Method of Evaluation for the Construction Geology of Transmission Line Based on Gray System Theory

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Abstract. A good engineering geological environment is the premise of engineering construction safety and security. The construction of transmission lines needs to take topography, stratigraphic lithology, engineering geological hazard, structural geology into consideration, but the survey personnel always judge the engineering geological environment roughly only based on individual subjective experience, personal professional level when selecting the transmission line route. We call this judgment process has a gray feature in the point of gray system, while the gray scale can be reduced by the calculation based on gray system, each factor play their role in the evaluation process in their respective weight, so the quantitative, clear results can be obtained. This paper constructs the index system of engineering geological factors of transmission line, using gray evaluation system, and with the help of AHP, the quantitative evaluation results are obtained, and provide a theoretical basis for geological environment evaluation of transmission line engineering. Finally, the geological evaluation is carried out by a real construction and realized the transformation from theory to tool.

1. Introduction

The grey system theory was proposed by Professor Deng Julong, a control expert at Huazhong University of Science and Technology in the 1980s. Relative to the black system (complete information lack) and the white system (complete information), the gray indicates that the information is incomplete or inaccurate, and mainly used to solve the problem of data lack and information ambiguity by using probability theory and mathematical statistics method for a whole with relatively insufficient information. The gray system including gray evaluation, gray prediction, gray correlation analysis, etc[1]. The degree of geological environment of the transmission line cannot be completely quantified, so it has gray characteristics. The gray system can reduce the gray level of each influencing factor, so that each factor can play its own role in the evaluation, so as to obtain quantitative results. Firstly, constructing the index system of engineering geological influence factors of transmission lines, uses the gray evaluation system to obtain the quantitative evaluation results with the aid of the analytic hierarchy process, which provides a theoretical basis for the geological environment evaluation of transmission lines. Finally, the index values of the geological environment influencing factors of the actual project are calculated, and the quantitative evaluation results are obtained to realize the transformation from theory to practice.
2. Analysis of Engineering Geological Influencing Factors and Weights of Transmission Lines

2.1. Geological influence factors of transmission lines
According to the line surveying part of the Design Manual for Power Engineering High Voltage Transmission Lines and Code for Power Engineering Survey. The influence of engineering geological conditions on transmission line engineering is mainly unfavorable geological phenomena (landslides, debris flows, karst, marshes, special soils, etc.), stratum lithology (physical and mechanical indicators of soil layers and bedrock integrity, hardness, weathering degree, etc.), structural geology (fracture structure, earthquake, etc.), topography (topography, slope, etc.) [2-3]. Therefore, the engineering geological influence factors of transmission lines are summarized into the above four aspects, and the index system is constructed.

2.2. Weight calculation
Impact factor weight analysis by the method of analytic hierarchy process, the method was proposed by the famous operations researcher T. L. Saaty of the University of Pittsburgh in the 1970s. The key of this method is to divide the target into different attributes and different levels according to specific conditions. The source of the basic information is the judgment of people on the relative importance of different factors at each level. However, the level of cognition of each person is inconsistent with the standard of judgment, so there will be some deviations in the process of judging relative importance. The AHP introduces judgment matrix to correct these deviations [4-5].

According to T. L. Saaty's 1–9 scale table. Different factors are assigned to different values for importance levels, \( b_{ij} \) denotes the relative importance of the index \( B_i \) to \( B_j \).

Table 1. T. L. Saaty Importance Scale
| Scaling | Implication |
|---------|-------------|
| 1       | \( i \) is as important as \( j \) |
| 3       | \( i \) is slightly more important than \( j \) |
| 5       | \( i \) is more important than \( j \) |
| 7       | \( i \) is very important than \( j \) |
| 9       | \( i \) is extremely important than \( j \) |
| 2, 4, 6, 8 | Importance between two adjacent judgments |

Normalize and judge the mutual relationship of each Engineering geological influence factors. The importance scale of geological environment influencing factors is shown in Table 2.

