Research on Support Type Selection of Foundation Pit of Rail Transit Station Based on Improved AHP Method

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Abstract: With the rapid development of underground space, a large number of complex foundation pit projects have emerged. It is undoubtedly an important task to select a safe, economic, scientific and reasonable support scheme and seek a scientific and reasonable optimization method of foundation pit support scheme in combination with regional characteristics. This paper tries to find a simple and practical method of scheme selection which meets people's psychological comparison scale. The traditional analytic hierarchy process (AHP) is improved, the grade of traditional evaluation index is improved, and the index scale is introduced. An analytic hierarchy process based on the seven grade index scale is put forward to make it more suitable for people's psychological comparison scale. Through consistency test, the scientificity and rationality of the improved layer analysis method are verified, and applied to the foundation pit engineering with close proximity to rail transit. Through the establishment of the tomographic structure model and judgment matrix, the calculation and optimization are carried out. It is found that the support scheme of diaphragm wall + internal support is the optimal scheme of the project. This method can provide theoretical support for the establishment of regional foundation pit support selection.

1. Introduction
In recent years, the foundation pit support project has developed rapidly, and its safety and economy have been paid more and more attention. What kind of support scheme is more economical and reasonable, some of them only rely on experience to choose the support scheme, resulting in poor economic benefits of the project. It is undoubtedly an important work to seek a scientific and reasonable optimization method of foundation pit supporting structure in combination with regional characteristics. In order to make the selection of support more scientific and reasonable, grey system theory and method, empirical weighted scoring method, fuzzy comprehensive evaluation method and analytic hierarchy process are applied. Analytic Hierarchy Process (AHP) proposed by Professor Sarty of Pittsburgh University are widely used in specific projects for the clear index. Ganggang Yu introduced index scale to improve the Analytic Hierarchy Process (AHP), which made up for the shortcomings of traditional analytic hierarchy process in index determination and consistency.
However, the scale division of its 9 grades is not in line with people's psychological comparative size. In practical use, it is prone to large scale differences due to subjective influence.

This paper tries to optimize the design scheme of foundation pit engineering of Jinan rail transit subway station by improving the scale grade and adopting the scale division method which more in line with people's psychological comparison scale.

2. Improved Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) calculates the relative weights of evaluation indexes at each level and the combined weights of evaluation indexes at each level to the total objectives through the steps of analyzing problems, establishing AHP model, constructing judgment matrix, single-level ranking and total-level ranking, and thus obtains the comprehensive evaluation ranking of different schemes [6]. The general working steps of AHP include:

(1) Establish a hierarchical structure model

Analyze the internal relationship between the various factors of the deep foundation pit support scheme, determine the main factor indicators, establish the hierarchical structure model, and divide the hierarchical structure into multiple layers, which can be divided into the general objective layer, criteria layer, sub-criteria layer, scheme layer, etc.

(2) Construction judgment matrix

According to the established hierarchical structure model, the specific operation is to compare and grade the importance of each factor by experts after determining the analytic hierarchy process model. For example, if the n factors of a certain level are compared with the importance of a factor A_k of the previous layer, B_i and B_j set two factors comparison, the comparison result is b_ij. Scoring uses 1-9 scale method in the traditional Analytic Hierarchy Process, which means 1 is equally important, 3 is slightly important, 5 is obviously important, 7 is strongly important, 9 is extremely important and 2, 4, 6, 8 is the median of the scale. The comparison value of b_ij between the two factors is obtained by experts, and the judgment matrix A= [b]n×n is formed.

Fine differences between indicators often make it difficult for experts to make accurate judgments and make great differences in scores. For this reason, this paper quotes the improved index scale proposed by Ganggang Yu, and divides the evaluation grade into four grades: Equally important, slightly important, obviously important and extremely important.

| scale | define | meaning |
|-------|--------|---------|
| 0     | Equally | Two schemes are equally important to an certain attribute |
| 9^2   | important | |
| 3     | slightly | Two schemes for a certain attribute, one scheme is slightly more important than the other |
| 5     | obviously | Two schemes for a certain attribute, one scheme is obviously more important than the other |
| 9^2   | important | Two schemes for a certain attribute, one scheme is extremely more important than the other |
| 7     | extremely | |
| 2, 4, 6 | Scale median | Represents the scale when two adjacent scales are compromised |
| 9^7, 9^9 | Scale reciprocal | The scale of scheme Ai to scheme Aj is a_i,j; Instead of 1/a_i,j |

