Study on Evaluation of Earthquake Evacuation Capacity in Village Based on Multi-level Grey Evaluation

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Abstract

The earthquake evacuation capacity in village is the ability measuring whether the residents can be safely evacuated during the earthquake and life can be effectively guaranteed after the earthquake. At present, the evaluation of earthquake evacuation capacity is short of effective methods in earthquake engineering, which not only affect the earthquake disaster prevention function of all kinds of resources, but also influence the refuge after the earthquake. Focusing on the earthquake evacuation capacity in village, the main influencing factors are discussed and an evaluation index system is established. By using AHP adopting index scale and multi-level grey evaluation, a method is presented. An illustration is provided to prove that the method is feasible.

Keywords: earthquake evacuation capacity; earthquake engineering; index scale; analytical hierarchy process (AHP); multi-level grey evaluation

1. Introduction

China is a more frequent earthquake country, located in the world's most active seismic zone between circum-Pacific seismic belt and the Eurasian seismic zone. According to “Seismic Ground Motion Parameter Zonation Map of China” (GB18306-2001), 6 degrees to 9 degrees earthquake region of China take up 60% of land area, of which more than 90% is rural areas and more than 90% of previous earthquake happened in the country. On the equal seismic intensity’s condition, the casualties and building damage in village are much higher than in city, because the rural economy is backward and public seismic facilities in rural villages are weak. Both the Wenchuan Earthquake in 2008 and the Yushu Earthquake in 2010 discover the above issues. One of the reasons leading to these problems is that the villagers do not consider seismic protection and construction quality is very poor. Another important reason is the lack of shelter space, the lower fortification level of transportation, medical care, communications and...
other disaster relief facilities [1] and the irrational spatial layout of these facilities.

The earthquake evacuation is that after the impending earthquake prediction released or when earthquake occurs, we can urgently move the residents from high-risk homes and work places to shelters which have been scientifically programmed beforehand, have standard management and provide basic living security system [2]. The earthquake evacuation capability in village is related to whether the residents can be safely evacuated during the earthquake and life can be effectively guaranteed after the earthquake. It is important for enhancing the ability of responding to disasters and protecting the safety of life and property, promoting rural economic and social sustainable development to study on evaluation methods of earthquake evacuation in village during the process of rural-urban integration.

2. Establishing evaluation indicator system

The establishment of evaluation indicator system of earthquake evacuation need take various resources with the capabilities of evacuation and disaster relief as evaluation index, to ensure critical resources to play a role of relief and supporting after earthquake.

2.1. Organization and management system

- Emergency organization of earthquake. The role of emergency administrative organization of earthquake is reasonably coordinating the work of various departments and achieving emergency earthquake evacuation and disaster relief, efficiently and orderly.
- Earthquake evacuation programming and contingency planning. The earthquake evacuation programming is the layout of shelter and road to meet the demand of the personnel in planning area for refuge and ensure the smooth flow of external relations in the earthquake. The earthquake contingency planning is including earthquake emergency management, command and rescue plans.

2.2. Seismic shelter for evacuation

- Seismic shelter for evacuation. The seismic shelter for evacuation is a refuge space that is built or rebuilt for victims according to earthquake evacuation programming [3].
- Evacuation road. The evacuation road system is a channel for evacuating people and transporting materials and controlling fire, and is an important part of seismic shelter for evacuation system.

2.3. Relief resources

- Medical assistance. The devastating earthquake will cause casualties to some extent. If the shelter is far from the hospital and is short of medical staff and the equipment is obsolete, a large number of casualties may dead due to delayed treatment.
- Material support. Emergency materials are one of the supporting conditions for earthquake evacuation. In the Wenchuan Earthquake, The lack of emergency supplies reserve and transportation difficulties because of road congestion affect the post-earthquake relief and refuge living of victims.
- Fire protection. When an earthquake occurs, the building collapses and combustible materials encountering a fire source can easily cause a fire. Victims in the refuge need fire control resources.

2.4. Emergency infrastructure

- Emergency communication. When the existing communication system is severely damaged or the emergency occurs, emergency communication facilities must be established for protecting the transmission of disaster information, relief information and personnel’s safety and danger information [4].
- Emergency water supply. The water supply system is an important part of the lifeline system of victims.
- Emergency power supply. The power supply system plays a great role in evacuation and rescue after the earthquake. If the power supply system is damaged, the device relying on the power will lose effectiveness.
The evaluation indicator system of earthquake evacuation consists of four parts, as shown in Table 1. In the table, the three layers of evaluation indicators are distributed. At last, the evaluation indicator system of earthquake evacuation capability in village is built.