Table 2. Geological Environment Influence Factor Importance Scale
| Influence Factor       | Topography | Structural Geology | Geology Disaster | Stratigraphic Lithology |
|------------------------|------------|--------------------|------------------|------------------------|
| Topography             | 1          | 2                  | 1/3              | 1/2                    |
| Structural Geology     | 1/2        | 1                  | 1/4              | 1/3                    |
| Geology Disaster       | 3          | 4                  | 1                | 2                      |
| Stratigraphic Lithology| 2          | 3                  | 1/2              | 1                      |

According to Table 2, the importance scale matrix \( B \) is obtained.

\[
B = \begin{bmatrix}
1 & 2 & 1/3 & 1/2 \\
1/2 & 1 & 1/4 & 1/3 \\
3 & 4 & 1 & 2 \\
2 & 3 & 1/2 & 1
\end{bmatrix}
\] (1)
The sum method commonly used for AHP calculation. [4-5] Firstly, normalized the each element of the judgment matrix by the equation (2).

$$\bar{b}_{ij} = \frac{b_{ij}}{\sum_{i=1}^{n} b_{ij}}, \quad i = 1, 2, 3, 4$$  \hspace{1cm} (2)

We can get:

$$\bar{B} = \begin{bmatrix}
0.153 & 0.200 & 0.160 & 0.130 & 4 \\
0.076 & 0.100 & 0.120 & 0.087 & 0 \\
0.461 & 0.400 & 0.480 & 0.521 & 7 \\
0.307 & 0.300 & 0.240 & 0.260 & 9
\end{bmatrix}$$  \hspace{1cm} (3)

Then the matrix $\bar{B}$ is summed by equation (4) and obtain the matrix $S$, then normalized.

$$\bar{S}_j = \sum_{j=1}^{n} \bar{b}_{ij}, \quad j = 1, 2, 3, 4$$  \hspace{1cm} (4)

$$S_i = \frac{\bar{S}_i}{\sum_{i} \bar{S}_i}, \quad i = 1, 2, 3, 4$$  \hspace{1cm} (5)

Then we get:

$$S = (0.161 \, 0, \, 0.096 \, 0, \, 0.465 \, 8, \, 0.277 \, 2)$$

Each of them is the approximate value of each indicator weight, and the sum of the individual values is 1.

3. Grey evaluation model

The four influencing factors of the transmission line engineering geology are represented as $M_1, M_2, M_3, M_4$, and the corresponding weights are $S_1, S_2, S_3, S_4$.

3.1. Assignment

In this paper, all indicators are divided into four criteria: excellent, good, medium and poor. The corresponding scores are 4, 3, 2, and 1, and the scores between the two levels are 3.5, 2.5, and 1.5. Taking unfavorable geological phenomena as an example, if there is no unfavorable geological phenomenon, the superior standard can be achieved, and the score is higher, which can be assigned a value of 4; if the rock mass along the line is loose and the slope is large, there is the possibility of landslide. The score is lower and can be assigned 1 or 1.5 depending on the likelihood of landslide and the size of the landslide. There are $p$ evaluators, the serial numbers are $n=1, 2, 3, ..., p$, respectively, which are assigned to the engineering geological conditions of the transmission line.

3.2. Evaluation sample matrix solution

According to the scores assigned by each index, the evaluation sample matrix is made. All experts assign the same factor as a row, and an expert assigns a value to all the factors, so that $n$ experts can be used to factor $Mi$. The score $d_{in} (i = 1, 2, 3, 4; n = 1, 2, ..., p)$ is made into the evaluation sample matrix $D$.

$$D = \begin{bmatrix}
d_{11} & d_{12} & \cdots & d_{1n} \\
d_{21} & d_{22} & \cdots & d_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
d_{11} & d_{12} & \cdots & d_{1n}
\end{bmatrix}$$  \hspace{1cm} (6)
3.3. Evaluation of gray class determination

In the process of evaluating a certain influencing factor, it can only be judged by good, bad or better qualitative judgment, but the exact score cannot be determined. This is called gray number in the gray system. The whitening weight function can quantitatively describe the degree to which a certain evaluation object belongs to a certain gray class (weighing function), that is, the relationship that varies with the size of the evaluated index. The gray class number, gray number and whitening weight function of the evaluation index are generally determined by actual problem analysis[1,5]. According to the complexity of the engineering geological environment selected in this paper, it is decided to divide into four evaluation ash class grades, the serial number is set to \( q \), and the \( q \) values are 1, 2, 3, and 4 respectively representing excellent, good, medium, and poor, and their corresponding gray numbers are set. The calculation method of the whitening weight function is detailed as follows.

