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Evaluation Model for Seismic Resilience of Urban Building Groups

Hao Ren [1], Chong Rong [2], Qinhu Tian [1,*], Weichao Zhang [1] and Dan Shao [1]

1 Shaanxi Earthquake Agency, Xi'an 710068, China; renhao@sxdzj.com.cn (H.R.); shaodanseis@163.com (D.S.)
2 School of Civil Engineering, Xi'an University of Architecture & Technology, Xi'an 710055, China
* Correspondence: glorich@126.com

Abstract: This paper analyzed the factors that influence the seismic resilience of urban building groups and studied the laws that influence internal factors and external factors. Based on the data from the first national comprehensive risk survey of natural disasters, a refined classification study of urban building groups was carried out. Based on the existing evaluation methods of seismic resilience of individual buildings, the recovery time was selected as the resilience evaluation index to calculate the effect of internal factors on the seismic resilience of urban building groups. Then, we studied the quantitative relationship between external factors (i.e., disaster relief capacity, population density, and economic level) and the evaluation indicators of seismic resilience of urban building groups, and we proposed the kilometer grid coefficient. Based on that, we proposed a calculation method of the effect of external factors on the seismic resilience of urban building groups. Considering the influence of internal and external factors, the evaluation model for the seismic resilience of urban building groups was established. And the model was applied in a typical city. This paper proposes a method to evaluate the seismic resilience of urban building groups, which can master the functional recovery time of urban building groups after an earthquake. Based on the proposed model, we can optimize the functional recovery path and emergency rescue path of the disaster area, as well as improve the resilience of urban building systems and the construction of resilient cities.

Keywords: urban building groups; evaluation method of seismic resilience; seismic resilience of buildings; functional recovery time

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1. Introduction

Since the 20th century, we have encountered many serious destructive earthquakes. After an earthquake, many problems exist in the disaster area, such as the difficulty in recovery of building function, long recovery time, and high cost. It is necessary to study the seismic resilience of urban buildings. Based on the seismic resilience of buildings, many scholars have urged the building of resilient cities [1]. Resilient cities refer to the ability of a city to maintain basic and emergency functions in an earthquake, without causing large-scale casualties. After an earthquake, all functions of the city can be quickly restored to normal [1]. In 2011, the National Scientific Research Council of the United States proposed the construction goal of "national earthquake recovery" [2]. In 2014, Japan released the basic plan of "land strengthening and toughening" [3]. In 2017, the China Seismological Bureau listed "resilient urban and rural areas" as one of the four major plans of the "national earthquake science and technology innovation project" [4]. Therefore, the construction and study of resilient cities are developing trends in earthquake prevention and disaster reduction [5–7]. It is important to improve the natural disaster risk prevention ability and ensure the sustainable development of economy and society.

Building groups are an important component of cities, and resilient cities include resilience in building systems, transportation systems, and communication systems. Building resilience is an important part of a resilient city, which will directly influence the personal casualty and the recovery ability of urban functions after an earthquake [8,9]. The seismic resilience of buildings refers to the ability to restore building functions after an earthquake has settled [10]. There have been many studies on the seismic resilience and evaluation method of single buildings [11–14]. However, few studies have focused on the seismic resilience of urban building groups [15–20]. And a large part of the studies focused on the community level and neglected the evaluation methods of seismic resilience of urban building groups. Existing studies on the urban building groups only considered the effect of the building on seismic resilience and failed to consider the influence of external factors. The seismic resilience of urban building groups is not only related to the internal factors of the buildings themselves, but also influenced by external factors such as disaster relief capacity, population density, and economic level of the social system. Under the same earthquake action, the stronger the disaster relief capacity, the shorter the recovery time of building functions. The more concentrated the population and wealth, the greater the losses caused by earthquakes and the greater the difficulty of recovery [1]. Ligang et al. [20] used the traffic system as an external factor to analyze the seismic resilience of urban building groups, which shows that additional consideration of external factors can make the evaluation results more reasonable and accurate.

As above, the existing studies failed to involve the external factors on the seismic resilience of urban building groups. However, the external factors are very important and multiplex, including the engineering system (transportation system, communication system, etc.) and social system (disaster relief capacity, population density, economic level, etc.). Meanwhile, they did not yet determine the current situation of the seismic resilience of urban building groups, especially for the urban building groups in the key earthquake monitoring and defense areas. Therefore, it is urgent to study the quantitative characterization method of the external factors and the accurate evaluation method of the seismic resilience of urban building groups.

