Study on the Evaluation of the Applicability of Recharge with Fuzzy Comprehensive Evaluation Method

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Abstract. Recharge is an effective method widely applied to avoid the potential environmental risks caused by the loss of groundwater during the excavation. In order to know the applicability of recharge in a specific project, a fuzzy comprehensive evaluation method is applied. Using the necessity, feasibility and economy evaluation indicators, a decision value can be computed in order to help the recharge decision-making. This method provides a clear and applicable way in similar projects.

1. Introduction

During the excavation of the foundation pit, the long-term and large-scale dewatering may lead to severe environment problem, such as ground subsidence and groundwater loss. Nowadays, the integrated construction method of pumping and recharge has been implemented in many projects nationwide to overcome this problem. In this method, while pumping in the pit, recharge system is applied outside of the pit to maintain the surrounding water level. This method can effectively avoid the adverse impact on the surrounding environment and achieve good results in many projects in different areas.

However, in some cases, the recharge effect is not evident as others, which shows the adaptability of recharge method is limited. And if the recharge water affects the groundwater quality, the recharge method should not be applied. And in some case, recharge may cost much money, making it hardly be applied.

Therefore, it is very necessary to mathematicalize and systematize the decision-making process. Because evaluation indicators such as the quality of recharge water, the distance between the building and the foundation pit, the risk loss level, the permeability of the aquifer, and the cost of recharge are difficult to quantify, it is necessary to apply the fuzzy relation synthesis principle to quantify some factors that are unclear and difficult to quantify, make fuzzy decisions, sort these indicators in a fuzzy environment, and finally decide whether or not to recharge.

2. Principle of Fuzzy Comprehensive Evaluation Method

Famous American computer and control expert Zadeh. A firstly introduced Fuzzy Sets concept to describe the notion whose extension is not clear. The basic idea is changing the absolute set into flexible common set, so that the element of "collections" of membership which can only be taken from {0, 1} expands to any value in the desirable range [0, 1]. Fuzzy comprehensive evaluation uses some concepts of fuzzy mathematics to provide an evaluation of the actual comprehensive evaluation problem.
The operation steps of fuzzy comprehensive evaluation are as follows:

Step 1: determine the evaluation index and comment set, establish the factor index and corresponding relationship of the evaluation object, \( U = \{ u_1, u_2, \ldots, u_m \} \) is the evaluation factor set, \( V = \{ v_1, v_2, \ldots, v_n \} \) is a set of comment levels.

Step 2: determine the weight vector matrix \( A \). Since there may be differences in the importance of different factors, the weight of each factor needs to be calculated. There are many ways to determine the weights, and usually the methods of analytic hierarchy process and principal component analysis can be used to assign weights.

Step 3: establish a suitable membership function to construct a weight judgment matrix \( R \).

\[
R = \begin{bmatrix}
    r_{11} & r_{12} & \cdots & r_{1n} \\
    r_{21} & r_{22} & \cdots & r_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    r_{m1} & r_{m2} & \cdots & r_{mn}
\end{bmatrix}
\]

Step 4: synthesize fuzzy comprehensive evaluation results to calculate weights. With the above two matrices (weight vector matrix \( A \) and weight judgment matrix \( R \)), the weight of the fuzzy comprehensive evaluation can be directly calculated, and the evaluation object can be comprehensively evaluated to obtain the comprehensive situation of the evaluation.

Step 5: Use suitable synthesis factors to synthesize, and explain the result vectors for decision evaluation.

Fuzzy operators commonly used are as following: "Min-Max"; "multiply and plus"; " Min/multiply and plus";" Min and multiply";" Min and plus" Fuzzy operators, etc.

3. Application of fuzzy comprehensive evaluation method

Fuzzy comprehensive evaluation method is taken into application in a subway station in Jiangsu Province as an example. The necessity of recharge is analysed, and the fuzzy comprehensive evaluation method is used to make a decision to determine whether recharge method should be carried out.

The necessary indicators mainly focus on the economic risk loss and environmental damage that may be caused if the water level outside the pit is out of control without recharge, including the amount of ground subsidence, the differential subsidence, the allowable values of subsidence and differential subsidence of the building (structure), and loss of groundwater resources.

