A Stability Evaluation Method of the Subgrade Loess Landslide

Yong Yao

ABSTRACT

Landslide is the inevitable geological hazard in all kinds of linear engineering. Based on the principle of fuzzy transformation and the principle of maximum membership degree, a method for the landslide stability was established. The indexes of landslide macroscopic deformation and slope characteristics were chosen as the evaluation factors, which were divided into stability, basic stability, instability and extreme instability. The weights were determined according to the scoring of the present experts. Landslide of the railway station was evaluated by this method, the result is [0.20, 0.23, 0.32, 0.24]. The stability level is unstable. The accuracy of this method is proved by comparing with the standard method.  

INTRODUCTION

A new railway, crosses Ningxia and Northern Shaanxi, reaches the central part of Shanxi and connects with the eastern coastal areas. This railway links the Northwest and Bohai economic circle closely together, strengthens the Northwest, North China, Shandong and other regions of social, economic, cultural, scientific and technological links. The railway plays an irreplaceable role in the implementation of the national strategy for the development of the western region. The topography along the railway section is divided into loess hill topography, loess low-relief terrain topography, loess hilly gully landform, rocky hilly and gully landform river valley landforms etc. The geological conditions are complicated, and the geological hazards such as landslides and debris flows occurrence. These unfavorable geological conditions threaten and hinder the

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construction of the railways and the safe operation in the future. Therefore, the geological disasters along the railway have attracted the attention of relevant researchers [1-2].

In the field, without detailed exploration data and experimental data, how to determine landslide stability preliminarily and rapidly? This problem is a key problem in the line engineering, which has a reference value for determining the direction of the line selection and the preliminary construction design.

In view of this problem, taking the Suide Train Station landslide as an example, a method for judging the stability of landslide is established in this paper. According to the field investigation data, the stability evaluation model is established. At that time, the Suide railway station and the landslide were not investigated in detail, and the data of drilling and soil test were incomplete. The evaluation result was compared with the standard method. The feasibility and correctness of the method were verified.

EVALUATION METHOD

Principle

The basic theories and methods of multilevel fuzzy evaluation in fuzzy mathematics are the principle of fuzzy transformation and the principle of maximum membership degree. The factor set and the hierarchical evaluation set of the fast landslide stability evaluation method are defined as \( U \) and \( V \):

\[
U = \{U_1, U_2, \ldots, U_m\}, \quad V = \{V_1, V_2, \ldots, V_n\},
\]

then the stability fuzzy comprehensive evaluation model is as follows:

\[
B = A \odot R
\]

In the formula, \( R = (r_{i,j})_{m \times n} \) is a fuzzy subset of \( U \times V \), which is usually called fuzzy matrix, obtained by the results of the single factor evaluation. \( r_{i,j} \) is the membership degree to the j comments of factor i.

\[
A = (a_1, a_2, \ldots, a_m) \text{ is a fuzzy subset of } U, \quad 0 \leq a_i \leq 1, \quad \sum_{i=1}^{m} a_i = 1.
\]

\[
B = (b_1, b_2, \ldots, b_n) \text{ is a fuzzy subset of } V, \quad \text{which is called the synthetic judgment result vector.}
\]

\( \odot \) is a composite operator, and ordinary multiplication is used in this paper. The key of fuzzy comprehensive evaluation is to establish the fuzzy relation matrix between \( U \) and \( V \), which are degree of membership and weight.
Determination And Classification of Evaluation Indexes

There is no specific survey data, so indexes which are easily obtained on the spot are chosen as evaluation factors, such as the macroscopic deformation signs of slope and landslide characteristics. According to the comprehensive influence of various evaluation factors on the stability of landslide, the rational stability grade is divided into four grades, there are stability, basic stability, instability and extreme instability (Table 1).