This paper studied the influence of internal factors (e.g., the performance of the building structures) and external factors (e.g., social system factors, which are independent of the building structures) on the seismic resilience of urban building groups. Then, we proposed the use of the recovery time of building functions after an earthquake as an evaluation indicator to classify the seismic resilience level of buildings. Based on the first national comprehensive risk survey of natural disasters in China, the refined classification of urban building groups was carried out, as well as the internal factors of the seismic resilience of urban building groups through the existing evaluation methods of seismic resilience of individual buildings. After that, this paper studied the quantitative relationship between various external factors and the evaluation index, and then proposed the influence coefficient of the kilometer grid as the quantitative representation of the influence of external factors. Based on the calculation method of the internal factors and the external factors of the seismic resilience of urban building groups, a comprehensive evaluation method was proposed and the corresponding evaluation model was established. Finally, we take a typical city as an example to apply the proposed model.

2. Influencing Factors of Seismic Resilience of Urban Building Groups

From the above analysis, there are two types of factors that influence the seismic resilience of urban building groups, including internal factors and external factors. The former mainly belong to building characteristics, and the latter mainly belong to urban group factors. We discuss these factors in the following sections.

2.1. Internal Factors

2.1.1. Structural Type

Structural type is an important factor of the seismic resilience of buildings, which influences their stiffness, layout, force transmission path, and failure mechanism. And different structural types lead to various seismic responses. Therefore, the different structural types under the same ground motion lead to different structural damages and building function loss, leading to different personal casualties. Based on the perspective of regional distribution, the proportion of housing structures is closely related to the level of economic development. In regions with a higher development of the regional economy, the proportion of high-rise structures and multi-story concrete structures is higher. Therefore, for the different levels of economic development of cities, the proportion of housing structures in these places is different. Based on the first national comprehensive risk survey of natural disasters, we obtained the data on millions of houses in Shaanxi Province. Based on the standard [21], we divided the urban housing structure into six categories, including high-rise concrete structures, multi-story concrete structures, steel structures, masonry structures, open structures, and steel-concrete composite structures. Taking Ankang City in Shaanxi Province as an example, the housing data comprised about 602,200 buildings and 190.4316 million square meters. The divided structural types are summarized in Table 1.

Table 1. Proportion of housing area in different structure types.

Structural Style	High-Rise Concrete Structure	Multi-Story Concrete Structure	Masonry Structure	Steel Structure	Open Structure	Steel-Concrete Composite Structure	Other
Proportion/%	13.1	38.3	26.6	8.4	5.4	4.6	3.6

2.1.2. Construction Age

As we know, the houses built in different periods are based on different standards and specifications [22]. Thus, the construction age can reflect some key factors, such as building fortification standards, building materials, and construction quality. A series of standards have been issued in China, including the seismic design of industrial and civil buildings (TJ 11-74) in 1974, the code for the seismic design of industrial and civil buildings (TJ 11-78) in 1978, the code for the seismic design of buildings (GBJ11-89) in 1989, the code for the seismic design of buildings (GB50011-2001) in 2001, and the code for the seismic design of buildings (GB50011-2010) in 2010. Each revision of the code for seismic design marks the continuous improvement and progress in the seismic fortification level of buildings in China [22]. Based on the successive revision of these codes, we divided the building construction years into four types: before 1989, 1990–2000, 2001–2010, and after 2011. We also took Ankang City in Shaanxi Province as an example, and the proportions of houses with different construction years are summarized in Table 2.

Table 2. Proportion of housing area in different construction years.

Construction Year	Built before 1989	1990–2000 Build	2001–2010 Build	After 2011 Build
Proportion/%	15.6	19.2	30.3	34.9

2.1.3. Building Function

In the cities with dense population and wealth, earthquakes will cause serious consequences, because of damage to non-structural components or structures. The interior of houses with different building functions will have different non-structural components, decorations, equipment configurations, etc. (such as schools, hospitals, and residential buildings), and their seismic performance will differ. And the building function can reflect the internal non-structural components, decoration, equipment configuration, etc. Buildings with different functions (such as schools, hospitals, and residences) have different characteristics, such as the loss effects of building functions, and the urgency and difficulty of building function recovery. In this paper, we divided the urban building groups into five categories according to their architectural functions, including residential buildings, schools, hospitals, offices, and business centers. We took Ankang City in Shaanxi Province as an example, and the proportions of houses with different building functions are summarized in Table 3.

Table 3. Proportion of housing area with different building functions.

Date of Construction	Residence	School	Hospital	Handle Official Business	Commercial Center
Proportion/%	64.3	5.3	3.6	16.2	10.6

2.2. External Factors

External factors refer to social system factors, such as population density, economic level, and disaster relief capacity. As we know, the seismic resilience of urban building groups is not only related to the internal factors of buildings, but also influenced by the external factors of social systems, such as disaster relief ability, population density, and economic level.

