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Study on Method for Quick Seismic Vulnerability Estimation of Building Structure

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Abstract

The seismic vulnerabilities of the same type of buildings are quite different due to the differences in aspects such as structural forms and component materials in different regions. In this paper, a calculation method was proposed for the use of the seismic vulnerability of building structures in known regions to estimate the seismic vulnerability of similar structures in unknown 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, based on the vulnerability matrix of earth-wood structure houses in existing regions, the expected values and standard deviations of seismic damage indexes for the vulnerability matrix of earth-wood structure houses in unknown regions were evaluated by considering the differences in influencing factors in different regions. Finally, the expected values and standard deviations of seismic damage index were taken as parameters, and the vulnerability matrix of unknown earth-wood structures was fitted by using Beta distribution function. The results of trial calculation showed that this method has higher reliability and effectiveness.

Keywords: earth-wood structure, seismic vulnerability, fuzzy analytical hierarchy approach, Beta distribution function

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, there are still more earth-wood structure houses in rural areas in economically backward 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 ($M \geqslant 8.0$, May 12, 2008) and the Yushu earthquake ($M \geqslant 7.1$, 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 structure, the vulnerability matrix of earth-wood structure houses can not be established and accurate vulnerability evaluation of earth-wood structure can not 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 weighted distance 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.

2. General thinking of matrix simulation method

It was assumed that the seismic vulnerability matrix of earth-wood structure houses in n regions (benchmark regions) was known, the 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 weighted distance interpolation, and 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;(4) the rationality and accuracy of this method were verified by example calculation and error analysis.

3. Selection and weight definition of main influencing factors

3.1 Selection of 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 degrees [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 structure can be summarized as following 14 articles: 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, 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.

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

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 degrees, 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; but when the seismic intensity was 8 degrees 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 to combine the ideas and methods of fuzzy mathematics with the analytic hierarchy process to the 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 2 – Scale value and meaning of 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 the factor X_i with the factor X_j, then the judgment a_j=1− a_{ij} is obtained by comparing the factor X_i with the factor X_i

Thereby the judgment matrix of 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 main influencing factors under different seismic intensities were shown in Table 3-6, among which the selection of comparison coefficient was mainly referred to the literatures of seismic engineering experts such as Yin Zhiqian and Sun Baitao[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.

Table 3 – Fuzzy judgment matrix of main seismic damage factors when the intensity was 6 degrees

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 main seismic damage factors when the intensity was 7 degrees

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 main seismic damage factors when the intensity was 8 degrees

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 main seismic damage factors when the intensity was 9-10 degrees

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

According to the obtained fuzzy judgment matrix, the general formula to solve the weight of the fuzzy judgment matrix proposed by Xu Zeshui[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:

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

In formula (2), ω_i is the influence weight of the i-th main influencing factor.
The calculation results were shown in Table 7:

Table 7 – Weights of various influencing factors under different seismic intensities

	Grade Ⅵ	Grade Ⅶ	Grade Ⅸ	Grade Ⅹ
X_1	0.333	0.317	0.333	0.333

X_2	0.400	0.367	0.300	0.250
X_3	0.266	0.317	0.367	0.417

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 fuzzy judgment matrix[14], the consistency of weight was checked by judgment matrix and its characteristic matrix. The characteristic matrix B was:

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

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

Then the weight compatibility index was:

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

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 decision-maker for the consistency of the fuzzy judgment matrix was, generally $T = 0.1$ was taken.

In this paper, formula (7), (8) and (9) were used to check whether the weight values in Table 7 were reasonable. See Table 8 for the calculation results.

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

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 matrixes 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, so the seismic capacities of earth-wood structure houses in different regions is different. According to the actual situation of the main influencing factors, the relative seismic capacities of the main influencing factors are determined by using expert scoring method. 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.

Table 9 – Scoring standard for 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

According to the housing census data, we could understand the specific situation 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 relative seismic capacity under seismic intensity j; F_m is the score of relative seismic capacity of the m-th main influencing factor; ω_{mj} is the comprehensive score of relative seismic capacity of the m-th main influencing factor under seismic intensity j.