<table>
<thead>
<tr>
<th>Index</th>
<th>Two level index</th>
<th>Stability</th>
<th>Basic stability</th>
<th>Instability</th>
<th>Extreme instability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroscopic deformation sign</td>
<td></td>
<td>No sign</td>
<td>Slight</td>
<td>Commonly</td>
<td>Obvious</td>
</tr>
<tr>
<td>Surface features deformation</td>
<td>Fracture density</td>
<td>0</td>
<td>1-3 /m</td>
<td>4-6/m</td>
<td>&gt;6/m</td>
</tr>
<tr>
<td>Fracture coalescence</td>
<td></td>
<td>Bad</td>
<td>Commonly</td>
<td>Secondary</td>
<td>Good</td>
</tr>
<tr>
<td>Slope feature</td>
<td>Slope height</td>
<td>≤10m</td>
<td>10-20m</td>
<td>20-30m</td>
<td>≥30m</td>
</tr>
<tr>
<td>Composite grade</td>
<td>≤20°</td>
<td>20-45°</td>
<td>45-60°</td>
<td>≥60°</td>
<td></td>
</tr>
<tr>
<td>Other index</td>
<td>Earthquake intensity</td>
<td>≤5</td>
<td>5-7</td>
<td>7-8</td>
<td>≥8</td>
</tr>
<tr>
<td>Maximum daily rainfall mm</td>
<td>≤30</td>
<td>30-50</td>
<td>50-80</td>
<td>≥80</td>
<td></td>
</tr>
<tr>
<td>Vegetation rate</td>
<td></td>
<td>60%</td>
<td>60%—40%</td>
<td>40%—20%</td>
<td>20%</td>
</tr>
<tr>
<td>Groundwater condition</td>
<td>No change</td>
<td>Slight change</td>
<td>Obvious change</td>
<td>Very obvious change</td>
<td></td>
</tr>
</tbody>
</table>

Weight Determination

The rapid evaluating of landslide stability, the weight of evaluation factors has a great impact on the final evaluation results. There are many ways to determine weight, such as expert estimation method and analytic hierarchy process [4]. Whether the method is adopted, the weight is reasonable or not depends mainly on the details of the landslide investigation and the experience of the experts. According to the scoring of 10 scholars and engineering technical personnel, the weights of each evaluation factor were determined based on the field survey data of landslide, the weights of macro deformation signs, slope features, and other
features are 0.4, 0.4 and 0.2 respectively. The weights of surface features
deformation, fracture density and fracture coalescence are 0.3, 0.3 and 0.4
respectively. The weights of slope height and comprehensive slope are 0.4 and 0.6
respectively. The weights of earthquake intensity, rainfall, vegetation rate and
groundwater are 0.2, 0.3, 0.2 and 0.3 respectively.

The Subordinate Degree of The First Grade Evaluation Factors

In order to meet the requirements of fuzzy mathematics calculation, need to be
quantified for each evaluation factor. The evaluation factors, which are qualitative
factors without investigation and geotechnical test data, cannot use the form of
membership function to express here. First Level Index are divided into stability,
basic stability, instability and extreme instability (Their membership is
determined as shown in Table I). \( v_1, v_2, v_3, v_4 \) respectively represent the
membership degree of stability, basic stability, instability and extremely unstable.
The membership degree of the two grade evaluation factors can be obtained
through the first level fuzzy evaluation.

<table>
<thead>
<tr>
<th>TABLE II. VALUE OF MEMBERSHIP.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v_1 )</td>
</tr>
<tr>
<td>Stability</td>
</tr>
<tr>
<td>Basic stability</td>
</tr>
<tr>
<td>Instability</td>
</tr>
<tr>
<td>Extremely unstable</td>
</tr>
</tbody>
</table>

The Basic Steps of Comprehensive Evaluation

The basic steps of landslide stability evaluation are as follows:
The first step is to determine the evaluation factors and their weights, and
establish the evaluation model.

According to the evaluation standard of the first grade evaluation index, the
first level fuzzy operation is carried out, and the two stage fuzzy vector is
calculated, which can be expressed as: B1, B2, B3.

According to the first fuzzy evaluation results and the two factor weights, the
two level evaluation is carried out to obtain the quality evaluation result vector B,
and the stability grade is determined according to the maximum membership
degree of fuzzy mathematics.
STABILITY EVALUATION OF RAILWAY STATION LANDSLIDE

According to the detailed site investigation of the landslide, the basic situation of the evaluation index is obtained (Table III).