Under the same earthquake, a stronger disaster relief ability and a more sufficient allocable building function restoration ability can lead to a shorter function recovery time of urban building groups. A more centralized population and wealth will lead to greater economic losses caused by the earthquake, more serious consequences caused by the building function interruption, and a greater restoration urgency of building functions. Therefore, the study on the seismic resilience of urban building groups, considering the external factors of social systems, will make the evaluation results more accurate and reliable.

For the situation in China, the eastern region has a higher population density and higher economic level than the western region. For the situation of Shaanxi Province, the Guanzhong region has a higher population density and higher economic level than northern and southern region in Shaanxi. Therefore, the population and economic distribution have a significant effect on the seismic resilience of urban building groups.

3. Data of Disaster Risk General Survey Results

The study of seismic resilience evaluation methods for urban building groups requires a large amount of data support, including building data and urban basic data (e.g., disaster relief capacity, population density, economic level). From 2021 to 2022, the first comprehensive risk survey of natural disasters was carried out in China. Based on the risk survey project, we obtained a large amount of construction data and urban basic data, including population, economy, number of disaster relief teams, number of material reserves (tents), and number of medical institutions and emergency plans in Shaanxi Province. After screening and processing, the data could be directly applied to the study of the seismic resilience evaluation method of urban building groups. The data sources of risk census mainly came from the statistical yearbook of the city and county (District); the statistical bulletin of national economic and social development; the official website of the government, the city, and county (district); and the administrative departments of various industries [23,24].

The construction data included residential buildings, schools, hospitals, offices, and business centers throughout the province. The content of the data mainly included building function, structural type, construction age, building area, number of floors, fortification category, seismic fortification intensity, regularity degree, reinforcement and reconstruction, site type, existing disasters, longitude and latitude, construction scale, and cost, as well as data on concrete strength, beam and column section size, reinforcement, shear wall, infill wall, ceiling, and other structural and non-structural components. In addition, detailed construction drawings of 2298 houses were obtained.

We took the Ankang City in Shaanxi Province as an example for analysis. We set a $30'' \times 30''$ kilometer grid as the calculation unit to process the population and economic data. Based on the population and economic data from the first risk survey, we could obtain the processed population kilometer grid data and GDP kilometer grid data of Ankang City, which are drawn in Figures 1 and 2.

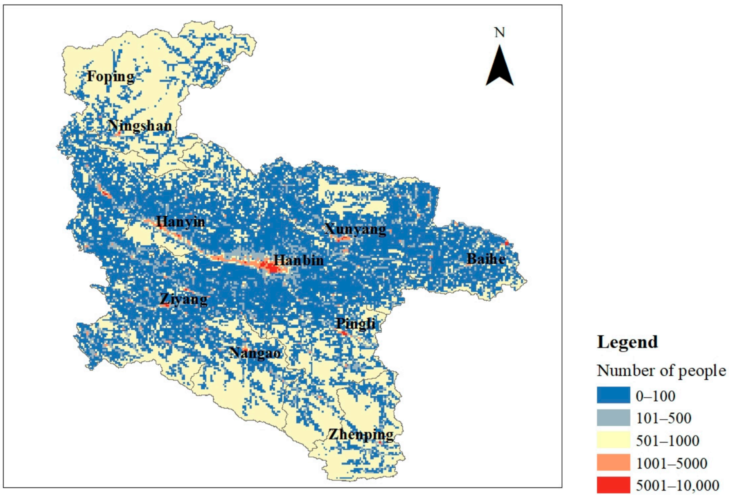


Figure 1. Population kilometer grid data of Ankang City.

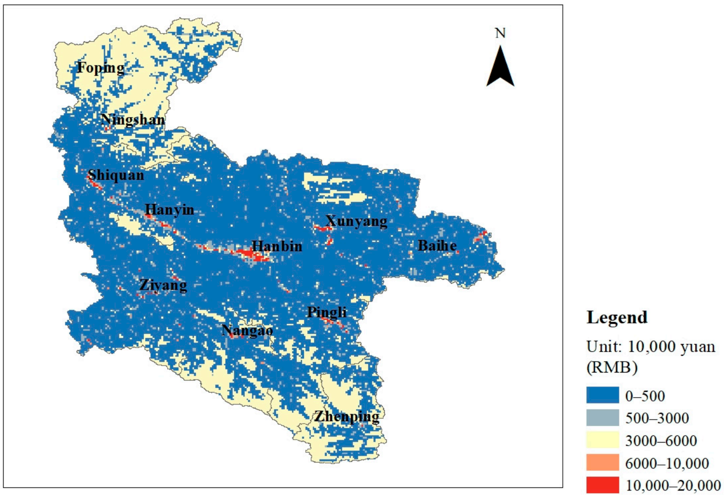


Figure 2. Economic kilometer grid data of Ankang City.

