Study on the optimization system of supporting schemes for foundation pit

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Abstract. At present, there are various supporting schemes for foundation pit that could be adopted in actual projects; however, there are also certain differences in construction cost and applicability of different schemes. To guarantee reasonable and efficient choice of supporting schemes for foundation pit, it is necessary to implement selection of supporting schemes purposefully. This essay discusses mainly the optimization system of supporting schemes for foundation pit. Through analysis of the affecting factors of supporting schemes of foundation pit, comprehensive optimization system of supporting schemes for foundation pit has been constructed, optimization model of supporting schemes based on TOPSIS has been created and comprehensive optimization system of supporting schemes for foundation pit has also been established.

Keywords: supporting schemes for foundation Pit, scheme optimization, TOPSIS.

1. Introduction

In recent years, with the constant development of social economy, upsizing and complication of projects accelerate and technical requirements for projects also keep increasing [1]. Moreover, during the process of urbanization, high-rise and super high-rise buildings spring up one after another and the underground installations in cities are much more complex [2]. Against such backgrounds, traditional supporting method of slope excavation could no longer meet the requirements of modern urban constructions. In actual construction of the projects, foundation pit supporting could possibly cause security accidents as foundation pit accident due to causes of design and construction, or possibly result in excessive investment due to conservativeness in design.

Therefore, how to guarantee the security and economic efficiency of supporting schemes of foundation pit is a problem existing now [3]. At present, the supporting methods of foundation pit most commonly seen include deep mixed cement-soil lateral wall, steel sheet pile, reinforced concrete sheet pile, profile steel lagging, drilling cast-in-place pile, digging pile, underground diaphragm wall, SMW construction method, soil nailing wall, etc. [4-6]. There are certain differences in construction cost and applicability of different schemes [7, 8]. To guarantee the rationality and efficiency in choosing supporting schemes of foundation pit, it is necessary to conduct research on selection of supporting schemes of foundation pit.

2. Construction of optimization system of supporting schemes for foundation pit

The construction of optimization system of supporting schemes for foundation pit shall be conducted under the guidance of scientificity, systematisms, feasibility, representativeness, independence, comparability and operability.

Optimization of supporting schemes for foundation pit shall not only take technical feasibility and construction feasibility into consideration, but shall consider the economic efficiency, construction quality, influences on environment, duration and technical advancement of the scheme. Generally speaking, the optimization of supporting schemes for foundation pit shall meet the following requirements:

1) The selected supporting scheme shall guarantee its technical feasibility of as possible on the basis of satisfying its scientificity and advancement;

2) On the basis of satisfying the requirements of foundation pit supporting, it is required to reduce the influences on the surrounding environments as far as possible so as to ensure the security and controllability of the follow-up construction, i.e. to meet the reliability of the scheme effects;

3) On the basis of satisfying the requirements of foundation pit supporting, it is required to guarantee comparatively short duration of the scheme as well as the accessibility of the scheme;

4) On the basis of satisfying the requirements of foundation pit supporting, various factors of the scheme, such as the duration, the cost and the quality, shall be considered comprehensively so as to put forward economical supporting schemes for foundation pit and to make the scheme economical and rational.

There are various factors that may affect the supporting scheme for foundation pit. Generally speaking, the following factors shall be taken into consideration while selecting the supporting schemes for foundation pit: capacity sustained by the supporting structure of the foundation pit, engineering geology and hydrogeological conditions, engineering environmental conditions, construction design scheme, foundation pit construction scheme as well as construction requirements of the foundation pit, the characteristics and the scope of application of existing foundation pit supporting techniques, the owners' requirements and the design specifications.

Only when various factors are considered fully while selecting supporting schemes for foundation pit, could the chosen scheme meet relevant requirements of the project. So, it is necessary to construct reasonably indicator system of optimization of supporting schemes for foundation pit on the basis of taking consideration fully the requirements of optimization of supporting schemes for foundation pit and the factors affecting selection of supporting scheme for foundation pit.

To construct indicator system of optimization of supporting schemes for foundation pit abiding by the principles of scientificity, systematisms, representativeness, independence, comparability and operability, the primary problem that shall be dealt with is the construction of the first level indicator system of optimization of supporting schemes foundation pit, i.e. to construct macroscopic framework of optimization system of supporting schemes for foundation pit.