### 3. Evaluation of earthquake evacuation capacity in village used multi-level grey method

Table 1 Evaluation indicator system of earthquake evacuation in village

<table>
<thead>
<tr>
<th>Target</th>
<th>The first level indicators</th>
<th>The second level indicators</th>
<th>The third level indicators</th>
</tr>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Organization and management system</td>
<td>Emergency organization of earthquake</td>
<td>Emergency administrative organization of earthquake</td>
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<td></td>
<td>Earthquake evacuation programming and contingency planning</td>
<td>Resident self-help organization</td>
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<td></td>
<td>Seismic shelter for evacuation</td>
<td>Earthquake evacuation programming</td>
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<td>Earthquake contingency planning</td>
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<td></td>
<td>Evacuation roads</td>
<td>Per capita effective area</td>
<td></td>
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<td></td>
<td>Medical assistance</td>
<td>The cover ratio of site services</td>
<td></td>
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<tr>
<td>Relief resources</td>
<td>Material support</td>
<td>The passage capacity of site</td>
<td></td>
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<tr>
<td></td>
<td>Fire protection</td>
<td>The number of passageway in village</td>
<td></td>
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<tr>
<td></td>
<td>Emergency communication</td>
<td>The effective width of the road</td>
<td></td>
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<tr>
<td></td>
<td>Emergency water supply</td>
<td>The distance of shelter and hospital</td>
<td></td>
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<tr>
<td></td>
<td>Emergency power supply</td>
<td>The number of doctor per thousand persons</td>
<td></td>
</tr>
<tr>
<td>Emergency infrastructure</td>
<td></td>
<td>The distance of shelter and material storage</td>
<td>Relief food reserves</td>
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</tbody>
</table>

These indicators of earthquake evacuation capacity in village are multi-level and complex, and most of indicators are qualitative. Therefore, the information in the evaluation process is uncertain and incomplete, which is named Grey. Therefore, the multi-level grey method [5], [6] is used in this paper to provide decision support on the evaluation of earthquake evacuation capacity in village.

The theories of multi-level grey method are as follows:

Assuming that the total object is $U$, the indicator of the first level is $u_i (i = 1,2,\cdots, l)$ and $l$ is the number of the first level indicators. The indicator of the second level is $u_{ij} (j = 1,2,\cdots, m^i)$ and $m^i$ is the number of the second level indicators included in $u_i$. The indicator of the third level is $u_{ijk} (k = 1,2,\cdots, n^{ij})$ and $n^{ij}$ is the number of the third level indicators included in $u_{ij}$.  

#### 3.1. Determining the weight of indicators

AHP method is used to determine the weight of all indicators. According to [7], when using index scale to build the comparison matrix, the consistency and fit of scale-weight are better than using classic 1-9 scale. Therefore, $9^{th}$-$9^{th}$ index scale is used to build the comparison matrix, and MATLAB is used to confirm the consistency of comparison matrix for reducing the computing error. The details of $9^{th}$-$9^{th}$ index scale can be found in [7].
Assuming that $a_i$ is the weight of $u_i$, then $A = (a_1, a_2, \ldots, a_i)$ is the weight vector of the first level indicators; assuming that $a_{ij}$ is the weight of $u_{ij}$, then $A = (a_{ij1}, a_{ij2}, \ldots, a_{ijn})$ is the weight vector of the second level indicators; assuming that $a_{ijk}$ is the weight of $u_{ijk}$, then $A = (a_{ijk1}, a_{ijk2}, \ldots, a_{ijkn})$ is the weight vector of the third level indicators.

3.2. Constituting comment set of evaluation indicator

We make out all the comment set of evaluation indicator. For example, the assessment standard was divided into four grades: excellent, good, medium and bad. These are endowed with the following values: 4~3, 3~2, 2~1 and 1~0. The bigger point means the better rank.

3.3. Confirmation of evaluation sample matrix

Assuming the value of $u_{ijk}$ that be given from the estimator $h(h = 1, 2, \ldots, p; p$ is the number of estimators) is $d_{ijkh}$, then the sample matrix for gray evaluation is $D$,

$$D = \begin{bmatrix}
d_{i11} & d_{i12} & \cdots & d_{i1p} \\
d_{i21} & d_{i22} & \cdots & d_{i2p} \\
\vdots & \vdots & \ddots & \vdots \\
d_{in1} & d_{in2} & \cdots & d_{inp}
\end{bmatrix} \begin{bmatrix}
u_{i11} \\
u_{i12} \\
\vdots \\
u_{in}
\end{bmatrix}$$

3.4. Determining the Gray Category

Assuming that the grade of gray category is $e(e = 1, 2, \ldots, g)$, that is, there have $g$ gray categories. By the fact itself, the difference whitening function can be chosen to describe gray category [8].