<table>
<thead>
<tr>
<th>First Level Index</th>
<th>Description</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface features deformation</td>
<td>Sabre trees, slowly surface sliding sign and steep trailing edge can be seen on the natural slope.</td>
<td>Extreme instability</td>
</tr>
<tr>
<td>Fracture density</td>
<td>There are a few cracks at the back of the slope</td>
<td>Basic stability</td>
</tr>
<tr>
<td>Fracture coalescence</td>
<td>Bad</td>
<td>Stability</td>
</tr>
<tr>
<td>Slope height</td>
<td>The mountain height is about 60~70m, and the landslide is about 40m high.</td>
<td>Extreme instability</td>
</tr>
<tr>
<td>Composite grade</td>
<td>The slope is about 50 degrees</td>
<td>Instability</td>
</tr>
<tr>
<td>Earthquake intensity</td>
<td>The earthquake intensity is 6 degrees</td>
<td>Basic stability</td>
</tr>
<tr>
<td>Maximum daily rainfall</td>
<td>The maximum rainfall is 133mm (1964.7.6), but the age is very long, and the present reference is limited, so it is determined to be unstable.</td>
<td>Instability</td>
</tr>
<tr>
<td>Vegetation rate</td>
<td>Vegetation Rate is about 30%.</td>
<td>Instability</td>
</tr>
<tr>
<td>Groundwater condition</td>
<td>No spring or ground water is visible.</td>
<td>Stability</td>
</tr>
</tbody>
</table>

(1) First class judgment

\[
B_1 = \begin{bmatrix}
0.3 & 0.3 & 0.4 \\
0.15 & 0.60 & 0.15 & 0.10 \\
0.60 & 0.25 & 0.10 & 0.05
\end{bmatrix} = \begin{bmatrix}
0.30 & 0.31 & 0.17 & 0.22 \\
0.05 & 0.10 & 0.25 & 0.60
\end{bmatrix}
\]

\[
B_2 = \begin{bmatrix}
0.4 & 0.6 \\
0.05 & 0.10 & 0.25 & 0.60 \\
0.10 & 0.15 & 0.60 & 0.15
\end{bmatrix} = \begin{bmatrix}
0.08 & 0.13 & 0.46 & 0.33 \\
0.15 & 0.60 & 0.15 & 0.10
\end{bmatrix}
\]

\[
B_3 = \begin{bmatrix}
0.2 & 0.3 & 0.3 \\
0.10 & 0.15 & 0.60 & 0.15 \\
0.10 & 0.15 & 0.60 & 0.15
\end{bmatrix} = \begin{bmatrix}
0.26 & 0.27 & 0.36 & 0.11 \\
0.60 & 0.25 & 0.10 & 0.05
\end{bmatrix}
\]

(2) Two level judgment
\[
B = \begin{pmatrix}
0.30 & 0.31 & 0.17 & 0.22 \\
0.08 & 0.13 & 0.46 & 0.33 \\
0.26 & 0.27 & 0.36 & 0.11
\end{pmatrix} = \begin{pmatrix}
0.20 & 0.23 & 0.32 & 0.24
\end{pmatrix}
\]

[0.20, 0.23, 0.32, 0.24] is the final fuzzy vector. According to the maximum principle of membership degree, the stability grade is determined, and the stability grade of the landslide is obviously instability. According to the detailed information of the landslide, the stability coefficient is 0.95 and the stability grade is also instability. Through the above research and the comparison of stability results, it is proved that the stability evaluation method established in this paper is feasible and reliable.

CONCLUSIONS

The rapid evaluation of landslide stability has always been the focus of the previous work. Taking a train station landslide as an example, a method for rapid evaluation of landslide stability is established on the basis of no detailed investigation and soil test data. This paper introduces the principle of the method, the selection and classification of the evaluation factors, the determination of the weights, the membership degree of the first grade evaluation factor, and the evaluation steps, etc. Then this method is applied to evaluate the stability of the railway station landslide. The result is [0.20, 0.23, 0.32, 0.24], and the stability level is unstable. Therefore, the method has certain reliability and practicability, and can obtain the result quickly.

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REFERENCES