4. Seismic Resilience Evaluation of Urban Building Groups

4.1. Evaluation Index

In existing studies, the popular evaluation indexes of seismic resilience of single buildings are building repair time and cost, personnel death, etc. And there are relatively mature evaluation methods. However, few studies have focused on the recovery time of building function, especially for the urban building groups after an earthquake. In cities with dense population and wealth, an earthquake will cause serious consequences such as building function interruption, because of damage to non-structural components or structures. Meanwhile, there are many differences in the degree of difficulty and the urgency of function recovery of different functional buildings. Therefore, it is important to evaluate the function recovery time of different functional buildings after an earthquake. This section takes the function recovery time as the single index to evaluate the seismic resilience of urban building groups, which helps the government master the building function recovery time and distribution and put forward appropriate emergency countermeasures.

In the evaluation standard for the seismic resilience of buildings, [11] divides the seismic resilience of buildings into three levels according to the repair time of buildings, including three stars (under rare earthquakes: TF $\leq$ 7 d), two stars (under rare earthquakes: TF $\leq$ 30 d), and one star (TF $\leq$ 30 d). Based on the evaluation method of building function restoration time [11], combined with the effect of building function restoration time in historical earthquakes on the function restoration and social order in the disaster regions, and through an expert questionnaire survey, the evaluation results of building seismic resilience were divided into five grades, as shown in Table 4. The relationship between the seismic resilience grade and the function recovery time is proposed in the table.

Table 4. Seismic resilience grade of buildings.

Resilience Rating	First-Class	Second Class	Third-Class	Fourth Class	Fifth Class
T_f/Day	[0,3]	(3,7]	(7,15]	(15,30]	>30

4.2. Quantitative Characterization of the Internal Factors

From the above analysis, the internal factors of the seismic resilience of urban building groups include structural types (represent structural damage and casualties), building functions (represent the building function of non-structural components, decoration, and equipment configuration), and construction years (represent seismic fortification, cost, and materials). We found that the above three factors are not independent of each other. Therefore, we used the multi-level classification tree method to classify and process existing building data, as shown in Figure 3. Based on the internal factors, the multi-level classification tree method was used to classify building data into many types of "level" and "class", which makes the calculation results more accurate.

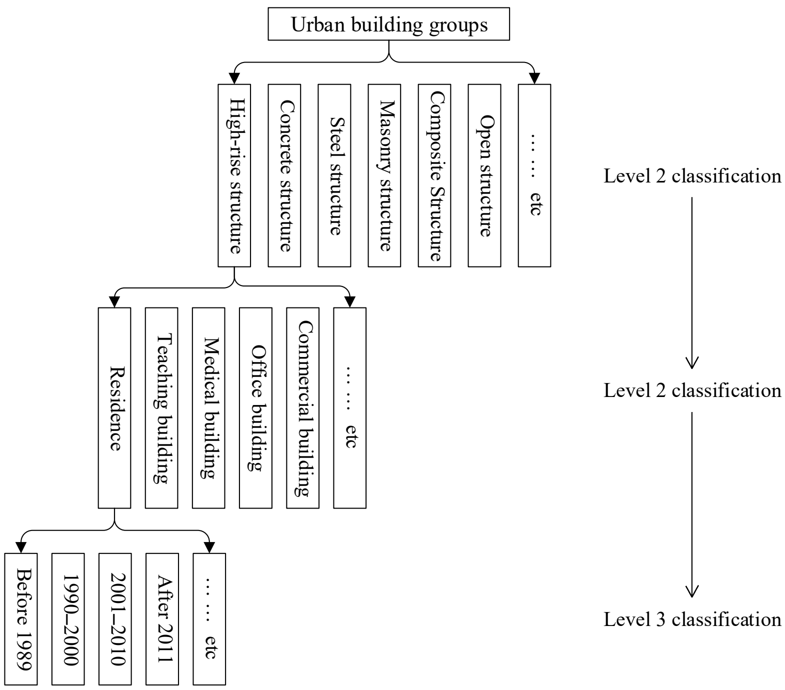


Figure 3. Multilevel tree classification of building data.

Based on the building data, we divided the urban building groups into 120 building units. Then, we selected 120 different building units as typical individual buildings with detailed survey data and construction drawings. In that case, we used the mature evaluation method of individual buildings [11] to calculate seismic resilience. Therefore, we proposed the evaluation method for internal factors of the seismic resilience of urban building groups. In order to improve computational efficiency, the vulnerability information of structural and non-structural components was based on the existing evaluation software of building seismic resilience [11,25]. Except for structural type, building function, and construction year, more internal factors can also be considered in future studies.