The first grade gray class is excellent \((q=1)\), and the gray number is specified as \( \mathbb{R}_1 \equiv [4, \infty] \). The whitening weight function is calculated as:

\[
f_1(d_{in}) = \begin{cases} 
  d_{in} / 4, & d_{in} \in [0,4] \\
  1, & d_{in} \in [4, \infty] \\
  0, & d_{in} \notin [0, \infty] 
\end{cases}
\]

The second grade gray class is excellent \((q=2)\), and the gray number is specified as \( \mathbb{R}_2 \equiv [0,3,6] \). The whitening weight function is calculated as:

\[
f_2(d_{in}) = \begin{cases} 
  d_{in} / 3, & d_{in} \in [0,3] \\
  (6-d_{in}) / 3, & d_{in} \in [3,6] \\
  0, & d_{in} \notin [0,6] 
\end{cases}
\]

The third grade gray class is excellent \((q=3)\), and the gray number is specified as \( \mathbb{R}_3 \equiv [0,2,4] \). The whitening weight function is calculated as:

\[
f_3(d_{in}) = \begin{cases} 
  d_{in} / 2, & d_{in} \in [0,2] \\
  (4-d_{in}) / 2, & d_{in} \in [2,4] \\
  0, & d_{in} \notin [0,4] 
\end{cases}
\]

The forth grade gray class is excellent \((q=4)\), and the gray number is specified as \( \mathbb{R}_4 \equiv [0,1,2] \). The whitening weight function is calculated as:

\[
f_4(d_{in}) = \begin{cases} 
  1, & d_{in} \in [0,1] \\
  2-d_{in}, & d_{in} \in [1,2] \\
  0, & d_{in} \notin [0,2] 
\end{cases}
\]

Set the \( q \)th gray evaluation weight vector of indicator \( M_i \) as \( m_{ie} \), and \( m_i \) represents the total gray evaluation power of each indicator gray class.

\[
m_{ie} = \sum_{n=1}^{p} f_e(d_{in}) \\
m_i = \sum_{e=1}^{q} m_{ie}
\]

3.4. Gray evaluation weight matrix construction

All evaluators claim that the indicator \( M_i \) is the gray evaluation right of the \( q \)th gray class, which is denoted as \( r_{ie} \), then
Corresponding to the evaluation of the gray level of excellent, good, medium and poor, and the sum of \( r_i \) is 1, the index \( M_i \) should also have 4 elements for the gray evaluation weight vector of each level of gray, namely \( R_i = (r_{i1}, r_{i2}, r_{i3}, r_{i4})^T \), which is the gray evaluation weight matrix of the influencing factors of the line engineering geological environment.

\[
R_i = \begin{bmatrix}
    r_{i1} \\
    r_{i2} \\
    r_{i3} \\
    r_{i4}
\end{bmatrix}, i = 1, 2, 3, 4
\]

3.5. Comprehensive evaluation and ranking of indicators

Comprehensive evaluation of \( M_i \), the evaluation result is \( B_i \), then \( B_i = S_i R_i = (b_{i1}, b_{i2}, b_{i3}, b_{i4}) \), from the \( M_i \) comprehensive evaluation result \( B_i \), the gray evaluation weight matrix \( R \) of the indicator \( M_i \) for each indicator gray class.

\[
R = \begin{bmatrix}
    B_1 \\
    B_2 \\
    B_3 \\
    B_4
\end{bmatrix} = \begin{bmatrix}
    b_{11} & b_{12} & b_{13} & b_{14} \\
    b_{21} & b_{22} & b_{23} & b_{24} \\
    b_{31} & b_{32} & b_{33} & b_{34} \\
    b_{41} & b_{42} & b_{43} & b_{44}
\end{bmatrix}
\]

Then, the comprehensive evaluation result is \( B = S_i R = (b_1, b_2, b_3, b_4) \).