The third step is Hierarchical single sorting and consistency check. That is to derive the importance order of all elements of the hierarchy from the judgment matrix to the upper layer of an element. The sorting method is the maximum characteristic root method. The forth step is to calculate the maximum characteristic root and check the consistency of single sort results. The fifth is check the
3. Engineering case analysis

3.1. Project Overview

The foundation pit of the Jianbang project is two triangular areas across the subway station. The depth is about 18m. The depth of the subway station is about 23.91m. The foundation pit of the development project is divided into area A foundation pit and area B foundation pit. The relationship is shown in Figure 1.

Stratum condition: the strata in the excavation depth range are: ① miscellaneous fill, ③ silty clay, ⑦ silty clay and ⑨ silty clay. The pit bottom is located in ⑩ silty clay layer, and the diaphragm wall bottom is located in ⑬ silty clay layer. The groundwater depth is about 2 m. The fine sand layer and its underlying pebble and gravel layers are confined aquifers with a large amount of water. The confined head depth is about 2.5 m. Excessive precipitation will adversely affect urban underground springs, so it is necessary to minimize pumping capacity.

The surrounding environment is shown in Figure 2. The fire building and the family building are only about 10~14m away from the development foundation pit. Although there is a plain pile foundation, the pile length is only 12m, and the layer is as high as 8~11 layers, which forms a large overload on the side of the foundation pit. Under the condition that its own weight is relatively large and the foundation is shallow, the excavation of foundation pit has the influence of certain horizontal and vertical uneven deformation, and the risk is large. The fire brigade's family building is about 10m away from the foundation pit, and the fire building is about 14m away from the foundation pit.

Figure 1. Relationship between foundation pit and subway station of development project and stratum situation

Figure 2. Surrounding environment of foundation pit
3.2. Foundation pit support scheme primary selection

The construction site is adjacent to the subway station structure and multi-storey residential buildings, and is very close to the foundation pit. There are traffic roads around the construction site. The deformation requirement is stricter. The safety grade of the foundation pit is one level. According to expert analysis, vertical excavation support measures should be adopted for the foundation pit of this project. There is confined water under the foundation pit, and it does not meet the requirements of anti-outburst. Therefore, besides the influence on the subway structure, the support plan should also focus on the influence of confined water jacking force and regional groundwater. Three alternative support schemes are proposed: scheme 1: diaphragm wall support + internal support, scheme 2: casing bite pile support + internal support, scheme 3: pouring pile support + internal support, as a primary option for foundation pit support.

(a) Scheme 1 Φ800 Diaphragm wall    (b) Scheme 2 Φ1000@900 casing bite pile support
(c)scheme 3 Φ1000@1400 pile support

Figure 3. Three schemes for primary selection

3.3. Establishment of evaluation index system

In order to select the best scheme, many experienced experts from construction, design, construction, supervision and other units are invited to determine the indicators affecting support. After many feedback modifications, four indicators, safety, cost, duration and environmental impact, are finally selected to establish the criteria layer. Each evaluation index can be found in the hierarchical structure evaluation index system of the figure below.
3.4. Use the improved analytic hierarchy process to determine the weight of each index and the single ranking of each index

The index system of support scheme can be divided into two levels according to the index structure chart. The first level is the criteria layer, which contains four indicators (B1, B2, B3, B4), and the second level is the sub-index layer which contains 12 evaluation indicators. The evaluation matrix is constructed by using the improved index scaling method. The scaling values of the first-level evaluation indicators are compared with each other as shown in the table below.