4.3. Quantitative Characterization of External Factors

4.3.1. Quantitative Characterization Method

We set a 30″ × 30″ kilometer grid as the calculation unit to analyze the external factors, such as population density, economic level, and disaster relief capacity. Then, we proposed an evaluation method for seismic resilience of urban building groups that considers the external factors. And we proposed the kilometer grid coefficient (M_{i}) to characterize the various external factors quantitatively. Then, the kilometer grid coefficient (M_{i}) of each external factor was combined by each weight value to obtain the comprehensive kilometer grid coefficient (U_{i}), which quantitatively characterizes the external factors on the seismic resilience of urban building groups.

From the above, this paper used the 30″ × 30″ kilometer grid as the calculation unit and used the comprehensive kilometer grid coefficient (U_{i}) to quantitatively characterize and calculate the comprehensive effect of external factors, such as population density, economic level, and disaster relief capacity. Thus, the seismic resilience of urban building groups can be accurately evaluated.

4.3.2. Various Kilometer Grid Coefficients

(1) Population density and economic level

Based on the ArcGIS platform, we obtained basis data in each kilometer grid, including the population data, GDP value, etc. Then, we used the ratio of population density (R_i) and GDP value (E_i) in each kilometer grid to the corresponding average value to represent the dimensionless coefficient. Therefore, we obtained the relative coefficient of the kilometer grid for population density (P_i) and economic level (J_i).

Based on the 23 historical earthquake data points summarized in reference [26], we assumed that the functional recovery time of the disaster region was approximately equal to the recovery time of the communication system. And the relationship between population density, economic level, and the function recovery time can be fitted as follows.

$$K_1 = -0.32\ln R_i + 2.45 \quad (1)$$

$$K_2 = 3.39E_i^{-0.238} \quad (2)$$

where K_1 is the correction coefficient of the population density, K_2 is the correction coefficient of the economic level, R_1 is the population density, and E_i is the GDP value.

By using K_1 and K_2 to correct P_i and J_i, we can obtain the kilometer grid coefficient (M_{1i}) of population density and the kilometer grid coefficient (M_{2i}) of economic level, respectively. They can characterize the effect of population density and economic level on the seismic resilience of urban building groups. Taking the population density as an example, the calculation process is as follows:

$$M_{1i} = P_i K_1 \quad (3)$$

$$P_i = \frac{R_i}{\overline{R}} \quad (4)$$

$$\overline{R} = \frac{1}{n}\sum_{i=1}^{n} R_i \quad (5)$$

where M_{1i} is the kilometer grid coefficient of population density; P_i is the relative coefficient of population density; K_i is the correction coefficient of population density; R_{i} is the population density in each kilometer grid; and $\overline{R}$ is the average population density of the entire kilometer grid.

(2) Disaster relief capabilities

Based on the "National Earthquake Emergency Plan" and expert questionnaire research, we determined the elements and quantitative characterization of disaster relief capabilities. The disaster relief capacity was calculated in a 30″ × 30″ kilometer grid unit. We divided disaster relief capabilities into five levels by considering a series of factors, including the number of disaster relief teams, material reserves, medical institutions, and emergency plans. The impact coefficient values of the corresponding level of disaster relief capability are shown in Table 5. It should be noted that the corresponding impact level should meet the four requirements within the kilometer grid simultaneously, and then the kilometer grid impact coefficient can take the corresponding value.

Table 5. Kilometer grid impact coefficient of disaster relief capacity.

Impact Level	First-Class	Second Class	Third-Class	Fourth Class	Fifth Class
Kilometer grid influence coefficient (W_i)	1.6	1.3	1.0	0.7	0.4
Number of disaster relief teams	≤8	9–15	16–25	26–40	More than 40
Quantity of material reserves/(tent)	≤5	6–10	11–15	16–20	More than 20
Number of medical institutions	0	≤1	2	3	4 or more
Emergency plan	incomplete	incomplete	Relatively complete	complete	complete

4.3.3. Weighting Values of the Influence Factors

Based on the Analytic Hierarchy Process [22], we calculated the weight values of external factors, including population density, economic level, and disaster relief capacity. The Analytic Hierarchy Process includes the following four steps: (1) establish a hierarchical structure model; (2) construct a judgment matrix; (3) calculate the maximum feature roots and feature vectors (i.e., weights); and (4) check consistency. For the matrix that passes the inspection, we can use the geometric average method to calculate the weight values, as follows.

$$r_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}} \quad (6)$$

where i = 1, 2, 3 . . . n; r_i is the weight value of each factor; a_{ij} is the correlation coefficient of the factors; and n is the number of the factors. Then, the calculation weight values of influencing factors are summarized in Table 6.