![Figure 1. Necessity indicators](image)

The set of evaluation factors for the necessity of recharge \( U = \{ u_1, u_2, \ldots, u_m \} \) are the importance of the structure, the distance between the structure and the foundation pit, the size of the water level in the pit, the difficulty of ground subsidence, reliability of construction technology of water-stop curtains, water resource protection requirements, etc. Comment rating set \( V = \{ v_1, v_2, v_n \} \) can be
divided into {very necessary, necessary, not necessary, unnecessary}. The weight of each evaluation factor is evaluated by the expert evaluation method, and the weight vector matrix A= \{a_1, a_2, ..., a_m\} = \{0.25,0.2,0.15,0.15,0.15,0.1\}.

The excavation depth of standard segment station is 16.66 m. The surrounding areas of the project are mainly commercial districts and schools, and the northeast side of the station is 1# and 3# commercial buildings with pile foundations. Among them, 1# commercial building has 18 floors and its basement border is about 40.3m away from the main foundation pit; 3# commercial building has 4 floors and its basement border is about 46.7m away from the east end of the main foundation pit. The north side of the station is a research institute, a 25 floors pile/foundation building whose basement border is approximately 38.6m away from the station. The buildings on the south side of the station are 6#, 10#, 23# apartment buildings, 6 and 10# apartment buildings are brick-concrete structure, 4~5 floors, raft foundation. The closest distance from them to the station is 42.2m and 39.6 m separately. 23# apartment building has 12/13 floors, and its pile foundation is about 45.5m from station. The judgment matrix R_1 = \{r_{ij}\} = \{0.3,0.25,0.25,0.2\} according to the evaluation method of the importance of surrounding buildings according to the expert evaluation method. The weight judgment matrix R_2 = \{r_{ij}\} = \{0.1,0.3,0.4,0.2\} obtained from the object distance evaluation.

The main layers involved in the project from top to bottom are as follows: fill layer ①, sandy silt layer ②, interposed silt sandy silt layer ③-1; silty sand layer③-2, silty sand layer ③-4, silty sand layer ⑤. The underground continuous wall is not completely inserted into the water-proof layer, and at the same time, the relative water-proof layer ④-2 layer is missing in some area. The submerged aquifer and the confined aquifer are interconnected. The judgment matrix based on the weighting judgment matrix of recharge necessity R_3 = \{r_{ij}\} = \{0.3,0.2,0.3,0.2\}. The obtained weighting judgment matrix based on the evaluation of the sensitivity of ground settlement R_4 = \{r_{ij}\} = \{0.4,0.3,0.0,2,0.1\}.

The enclosure structure is 800 mm thick underground continuous wall, and the joints of the underground continuous wall are made of I-beam. The judgment matrix R_5 = \{r_{ij}\} = \{0.2,0.3,0.3,0.2\} according to the weight evaluation of the construction reliability of the water-stop curtain.

The construction area is an area with highly compressive soft soil layer. The pumping of groundwater will cause a significant drop in water level, a decrease in hydrostatic pressure, and an increase in effective stress. This will cause geological environmental problems such as ground subsidence and water salinization. The judgment matrix R_6 = \{r_{ij}\} = \{0.3,0.3,0.2,0.2\} according to the assessment of water resources protection requirements.

The obtained weight judgment matrix R is as follows:

\[
R = \begin{bmatrix}
0.3&0.25&0.25&0.2 \\
0.1&0.3&0.4&0.2 \\
0.3&0.2&0.2&0.2 \\
0.4&0.3&0.2&0.1 \\
0.2&0.3&0.3&0.2 \\
0.3&0.3&0.2&0.2
\end{bmatrix}
\]

The weight vector matrix A is determined by the experts, here A = \{a_1, a_2, ..., a_m\} = \{0.25,0.2,0.15,0.15,0.15,0.1\}.

The use of "multiply and plus" fuzzy operator, B = A*R = \{0.2600, 0.2725, 0.2825, 0.1850\}, if the evaluation system V= \{necessary, necessary, not necessary, unnecessary\} is corresponding to value \{4,3,2,1\}. The final score is F_1 = B*V = 2.6075, and it is more inclined to be necessary.

4. Conclusion
Recharge is an effective but limited method to eliminate the environment impact caused by the excavation of pit. Fuzzy Comprehensive Evaluation Method is applied to the determination of
recharge. Fuzzy Comprehensive Evaluation Method can quantify the ‘yes or no’ indicators into values 0 to 1.

Fuzzy comprehensive evaluation method is taken into application in a subway station in Jiangsu Province as an example. The necessity of recharge is analysed and finally the result is more inclined to be necessary.

The use of Fuzzy Comprehensive Evaluation Method helps to make the recharge decision-making process more transparent and intuitive. This application in a project will guide the similar project to decide whether recharge is needed or not.

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