3.5. Calculating the coefficient for gray evaluation

For the indicator $u_{ijk}$, the coefficient for gray evaluation that the target evaluated is belonging to the gray category $e$ is written as $X_{i1e}$, then $X_{i1e} = \sum_{h=1}^{p} f_e(d_{ijkh})$, where $f_e$ is whitening function for the gray category $e$. For the indicator $u_{ijk}$, the total gray evaluation coefficient of the target belonging to the every gray category is expressed as $X_{ijk} = \sum_{e=1}^{g} X_{i1e}$.

3.6. Calculating the weighting vector and the weighting matrix of gray evaluation

For the indicator $u_{i1}$, the gray evaluation weight of all estimators considering that the target should belong to the category $e$ is written as $r_{i1e}$, then $r_{i1e} = X_{i1e}/X_{iyk}$, and the weight vectors of gray evaluation is $r_{ijk} = (r_{ijk1}, r_{ijk2}, \ldots, r_{ijkg})$. The gray evaluation weighting matrix of $u_{i1}$ for all gray categories can be obtained and written as $R_{ij}$. 
3.7. Multi-level gray comprehensive evaluation

The result of \( u_i \) comprehensive evaluation is written as \( B_i \), then \( B_i = A_i \cdot R_i = (b_{i1}, b_{i2}, \cdots, b_{ig}) \).

As to the indicator \( u_i \), through the comprehensive evaluation result of \( u_i \), the gray evaluation weighting matrix of \( u_i \) for all gray categories can be obtained, and written as \( R_i \), then

\[
R_i = \begin{bmatrix}
    B_{i1} \\
    B_{i2} \\
    \vdots \\
    B_{im}
\end{bmatrix} = \begin{bmatrix}
    b_{i11} & b_{i12} & \cdots & b_{i1g} \\
    b_{i21} & b_{i22} & \cdots & b_{i2g} \\
    \vdots & \vdots & \ddots & \vdots \\
    b_{im1} & b_{im2} & \cdots & b_{img}
\end{bmatrix}
\]

The result of \( u_i \) comprehensive evaluation is written as \( B_i \), then \( B_i = A_i \cdot R_i = (b_{i1}, b_{i2}, \cdots, b_{ig}) \).

As to the total object \( U \), through the comprehensive evaluation result of \( u_i \), the gray evaluation weighting matrix of \( U \) for all gray categories can be obtained, and written as \( R \), then

\[
R = \begin{bmatrix}
    B_1 \\
    B_2 \\
    \vdots \\
    B_m
\end{bmatrix} = \begin{bmatrix}
    b_{11} & b_{12} & \cdots & b_{1g} \\
    b_{21} & b_{22} & \cdots & b_{2g} \\
    \vdots & \vdots & \ddots & \vdots \\
    b_{m1} & b_{m2} & \cdots & b_{mg}
\end{bmatrix}
\]

The result of \( U \) comprehensive evaluation is written as \( B \), then \( B = A \cdot R = (b_1, b_2, \cdots, b_g) \).

3.8. Calculating the comprehensive evaluation value

According to the maximum principle, we can determine the grey grades of the earthquake evacuation capacity in village. But sometimes judgments will be distorted because of losing too much information. At this time, we can deal with \( B \) further, make it single-value using. The vector value of each grade of gray category is \( C \), \( C = (d_1, d_2, \cdots, d_g) \). Then the comprehensive evaluation target is \( W, W = B \cdot C^T \). According to the value of \( W \), strong or weak of earthquake evacuation capacity can be estimated, and the value is the more the better.

4. The application of multi-level gray evaluation method

Using the indicator system and evaluation method above, this section will evaluate the earthquake evacuation capacity of a town. All origin data come from the article [9].

4.1. Determining the weight of indicators

According to the point by experts given and using the index scale, the comparison matrix can be built. As example, the comparison matrix of the first level indicators is \( Z \), then
The weight vector is \( A = (0.0665, 0.4690, 0.2878, 0.1766) \). In the same way, \( A_i \sim A_{43} \) can be get.

4.2. Constituting comment set of evaluation indicator

All the comment set of the third level indicators \( u_{ik} \) can be found in table 2.