Table 6. Weight values of various influence factors.

Influence Factor	Population Density	Economic Level	Disaster Relief Capability
Weight value	0.16	0.31	0.53

4.3.4. Comprehensive Kilometer Grid Coefficient

We obtained the comprehensive kilometer grid coefficient (U_i) by combining the kilometer grid influence coefficients of population density (M_{1i}), economic level (M_{2i}), disaster relief capacity (M_{3i}), and the corresponding weight values. The comprehensive kilometer grid coefficient can quantitatively reflect the effect of population density, economic level, disaster relief capacity, and other factors within the *i*-th kilometer grid on the seismic resilience of urban building groups, as follows.

$$U_i = r_1 M_{1i} + r_2 M_{2i} + r_3 M_{3i} \quad (7)$$

where U_i is the comprehensive kilometer grid coefficient of seismic resilience of urban building groups, and r_1, r_2, and r_3 represent the weight values of the influence factors.

4.4. Evaluation Model of Seismic Resilience of Urban Building Groups

From the above sections, we analyzed the effect of internal factors and external factors on the seismic resilience of urban building groups. And we proposed the corresponding calculation method, based on the quantitative relationship. Therefore, this section establishes the evaluation model of seismic resilience of urban building groups with internal and external factors.

We establish the evaluation model of seismic resilience for urban building groups in the following steps. First, a multi-level classification tree method is used to refine the classification of the building data. The complex urban building group can be divided into *N* building units. It is assumed that the database is large and extensive. Thus, the urban building groups in any region can be simulated by the combination of M $(M \leq N)$ building units in the database. Then, one typical building is selected in each building unit and calculated to obtain the functional recovery time T_i. The calculated process is the seismic resilience evaluation method of single buildings in the standard [11], which only considers the internal factors. Based on the seismic resilience calculation results and the longitude and latitude of all individual buildings in the ArcGIS platform, we can obtain the seismic resilience calculation results and distribution of urban building groups that only consider internal factors. Subsequently, the urban basic data are partitioned into kilometer grids. And we can obtain the comprehensive kilometer grid coefficient U_i to quantitatively calculate the comprehensive impact of the external factors. Finally, the seismic resilience calculation result (T_i) of the internal factors is corrected using the comprehensive kilometer grid coefficient U_i of the external factors, which is the seismic resilience evaluation result of urban building groups with internal and external factors (e.g., $T_i \times U_i$). Based on the above ideas, the flowchart of the evaluation model of seismic resilience for urban building groups through classification and zoning is shown in Figure 4.

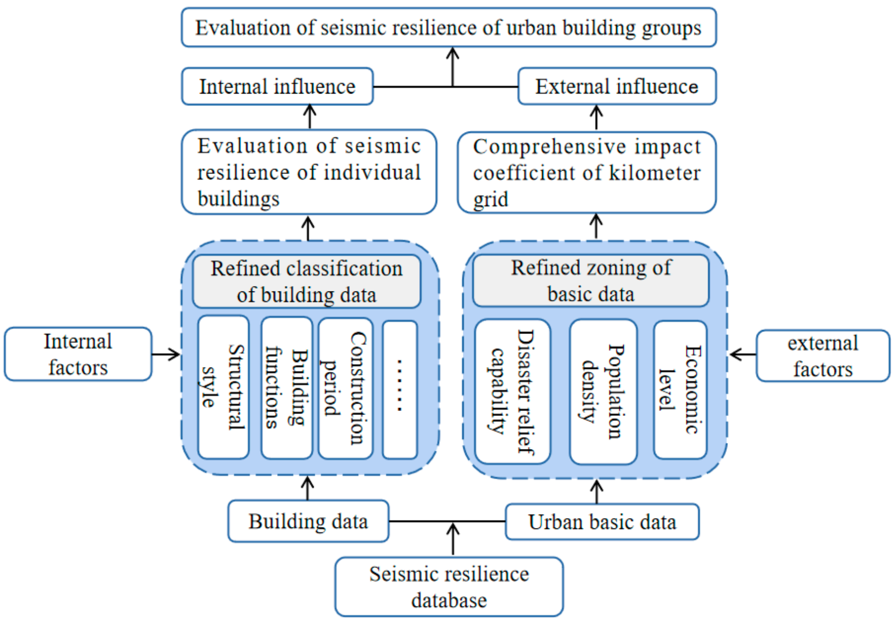


Figure 4. Flow chart for seismic resilience evaluation of urban building groups through classification and zoning.