It could be seen from the above analysis that, during optimization of supporting schemes of foundation pit, based on capacity sustained by the supporting structure of the foundation pit, engineering geology and hydrogeological conditions, engineering environmental conditions, construction design scheme, foundation pit construction scheme as well as construction requirements of the foundation pit, the characteristics and the scope of application of existing foundation pit supporting techniques, the owners' requirements and the design specifications, the influencing factors of supporting schemes for foundation pit could be classified into four types, which are respectively technical feasibility, effect reliability, construction accessibility and economic rationality.

After the first level indicator system is constructed, the following task is to construct the second level indicator systems of the four first level indicators in the first level indicator system of optimization of supporting schemes for foundation pit respectively and form finally the indicator system of optimization of supporting schemes for foundation pit.

1) Technical feasibility.

Technical feasibility refers to mainly the degrees of the selected supporting scheme for foundation pit in technical advancement, technical maturity, and adaptability with hydrogeological conditions.

Technical feasibility could be reflected by four indictors, which are technical advancement, technical maturity, adaptability with hydrogeological conditions as well as adaptability with design specifications.

2) Effect reliability.

Effect reliability refers to refers to mainly the satisfaction degrees of the selected supporting

scheme for foundation pit in design strength, stiffness, stability, durability and mechanical property.

Effect reliability could be reflected by five indictors, which are satisfaction degrees of indicator strength requirement, stiffness requirement, stability requirement, durability requirement and dynamic performance requirement.

3) Construction accessibility.

Construction accessibility refers to mainly the degrees of the selected supporting scheme for foundation pit in construction complexity, supply of construction equipment, supply of construction materials, construction period and construction distractions.

Construction accessibility could be reflected by five indictors, which are construction difficulties, equipment supply, supply of construction materials, construction period and construction distractions.

4) Economic rationality.

Economical rationality refers to mainly the conditions of the selected supporting scheme for foundation pit in project cost and future maintenance cost.

Economic rationality could be reflected by two indictors, which are the construction cost and the future maintenance cost of the scheme.

Based on the above analysis, the final indicator system of the optimization of supporting schemes for foundation pit is shown in Table 1.

From Table 1, it could be seen that in the designed indicator system, altogether 4 first level indicators are related, which are respectively technical feasibility, effect reliability, construction accessibility and economic rationality and 16 second level indicators. This indicator system could reveal comprehensively the requirements of the optimization of supporting schemes for foundation pit and provide support for implementing rationally the selection of supporting schemes for foundation pit.

Table 1. Indicator system of the optimization of supporting schemes for foundation pit.

Target level	First level indicator	Second level indicator
Optimization of supporting schemes for foundation pit	Technical feasibility X_1	Technical advancement X_{11}
		Technical maturity X_{12}
		Adaptability with hydrogeological conditions X_{13}
		Adaptability with design specifications X_{14}
	Effect reliability X_2	Satisfaction of strength requirement X_{21}
		Satisfaction of stiffness requirement X_{22}
		Satisfaction of stability requirement X_{23}
		Satisfaction durability requirement X_{24}
		Satisfaction dynamic performance requirement X_{25}
	Construction accessibility X_3	Construction difficulties X_{31}
		Equipment supply X_{32}
		Supply of construction materials X_{33}
		Construction period X_{34}
		Construction distractions X_{35}
	Economic rationality X_4	Scheme cost X_{41}
		Future maintenance cost of the scheme X_{42}

3. Construction of optimization model of supporting schemes for foundation pit based on TOPSIS

The objective of implementing optimization of supporting schemes for foundation pit is to select the best scheme with technical feasibility, effect reliability, construction accessibility and economic efficiency as the executive scheme from various alternative offers. Therefore, optimization of supporting schemes for foundation pit shall compare comprehensively various schemes with quantitative evaluation method, trying to reveal the differences between different

supporting schemes for foundation pit, which is of great significance for the selection of supporting schemes for foundation pit [9, 10].

From the constructed indicator system of optimization of supporting scheme for foundation pit it could be seen that such indicator system is a rather complex system involving altogether 16 evaluation factors, between each of which there are plenty of uncertainties. Meanwhile, these factors could not be expressed directly with values, but shall be determined through subjective judgment and investigation and analysis. So, it is necessary to construct a kind of decision-making model that could not only conduct comprehensive analysis of the advantages and disadvantages of the supporting schemes for foundation pit but also could treat quantized indicators and non-quantized indicators synthetically.