5. Seismic damage matrix simulation

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

Table 10 – Correlation between seismic damage index and 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

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 verse 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 was:

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

and thus：

$$Dr_j = \frac{\sum_{i=1}^{n} \frac{Dr_{ij}}{d_{ij}^2}}{\sum_{i=1}^{n} \frac{1}{d_{ij}^2}} \tag{8}$$

$$\delta_j = \frac{\sum_{i=1}^{n} \frac{\delta_{ij}}{d_{ij}^2}}{\sum_{i=1}^{n} \frac{1}{d_{ij}^2}} \tag{9}$$

In the formula, d_{ij} is the weighted distance between the relative seismic capacities in the target region and the benchmark region under the seismic intensity j; F_{0j} is the comprehensive score of the relative seismic capacity of the target region under the seismic intensity j; F_{ij} is the comprehensive score of the relative seismic capacity of the i-th benchmark region under the seismic intensity j; Dr_j is the expected value of the seismic damage index of the vulnerability matrix of the target region under the 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 the seismic intensity j; δ_j is the standard deviation of the seismic damage index for the vulnerability matrix in the target region under the seismic intensity j; δ_{ij} is the standard deviation of the seismic damage index for the vulnerability matrix in the i-th benchmark region under the seismic intensity j;

Liu Rushan [18] et al proposed a method for the use of Beta distribution function to fit the vulnerability matrix by taking the seismic damage index as continuous variable and taking the expected value and standard deviation of 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 parameter a and b of seismic damage index, the values of parameter a_j and b_j of Beta distribution function under intensity j were calculated as follows:

$$a_j = \frac{Dr_j^2 - Dr_j^3}{\sigma_j^2} - Dr_j \tag{10}$$

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

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

$$f(Dr; a_j; b_j) = \frac{Dr^{a_j - 1}(1 - Dr)^{b_j - 1}}{\int_0^1 t^{a_j - 1}(1 - t)^{b_j - 1} dt} \qquad 0 \le Dr \le 1 \tag{12}$$

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.

$$p_{ij} = \int_{Dr_{i1}}^{Dr_{i2}} f(Dr; a_j, b_j) dDr \tag{13}$$

In the formula: Dr - continuous variable of seismic damage index; p_{ij} - probability of grade i damage under seismic intensity j; D_{ri1}-the lower limiting value of the range of seismic damage index for grade i damage; D_{ri2}- upper limit value of the range of seismic damage index for grade i damage.

6. Analysis of examples

The acknowledgements provide an opportunity to express appreciation to those who contributed significantly to the preparation of the paper. They may be written in free style, and must be brief. 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 the western China were 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 were shown in Table 11:

Table 11 – Specific conditions of main influencing factors in benchmark region and Gansu region

	Number of floors	Load bearing wall	Internal support
Sichuan Province	The houses had one or two floors	The wall thickness was 30-50cm, and the wall integrity was ordinary.	Some houses had supporting structures such as wooden frames and wooden columns, the internal supporting condition was ordinary.
Xinjiang Uygur Autonomous Region	The houses mainly had one floor	The wall thickness was 30-50cm, 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 80cm 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 30-50cm, and the wall integrity was ordinary.	Some houses had supporting structures such as wooden frames and wooden columns, the internal supporting condition was good.

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

Table 12 – Scores of main influencing factors of 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

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 were calculated as follows:

Table 13 – Comprehensive scores of relative seismic capacities of benchmark regions and Gansu region

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

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 Gansu region were calculated according to formula (8) (9):

Table 14 – Expected values of seismic damage indexes in each benchmark region

	Grade Ⅵ	Grade Ⅶ	Grade Ⅷ	Grade Ⅸ	Grade Ⅹ
Sichuan	0.172	0.358	0.592	0.770	0.900
Xinjiang	0.250	0.405	0.632	0.806	0.909
Yunnan	0.137	0.332	0.559	0.755	0.900

Table 15 – Standard deviation of seismic damage index in each benchmark region

	Grade Ⅵ	Grade Ⅶ	Grade Ⅷ	Grade Ⅸ	Grade Ⅹ
Sichuan	0.172	0.358	0.592	0.770	0.900
Xinjiang	0.250	0.405	0.632	0.806	0.909
Yunnan	0.137	0.332	0.559	0.755	0.900

Table 16 – 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

Formula (10) and (11) were used to calculate the Beta distribution parameters under different seismic intensities, the Beta distribution function curve of continuous seismic damage index under different intensities was shown in Figure 1:

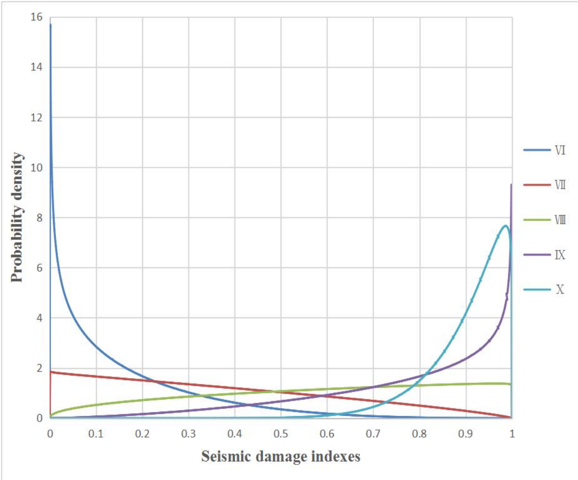

Figure 1 – Probability density distribution curves of seismic damage indexes under different seismic intensities

According to the Beta probability density distribution of the obtained seismic damage indexes, the vulnerability matrix was fitted by using the formula (13). The fitting results and the vulnerability matrix obtained through the actual seismic damage investigation were shown in Table 17 and 18:

Table 17 – Vulnerability matrix of earth-wood structure houses in Gansu Province fitted by this 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 18 – 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

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 19, the error between the expected value of the seismic damage index obtained by simulation in Table 16 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 was feasible.

Table 19 – Comparison between the expected value of seismic damage index obtained by simulation and the expected value of 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

7. 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 that 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 this method can also be applied to the evaluation of other structures.

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9. References

[1] Yin Zhiqian. Method of prediction for seismic disaster and loss[M].Beijing:Seismological Press,1996:1-3,28-31.(in Chinese)

[2] Hu Shaoqing,Sun Baitao,Wang Dongming,et al.Approach to making empirical earthquake damage matrix [J].Earthquake Engineering And Engineering Vibration,2007,27(06):46-50. (in Chinese)

[3] Chen Bin .Analysis of earthquake damage of rural buildings in western China and study on seismic resistant measures [J].Construction Quality, 2014,32(06):23-27. (in Chinese)

[4] Yuan Yifan.Loss assess ment of Wenchuan Earthquake[J]. Earthquake Engineering And Engineering Vibration,2008,28(05):10-19. (in Chinese)

[5] Yin Zhiqian, Yang Shuwen. Seismic loss analysis and fortification criterion [M]. Beijing: Seismological Press, 2004: 74—80. (in Chinese)

[6] Zhang Guixin, Sun Baitao. A method for earthquake damage prediction of building groups based on multiple factors [J]. World Earthquake Engineering,2010,26(01):26-30. (in Chinese)

[7] Sun Baitao,Zhang Guixin. Study on vulnerability matrices of masonry buildings of mainland China[J]. Earthquake Engineering and Engineering Vibration,2018,17(02):251-259.

[8] Xu Zeshui. Algorithm for priority of fuzzy complementary judgement matrix [J]. Journal of Systems Engineering,2001,16(04):311-314. (in Chinese)

[9] Sun Baitao ,Hu Shaoqing.Seismic damage prediction for a single building based on a fuzzy analytical hierarchy approach [J] .Engineering Mechanics,2018,35(12):185-193+202. (in Chinese)

[10] Ji Dongchao, Song Bifeng, Yu Tianxiang. The method of decision-making based on FAHP and its application [J]. Fire Control and Command Control,2007,32(11):38-41. (in Chinese)

[11] Sun Baitao, Zhang Guixin. A method for earthquake damage prediction of building group considering seismic fortification level [J]. China Civil Engineering Journal,2013,46(05):117-121. (in Chinese)

[12] Sun Baitao,Zhang Guixin. The Wenchuan earthquake creation of a rich database of building performance[J]. Science China Technological Sciences,2010,53(10):2668-2680.

[13] Yao Xinqiang. Analysis of Tianjin rural residential vulnerability and seismic capacity distribution[D].Institute of Engineering Mechanics ,China Earthquake Administration,2016. (in Chinese)

[14] Chen Huayou, Zhao Jiabao. Research on compatibility of fuzzy judgement matrices [J]. Operations Research and Management Science,2004,13(01):44-47. (in Chinese)

[15] Luo Shuguang. Anti-seismic and practice of rural housing in western China [D].Xi’an University of Architecture and Technology,2011. (in Chinese)

[16] Hu Yuxian. Earthquake engineering [M]. Beijing: Seismological Press, 1988. (in Chinese)

[17] Tang Zesheng.3D data field visualazation [M].Beijing：Tsinghua University Press,1999. (in Chinese)

[18] Liu Rushan,Hu Shaoqing,Wu Yubin,et al.Research on structure vulnerability expression way based on seismic motion parameter[J]. Earthquake Engineering And Engineering Vibration,2009,29(06):102-107. (in Chinese)