5. Evaluation System of Seismic Resilience Ability of Urban Building Groups

In order to achieve a large-scale and extensive evaluation of urban building groups and increase the visualization function, it is necessary to combine the calculation results of seismic resilience with geographic information disciplines. And this section uses different colors to mark the kilometer grids to reflect the functional recovery time and distribution of urban building groups. Therefore, the evaluation results can be accurately and effectively presented to decision-makers. By applying the seismic resilience evaluation method on the ArcGIS platform, we can establish the seismic resilience evaluation system of urban building groups. From the above, the evaluation system of the seismic resilience capacity of urban building groups was established. And the evaluation results can be visualized.

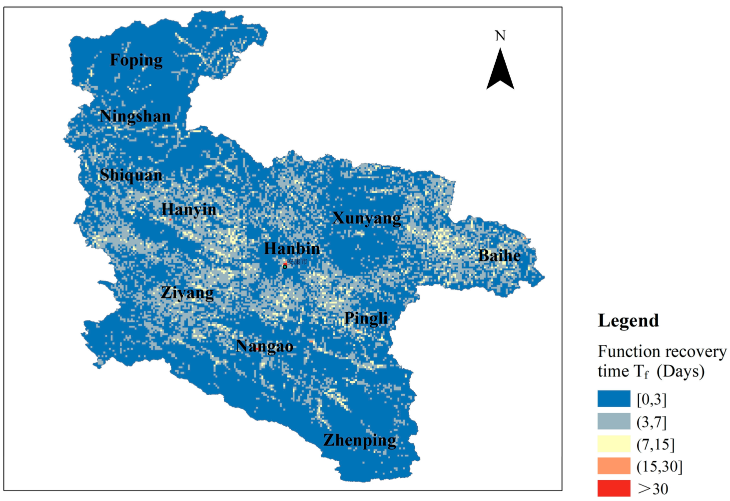
The section takes Ankang City in Shaanxi Province as an example to describe the proposed method. Based on the proposed refined classification research method, tens of thousands of urban building groups in Ankang City were divided into 120 building units, which were selected in the study area. Then, the existing evaluating methods of individual buildings were used to calculate the seismic resilience and analyze the effect of internal factors on the seismic resilience of urban building groups. And the proposed kilometer grid coefficient was used to calculate the effect of external factors on the seismic resilience of Ankang City. Finally, the seismic resilience evaluation results of the building groups in Ankang City were obtained using the post-earthquake functional recovery time.

By using the proposed model and above system, the seismic resilience of building groups in Ankang City was calculated under three levels of earthquake action with exceedance probabilities of 63%, 10%, and 2% in 50 years. Under the three levels of earthquake action, the evaluation results and distribution of seismic resilience are summarized in Figure 5.

The study results show that under an earthquake with a probability of exceeding 63% in 50 years, 98.6435 million square meters of buildings in Ankang City can be restored within 3 days, 136.7278 million square meters can be restored within 7 days, and 11.8067 million square meters can be restored over 30 days.

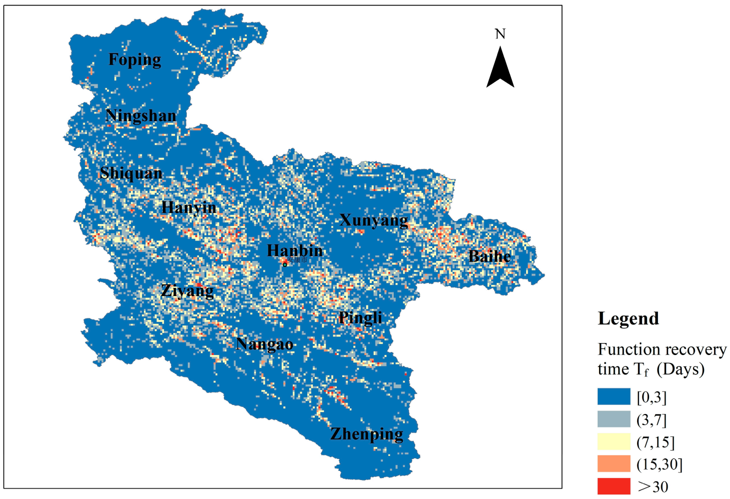
Under an earthquake with a probability of exceeding 10% in 50 years, 35.4203 million square meters of houses can be restored within 3 days, 63.6042 million square meters can be restored within 7 days, and 28.9456 million square meters can be restored over 30 days.

Under an earthquake with a probability of exceeding 2% in 50 years, 9.9024 million square meters of houses can be restored within 3 days, 33.1351 million square meters can be restored within 7 days, and 93.3115 million square meters can be restored over 30 days.