TOPSIS is a kind of distance comprehensive evaluation method, which could conduct ranking comparison of all supporting schemes for foundation pit, utilizing the original data matrix based on standardization to find out the optimal and the worst supporting scheme from limited supporting schemes, from which the distances between some supporting scheme for foundation pit and the optimal and the worst schemes could be obtained and the degree of closeness between the optimal scheme and all the supporting schemes could also be obtained [11]. After that all the schemes would be ranked according to their closeness. Such characteristic of TOPSIS conforms to the objective and requirement of optimization of supporting schemes for foundation pit, so it is with better applicability [12].

Procedures of the construction of optimization model of supporting schemes for foundation pit based on TOPSIS is as the follows [13]:

(1) Construct the indicator system of optimization of supporting scheme for foundation pit.

The indicator system of optimization of supporting schemes for foundation pit is as shown in Table 1.

(2) Determine the weights of the indicators in the indicator system of optimization of supporting scheme for foundation pit.

First invite experts to determine the weights of the indicators in the indicator system of optimization of supporting scheme for foundation pit with AHP method respectively; then synthesize the opinions of the experts, taking the arithmetic mean value of the indicator weight evaluation results of each expert as the final weight of each indicator.

(3) Establish single factor evaluation matrix.

Establishment of single factor evaluation matrix requires three steps, which are respectively:

1) Determine single factor characteristic quantity X.

m optimization indicators of supporting system for foundation pit form n evaluation values of the optional supporting schemes for foundation pit. The judgment of n optional supporting schemes for foundation pit with the optimization indicator of each supporting scheme for foundation pit could be expressed with indicator characteristic value, that is:

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} = (x_{ij})_{m\times n}, \tag{1}$$

where, x_{ij} ($i = 1, 2,\ldots, 16, j = 1, 2,\ldots, n$) is the indicator characteristic value of the evaluation indicator i of supporting scheme for foundation pit.

In the indicator system of optimization of supporting schemes for foundation pit constructed in this essay, the indicator that could not be represented with values directly is named as qualitative index, while those that could be represented with values directly are known as quantitative index. For these two kinds of indexes, the ways of determining their characteristic quantities are different to some certain.

The characteristic value of qualitative index could be determined by expert evaluation. Since the contents of different qualitative indicator evaluation are also different, different types of qualitative index and index comment set and index evaluation are defined respectively in this

essay.

In this essay, among the 16 indicators in the indicator system, except the two second level indicators under the first level indicator of economic rationality (X_4), i.e. scheme cost (X_{41}) and future maintenance cost (X_{42}), all the other 14 secondary indicators are qualitative indicator, the evaluation results of which could be classified as "very high" ($\tilde{V}_1$), "high" ($\tilde{V}_2$), "common" ($\tilde{V}_3$), "low" ($\tilde{V}_4$), "very low" ($\tilde{V}_5$), $\mathbf{V} = \{\tilde{V}_1, \tilde{V}_2, \ldots, \tilde{V}_i, \ldots, \tilde{V}_n\}$. There values are appointed as 1.0, 0.8, 0.6, 0.4 and 0.2. Evaluations for these four indicators are obtained by survey, i.e. the experts of the optimization group of the supporting schemes for foundation pit shall conduct survey respectively and then treat and analyze the data obtained and the arithmetic mean value of the corresponding value of the experts' evaluation results would be taken as the results of the optional supporting schemes for foundation pit.

The two second level indicators under the first level indicator of economic rationality (X_4), namely the scheme cost (X_{41}) and future maintenance cost (X_{42}), are quantitative indicators, for which the specific values of the optional supporting schemes for foundation pit are taken respectively as their indicator characteristic value.

2) Determine the indicator membership matrix R.

The superior membership of each indicator could be calculated after the characteristic quantity of each evaluation index is determined. In the indicator system constructed in this essay, some indicators are the larger the better while some others are the smaller the better.

For indicators the larger the better, the following formula could be used to compute their memberships:

$$r_{ij} = \frac{x_{ij}}{x_{i\max} + x_{i\min}}, \quad j = 1, 2, \ldots, n. \tag{2}$$

Among which, r_{ij} is the degree of the ith indicator of the supporting scheme j belonging to excellence: $x_{i\max} = \max_j\{x_{ij}\}$, $x_{i\min} = \min_j\{x_{ij}\}$.