3.6. Gray level setting and comprehensive evaluation value calculation

The evaluation value is \( Z = B^T X \), \( X \) is the vector formed by the gray level assignment of each gray class. The gray level vector \( X = (4, 3, 2, 1) \) is set in this paper, and the final rating is obtained. The \( Z \)-point represents the excellent level of the engineering geological environment.

4. Engineering applications

4.1. Evaluation object

The landform types in North China are simple, the terrain is less fluctuating, the geological disasters and bad geological phenomena are less, and the stratum changes are also small. Except for the soft soil distribution in the coastal areas of Cangzhou and the existence of collapsible loess in some areas of the Taihang Mountains in the west, most of the areas are good. The geological conditions are good, and the unfavorable factors of engineering are less in the geological environment. This paper selects the Xinji-Cuichi, Anping-Cuichi π into Taicheng (Hulin) 220kV line project for geological environment evaluation.

4.2. Line Engineering Geology Overview

(1) Topography. The line is located in the east of Hengping Anping County. It is located in the southeast of Hebei Plain. The landform type belongs to the north China alluvial plain. The terrain is gentle, slightly west high and low east, with an average slope of 1/3250. The terrain along the line is open and flat.

(2) Formation lithology. According to the existing engineering geological data, the foundation soil along the line is the Quaternary alluvial sediment. The lithology of the stratum is dominated by silt and sand soil. According to the lithology characteristics and physical and mechanical properties of the stratum, top to bottom respectively for:
1) Silt. Yellow brown - brownish yellow, slightly wet - wet, slightly dense - medium dense, soil is relatively uniform, with a silty texture, a thin layer of partially interspersed silty clay, moderate shaking reaction, rapid shaking reaction at lower part, dull, dry strength and Low toughness. The layer thickness is 6.00~6.50m, $\omega_0$ is 18.0%~27.0%, $\rho_0$ is 1.80~1.90 g/cm$^3$, $e_0$ is 0.750~0.930, and $c$ is 9.0~23.0 kPa. $\phi$ is 12.0°~30.0°, and the bearing capacity characteristic value $f_{ak}$ is 110~130 kPa.

2) Silty clay. Gray-brown, plastic, see layering and rust spots, uneven soil, local clay layer, no shaking reaction, luster, medium strength and toughness. The layer is unevenly distributed, the local part is missing, the layer thickness is about 1.50 m, $\rho_0$ is 1.90~2.00 g/cm$^3$, $e_0$ is 0.790~0.880, and $I_L$ is 0.55~0.95. $c$ is 15.0~40.0 kPa, $\phi$ is 5.0°~14.0°, and the bearing capacity characteristic value $f_{ak}$ is 140~160 kPa.

3) Fine sand. Gray-brown-grey-white, medium-density-compact, sandy sand is more uniform, particle sorting is general, roundness is better, mineral composition is quartz, feldspar and mica, and the filler is silt. The maximum exposed thickness of this layer is 3.30 m, $\rho_0$ is 1.85~2.00 g/cm$^3$, $e_0$ is 0.740~0.830, $c$ is 0~3.0 kPa, $\phi$ is 20.0°~35.0°, bearing capacity The characteristic value $f_{ak}$ is 160 to 180 kPa.

There is no high-crossing tower in this line project and there is no saturated silt and sand in the foundation soil, so the problem of foundation soil liquefaction is not considered.

3) Structural geology and earthquakes. According to the "China Earthquake Peak Acceleration Zoning Map" (GB18306-2001) and "Architectural Seismic Design Code" (GB50011-2010), the seismic acceleration of 10% of the 50-year surpassing probability of the area along the line is 0.10 g, corresponding to the seismic fortification The intensity is 7 degrees.