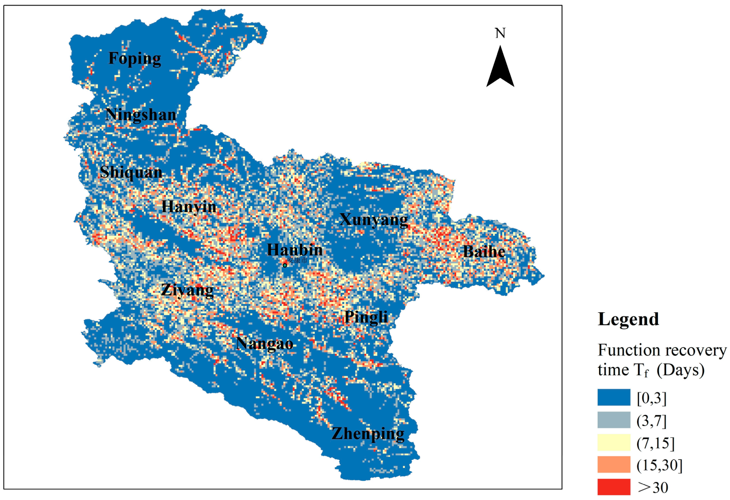


(**a**)

Figure 5. *Cont.*



(**b**)



(**c**)

Figure 5. Distribution of seismic resilience capacity of building groups in Ankang City: (**a**) 50-year probability of exceeding 63%; (**b**) 50-year probability of exceeding 10%; and (**c**) 50-year probability of exceeding 2%.

In addition, this section calculates the proportion of building area in different functional recovery times after encountering earthquakes with different probability levels in the Ankang City building groups, as shown in Tables 7–9.

Table 7. Proportion of building function recovery time under earthquake action with a probability of exceeding 63% in 50 years/%.

Function Recovery Time/Day	[0,3]	(3,7]	(7,15]	(15,30]	>30
Residence	53	16	14	9	8
Teaching building	60	16	11	8	5
Medical building	54	21	13	6	6
Office building	47	25	16	7	5
Commercial building	45	22	19	7	7

Table 8. Proportion of building function recovery time under earthquake action with a probability of exceeding 10% in 50 years/%.

Function Recovery Time/Day	[0,3]	(3,7]	(7,15]	(15,30]	>30
Residence	21	14	17	31	17
Teaching building	15	18	22	32	13
Medical building	18	15	28	21	18
Office building	15	16	31	26	12
Commercial building	24	11	28	21	16

Table 9. Proportion of building function recovery time under earthquake action with a probability of exceeding 2% in 50 years/%.

Function Recovery Time/Day	[0,3]	(3,7]	(7,15]	(15,30]	>30
Residence	9	12	12	16	51
Teaching building	3	14	19	15	49
Medical building	4	12	24	14	46
Office building	2	14	21	15	48
Commercial building	8	9	13	19	51

6. Conclusions

This paper mainly focuses on the factors that influence the seismic resilience and the evaluation methods of seismic resilience of urban building groups. Then, this paper proposes an innovative evaluation method for seismic resilience of urban building groups, which considers the internal and external factors. Therefore, the preliminary evaluation of the seismic resilience capacity of urban building groups is achieved. Based on the above studies, the following conclusions are drawn.

(1) A quantitative characterization method for the internal factors on the seismic resilience of urban building groups was proposed through the refined classification study of urban building groups.
(2) A quantitative relationship model was proposed between external factors and evaluation indicators, including disaster relief capacity, population density, and economic level. The comprehensive kilometer grid coefficient was proposed to characterize and calculate the effect of external factors on the seismic resilience of urban building groups.
(3) Based on the quantitative characterization and calculation method of the effect of internal and external factors on the seismic resilience of urban building groups, we established the evaluation model for the seismic resilience of urban building groups.
(4) Based on the proposed method, we calculated the seismic resilience of buildings in Ankang City. Under minor earthquakes, about 55% of buildings can be restored to use within 3 days, and about 90% of buildings can be restored to use within 15 days. Under moderate earthquakes, about 18% of buildings can be restored to use within 3 days, and about 58% of buildings can be restored to use within 15 days. Under major earthquakes, only 5% of buildings can be restored to use within 3 days, while over 50% of buildings would require over 30 days to be restored or would be difficult to repair.

In this article, the proposed evaluating method for the seismic resilience of urban building groups only attempts to consider the influence of three external factors, i.e., population density, economic level, and disaster relief capacity. In order to obtain more accurate evaluation results of the resilience of urban building groups, it is necessary to fully consider more external factors and the coupling effect between various factors in future studies.

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