In the optimization system of supporting schemes for foundation pit constructed in this essay, the indicators the larger the better include technical advancement (X_{11}), technical maturity (X_{12}), adaptability with hydrogeological condition (X_{13}), adaptability with design specification (X_{14}), satisfaction degree of strength requirement (X_{21}), satisfaction degree of stiffness requirement (X_{22}), satisfaction degree of stability requirement (X_{23}), satisfaction degree of durability requirement (X_{24}) and satisfaction degree of dynamic performance requirement (X_{25}).

The membership of the indicators the smaller the better could be computed with the following formula:

$$r_{ij} = 1 - \frac{x_{ij}}{x_{i\max} + x_{i\min}}, \quad j = 1, 2, \ldots, n. \tag{3}$$

In the optimization system of supporting schemes for foundation pit constructed in this essay, except the indicators the larger the better, all the other indicators are the smaller the better.

In the formula, r_{ij} is the degree of the indicator i of the optional supporting scheme j belonging to excellence: $x_{i\max} = \max_j\{x_{ij}\}$, $x_{i\min} = \min_j\{x_{ij}\}$.

Based on Eqs. (1), (2) and (3), the indicator characteristic quantity matrix could be converted into indicator membership matrix:

$$\mathbf{R} = \begin{pmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{pmatrix} = (r_{ij})_{m\times n}. \tag{4}$$

Among which, $i = 1, 2, \ldots, 16$; $j = 1, 2, \ldots, n$.

3) Determine the ideal and the negative ideal supporting scheme for foundation pit.

The indicator membership of the ideal supporting scheme for foundation pit shall be the maximum value of the corresponding indicator membership of all the supporting schemes for foundation pit, i.e.:

$$\mathbf{R}^* = (r_1^* \ \ r_2^* \ \ ... \ \ r_m^*). \tag{5}$$

Among which $r_i^* = \max_j\{x_{ij}\}$ $(i = 1, 2,\ldots, 16, j = 1, 2,\ldots, n)$.

The indicator membership of the negative ideal supporting scheme for foundation pit shall be the minimum value of the corresponding indicator membership of all the supporting schemes for foundation pit, i.e.:

$$\mathbf{R}^- = (r_1^- \ \ r_2^- \ \ ... \ \ r_m^-). \tag{6}$$

Among which, $r_1^- = \min_j\{x_{ij}\}$ $(i = 1, 2,\ldots, 16, j = 1, 2,\ldots, n)$.

(4) Make final decision.

1) Calculate the differences between all the optional supporting schemes for foundation pit and the ideal supporting scheme and the negative ideal supporting scheme.

Weight Euclidean distance is adopted as the indicator of measuring the difference. The differences between all the optional supporting schemes for foundation pit and the ideal supporting scheme and the negative ideal supporting scheme are respectively d_j^* and d_j^-, then:

$$d_j^* = \sqrt{\sum_{i=1}^{m} W_i(r_{ij} - r_i^*)^2}, \ \ j = 1, 2, \ldots, n, \tag{7}$$

$$d_j^- = \sqrt{\sum_{i=1}^{m} W_i(r_{ij} - r_i^-)^2}, \ \ j = 1, 2, \ldots, n. \tag{8}$$

2) Calculate the close degree between all the optional supporting schemes for foundation pit and the ideal supporting scheme and the negative ideal supporting scheme.

The close degree of the optional supporting scheme for foundation pit and the ideal supporting scheme is defined as C_j, the expression of which is:

$$C_j = \frac{d_j^-}{d_j^* + d_j^-}. \tag{9}$$

Generally, $0 \le C_j \le 1$. The closer the C_j value is to 1, the higher is the excellence degree of the supporting scheme for foundation pit. According to the size of C_j, rank all the optional supporting schemes for foundation pit and then select the supporting scheme with the optimal synthesized conditions as the supporting scheme for foundation pit for specific project.

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4. Conclusions

Present studies on supporting schemes for foundation pit is mainly focused on technical level. However, from the aspect of the characteristics of supporting schemes for foundation pit, optimization study of selecting the best supporting scheme for foundation pit is still inadequate in current studies. That's why the essay probes systematically the optimization system of supporting

schemes for foundation pit, trying to construct in theory the indicator system and the optimization model of optimization of supporting schemes of foundation pit, which is of better theoretical and practical significance.

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