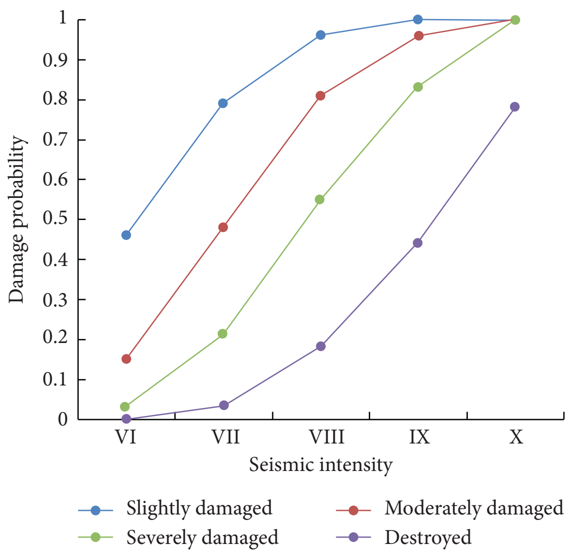

Figure 3: Vulnerability curve of earth-wood structure houses in Shigatse region.

compared with Yunnan, the expected value of the earthquake damage index for structural houses is higher than Yunnan.

It can be seen that the vulnerability analysis of the earth-wood structure houses in Shigatse, Tibet, using this method meets the expected results.

8. Conclusion

The vulnerability matrix of earth-wood structure houses in Gansu province was fitted using the calculation method proposed in this paper. In this paper, according to the needs of vulnerability estimation of earth-wood structure houses, a quick calculation method for fitting the vulnerability matrix of earth-wood structure houses is proposed. Based on the vulnerability matrix of the earth-wood structures in the benchmark region, considering the influence weights of the main influencing factors on the seismic capacity of the building under different seismic intensities and the difference in the actual situation of the influencing factors in different regions, the comprehensive scores of relative seismic capacities of the earth-wood structure houses in the benchmark region and the target region are calculated, respectively, and then, the expected values and standard deviations of the seismic damage indexes in the target are obtained by using the inverse distance weighted interpolation method. Finally, the beta distribution function is used to fit the seismic damage matrix in the simulated region. The earth-wood structures in Gansu province are checked by using the method in this paper, and the error between the calculated results and the actual seismic damage results is within a reasonable range.

The method proposed in this paper can quickly evaluate the vulnerability of earth-wood structure houses in a certain region, which considers the influence of different influencing factors on the seismic capacities of the structures under different seismic intensities compared with the previous methods. The accuracy of this method is affected by the selection of the benchmark region and the reasonableness of the relative seismic capacity scores evaluated by relevant experts on the main influencing factors. Generally, the region with earth-wood structures similar to those of the target region should be selected as the benchmark region, and the average value of the scores of multiple relevant experts should be used for evaluation. In this paper, only the vulnerability of earth-wood structures is evaluated, and how this analogy method can also be applied to houses of other types of structures needs further study.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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