Table 2. Judgment matrix of the project

|   | A | B1 (security) | B2 (economic) | B3 (Construction period) | B4 (environmental impact) |
|---|---|--------------|---------------|-------------------------|---------------------------|
| B1 (security) |   | 0            | 5             | 7                        | 0                         |
| B2 (economic) |   | 1/9          | 9             | 0                        | 1/9                       |
| B3 (Construction period) |   | 1/9          | 3             | 0                        | 1/9                       |
| B4 (environmental impact) |   | 0            | 5             | 3                        | 0                         |

According to formula $M_i = \frac{1}{\prod_{j=1}^{n} a_{ij}} (i = 1,2,3,4)$, calculate $M_i$ successively:

- $M_1 = 2.56$  
- $M_2 = 0.361$  
- $M_3 = 0.577$  
- $M_4 = 1.873$

Then normalize according to formula $W_i = \frac{M_i}{\sum_{i=1}^{4} M_i}$, and calculate $W_i$ successively:

- $W_1 = 0.477$  
- $W_2 = 0.067$  
- $W_3 = 0.107$  
- $W_4 = 0.349$

The maximum eigenvalue of the judgment matrix is $\lambda_{\text{max}} = 4.25$. The consistency test of the judgment matrix is $\frac{CI}{RI} = 0.083$. According to the table, the random consistency index of the fourth-order matrix $RI = 0.90$ and the consistency ratio of the matrix $CR = \frac{CI}{RI} = 0.092$, indicating that the judgment matrix meets the consistency requirement.

Therefore, the weight of the evaluation index is assigned as $W = (0.477, 0.067, 0.107, 0.349)$.

According to the above process, the weights of the indicators of the second level index layer to a certain index of the upper layer are calculated, and the results are listed in the following table 6.

Table 3. Safety requirements scale value and weight calculation result

|   | B1 | C11 | C12 | C13 | C14 | $M_i = \frac{1}{\prod_{j=1}^{n} a_{ij}}$ | $W_i = \frac{M_i}{\sum_{i=1}^{4} M_i}$ | Consistency test |
|---|---|-----|-----|-----|-----|--------------------------------|----------------|----------------|
| C11 |   | 0   | 5   | 0   | 3   | 1.873                          | 0.387          |               |
| C12 |   | 5   | 0   | 3   | 3   | 0.675                          | 0.139          |               |
| C13 |   | 1/9 | 9    | 0   | 5   | 1.873                          | 0.387          |               |
| C14 |   | 1/9 | 9    | 5   | 0   | 0.422                          | 0.087          |               |

The same method can determine the weights of the remaining three groups of indicators and list the results in the general sorting table.
3.5. Hierarchical total sorting:
Continue to determine the index scale of the D layer to the C layer according to the above method, and determine the total order of the scheme.

|        | C11 | C12 | C13 | C14 | C21 | C22 | C23 | C31 | C32 | C41 | C42 | C43 | D次数 |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| D1     | 0.438 | 0.436 | 0.418 | 0.477 | 0.323 | 1/3 | 0.454 | 0.642 | 1/3 | 0.323 | 0.442 | 0.477 | 0.450 |
| D2     | 0.320 | 0.354 | 0.418 | 0.387 | 0.236 | 1/3 | 0.369 | 0.25 | 1/3 | 0.236 | 0.323 | 0.387 | 0.344 |
| D3     | 0.242 | 0.210 | 0.194 | 0.386 | 0.441 | 1/3 | 0.177 | 0.108 | 1/3 | 0.441 | 0.235 | 0.386 | 0.263 |

Table 4. Computation results of total ranking of schemes

It can be seen that the scheme 1 of the underground continuous wall + inner support is the best solution in terms of safety, economy, construction period and environmental impact. The optimum supporting scheme is diaphragm wall + internal support scheme. The groundwater level of the project is relatively high, and there is a high head confined water layer, which has high requirements for water stoppage and precipitation. Diaphragm wall can be used as retaining wall and water retaining structure at the same time.

4. Conclusion
(1) According to the characteristics of the foundation pit, the traditional tomographic analysis method is improved, and a more operable index scale system is proposed, which is more practical and scientific.
(2) The supporting scheme of foundation pit is preliminarily screened by factors such as supporting form and surrounding environment of foundation pit, engineering geology, hydrology, construction period and cost of foundation pit, and the appropriate alternative supporting scheme is selected. The improved index scale analytic hierarchy process is used to optimize the supporting scheme, the preferred results are consistent with the actual form of support employed. Finally, it proves that the improved method is feasible.
(3) The improved analytic hierarchy process can provide theoretical guidance for the selection of regional supporting structures.

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