The active faults since the Quaternary have not been found in the nearby area, the neotectonic movement is relatively stable, the seismic activity is relatively weak, and the distance from the nearest fault is greater than 7km, meeting the requirements of the route engineering related specifications for the avoidance distance.

4) Unfavorable geological phenomena. According to the investigation and on-site reconnaissance, there are no adverse geological effects such as landslides, collapses, goafs, mudslides, karsts and soil caves along the proposed route, and there are no major adverse geological effects that are difficult to cross.

4.3. Incorporate numerical values into the evaluation system

Firstly, make the geological environment evaluation matrix of the project:

$$D_1 = \begin{bmatrix} 3.5 & 4.0 & 4.0 & 3.5 & 3.5 \\ 4.0 & 4.0 & 4.0 & 3.0 & 3.5 \\ 4.0 & 4.0 & 4.0 & 3.5 & 4.0 \\ 3.5 & 4.0 & 3.5 & 3.5 & 3.5 \end{bmatrix}$$ (15)

The scoring matrix $D_1$ is processed by the model to obtain an evaluation matrix $R$ for the evaluation index.

$$R_1 = [0.1875, 0.2500, 0.3750, 0.1875]$$

$$R_2 = [0.5023, 0.4163, 0.0815, 0]$$

$$R_3 = [0.5652, 0.4058, 0.0290, 0]$$

$$R_4 = [0.4737, 0.4211, 0.1053, 0]$$ (16)
\[
\begin{align*}
\mathbf{B}_1 = \mathbf{S}_1 \cdot \mathbf{R}_1 &= [0.080 \ 0.067 \ 0.013 \ 1 \ 0] \\
\mathbf{B}_2 = \mathbf{S}_2 \cdot \mathbf{R}_2 &= [0.048 \ 0.040 \ 0.007 \ 8 \ 0] \\
\mathbf{B}_3 = \mathbf{S}_3 \cdot \mathbf{R}_3 &= [0.263 \ 0.189 \ 0.013 \ 5 \ 0] \\
\mathbf{B}_4 = \mathbf{S}_4 \cdot \mathbf{R}_4 &= [0.131 \ 0.116 \ 7 \ 0.029 \ 2 \ 0]
\end{align*}
\]

(17)

\[
\mathbf{R} = \begin{bmatrix}
\mathbf{B}_1 \\
\mathbf{B}_2 \\
\mathbf{B}_3 \\
\mathbf{B}_4
\end{bmatrix} = \begin{bmatrix}
0.080 & 0.067 & 0.013 & 1 & 0 \\
0.048 & 0.040 & 0.007 & 8 & 0 \\
0.263 & 0.189 & 0.013 & 5 & 0 \\
0.131 & 0.116 & 7 & 0.029 & 2 & 0
\end{bmatrix}
\]

(18)

\[
\mathbf{B} = \mathbf{S} \cdot \mathbf{R} = \begin{bmatrix}
0.176 & 0.135 & 0 & 0.017 & 2 & 0
\end{bmatrix}
\]

(19)

\[
Z = \mathbf{B} \cdot \mathbf{X}^T = 1.1159
\]

(20)

In this operation, it plays two roles. On one hand, it reduces the gray scale of the data and makes the data as accurate as possible. On the other hand, it exerts the weight of each data, so that each data plays its role in the evaluation process. Some role. These two processes make the entire evaluation process more scientific and precise. The final calculation results show that the engineering geological environment in the region is good and suitable for the construction of transmission lines.

5. Conclusion

By using the analytic hierarchy process to calculate the weight and gray system theory, the gray level of data is reduced, the deviation is corrected, and the weight of each data in the evaluation process is played. The quantitative evaluation of the engineering geological environment of the transmission line is obtained. The results show that the evaluation method can be applied to the evaluation of the influencing factors of the geological environment of the transmission line, and the transformation from theory to practice is realized. However, this paper only analyzes and evaluates the geological environment of the transmission line. In the actual situation, there are still many factors to be considered in determining a route, such as hydrological conditions and meteorological conditions. This requires exploring a more complete evaluation method.

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