Table 2 The assessment standard of earthquake evacuation capacity in village

<table>
<thead>
<tr>
<th>Point</th>
<th>4.0~3.0</th>
<th>3.0~2.0</th>
<th>2.0~1.0</th>
<th>1.0~0.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>Excellent</td>
<td>Good</td>
<td>medium</td>
<td>bad</td>
</tr>
</tbody>
</table>

4.3. Determining the sample matrix

According to the table 2, the points are given by 5 experts. Then we can get the sample matrix \( D \).

\[
D = \begin{bmatrix}
        d_{111} & d_{112} & d_{113} & d_{114} & d_{115} \\
        d_{121} & d_{122} & d_{123} & d_{124} & d_{125} \\
        \vdots & \vdots & \vdots & \vdots & \vdots \\
        d_{431} & d_{432} & d_{433} & d_{434} & d_{435}
\end{bmatrix}
\]

\[
= \begin{bmatrix}
        4 & 4 & 3.7 & 3.5 & 3.6 \\
        0.3 & 0.5 & 0.5 & 0.5 & 0.3 \\
        \vdots & \vdots & \vdots & \vdots & \vdots \\
        0.3 & 0.2 & 0.5 & 0.5 & 0.3
\end{bmatrix}
\]

4.4. Determining the gray category

There are four categories and \( g = 4 \). The gray number and the whitening function are as follows: the first one is "excellent" and its whitening function is \( f_1(x) \) (figure 1(a)); the second one is "good" and its whitening function is \( f_2(x) \) (figure 1(b)); the third one is "medium" and it's whitening function is \( f_3(x) \) (figure 1(c)); the forth one is "bad" and it's whitening function is \( f_4(x) \) (figure 1(d)).

![Fig.1 The relation between gray number and the whitening function](image)

4.5. Calculating the coefficient for gray evaluation

For \( u_{111} \cdot X_{111} = 4.7; X_{1112} = 3.733; X_{1113} = 0.6; X_{1114} = 0 \). The total gray evaluation coefficient of the target belonging to the every gray category is \( X_{111} = 9.033 \). we can get other total gray evaluation coefficients in this way.
4.6. Calculating the weighting vector and the weighting matrix of gray evaluation

The weighting vector that all estimators believe that indicator $u_{111}$ belong to each gray category is $r_{111} = (0.520, 0.413, 0.67, 0)$. Then after the weighting vector of gray evaluation being synthesized, $R_{11}$ can be obtained. We can get $R_{12} \sim R_{43}$ in the same way.

$$R_{11} = \begin{bmatrix} 0.520 & 0.413 & 0.067 & 0 \\ 0.072 & 0.096 & 0.145 & 0.687 \end{bmatrix}$$

4.7. Multi-level gray comprehensive evaluation

For $u_{11}$, the result of comprehensive evaluation is written as $B_{11}$. In a similar way, we can get $B_{12} \sim B_{43}$.

$$B_{11} = A_{11} \cdot R_{11} = (0.4362, 0.3538, 0.081, 0.129)$$

For $u_{1}$, through the comprehensive evaluation result of $u_{i,j}$, $R_{i}$ (in the same way), can get $R_{2} \sim R_{4}$ can be obtained, then

$$R_{1} = \begin{bmatrix} B_{11} \\ B_{12} \end{bmatrix} = \begin{bmatrix} 0.4362 & 0.3538 & 0.081 & 0.129 \\ 0.4243 & 0.4293 & 0.1465 & 0 \end{bmatrix}$$

The result of $u_{1}$ comprehensive evaluation is $B_{1} = A_{1} \cdot R = (0.4339, 0.3679, 0.0933, 0.1048)$. For the total object $U$, the gray evaluation weighting matrix for all gray categories can be obtained, and written as $R$. The result of $U$ comprehensive evaluation is $B = A \cdot R = (0.4217, 0.3555, 0.1069, 0.1158)$.

4.8. Calculating the comprehensive evaluation value

Assuming that $C = (4, 3, 2, 1)$, then the comprehensive evaluation value of target is $W = B \cdot C^T = 3.083$.

According the analysis above, the earthquake evacuation capacity of this town belongs to "excellent" gray category, but it also close to the "good" gray category. All experts agree with the result.

5. Conclusion

The paper analyzes the main factors, which are the key resources for disaster prevention and supporting the life of residents in village, and has established evaluation indicator system of earthquake evacuation capacity in village. By using multi-level grey evaluation, the distributed information process of estimators is described as a weighting vector. Make the vector single-value and comprehensive evaluation value is calculated. The uncertainty which results from the individual differences of expert is avoided. Considering the influence of the evaluation indicator’s weight to assessment results, AHP adopting index scale is used to determine index the weight of indicators. So the consistency and fit of the result are better than using classic scale and the accuracy of evaluation results is improved, which is important for earthquake engineering.

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References


