Soil parameters inversion and influence based on MIDAS GTS

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Abstract. The foundation pit engineering design is continuously optimized and improved. With the development of scientific computing, especially the finite element analysis software technology in the popularization of soil parameter inversion, it provides a new technical approach. Midas GTS was developed to quickly complete the analysis and design of geotechnical and tunnel structures. It provides a variety of theoretical analysis and design functions, as well as a variety of constitutive and user-defined constitutive models to properly analyze the safety of foundation pit design. has become an important method for obtaining effective parameters in recent years.

1. Introduction
In the traditional foundation pit design, the foundation pit cannot be comprehensively and effectively predicted. Before the foundation pit simulation prediction, choosing the correct constitutive model and soil mechanics parameters can make the prediction result more realistic, but how to be more accurate in the actual project [1-3]. Obtaining soil mechanics parameters is the key to ensuring the safety of foundation pit construction and foundation pit construction. The soil mechanics parameters obtained through laboratory tests or in-situ in-situ tests change the stress and strain of the soil due to changes in the site environment, resulting in inaccurate results [4-6]. In this paper, the on-site monitoring of a deep foundation pit is carried out, and the obtained measured data is analyzed. Then, combined with the finite element analysis software of the soil and tunnel, Midas GTS, the two-dimensional finite element of the deep foundation pit and the deep foundation pit of the subway are carried out [7,8]. Numerical simulation, combined with BP neural network to invert the mechanical parameters of the soil, select BP neural network theory suitable for this project.

2. Midas GTS basic principles and processes

2.1. Model establishment
In this paper, the foundation pit is 237m long, the average width is 20m, and the depth of the foundation pit is 18m. The bottom plate of the main body of the foundation pit is located in the strong weathered granite layer, and is located in the second layer of silty clay and coarse sand layer. The main body envelope structure of the station adopts the form of retaining pile + inner support + rotary jetting pile water stop curtain. The main body retaining pile is made of 1000mm bored pile and supported by three concrete supports. The excavated foundation pit is excavated twice, with a width of 20m and a depth of 18m. The size of the two-dimensional finite element model is 104m×56m, the supporting structure is...
embedded at a depth of 5m, three concrete supports are installed in the pit, and two anchors are provided on the pile side. The beam unit is selected for the support pile and the inner support attribute, and the anchor truss is selected for the anchor attribute. The mesh size of the excavation part is set to 0.8, and the grid size of the unexcavated part is set to 3. The anchor rod adopts the anchor modeling assistant, the grouting length is 8 meters, the unfilled length is 5 meters, and the pre-stress of 300KN is applied in the grouting area. The support pile is drawn from the geometric line. The boundary conditions are automatically constrained in the constraint. The static load includes the prestressed load and the dead weight of the bolt. The construction phase is divided into 5 parts; it is divided into three excavations.

Table 1. Characteristics of soil parameters

| Name                | Thickness (m) | Model Type     | Elastic Modulus (MPa) | Poisson Ratio (μ) | Bulk Weight γ (KMN⁻³) | Cohesion (kpa) | Friction Angle (°) |
|---------------------|---------------|----------------|-----------------------|------------------|-----------------------|----------------|-------------------|
| Prime fill          | 2             | Moore-Cullen   | 6                     | 0.25             | 16.5                  | 10             | 15                |
| Silty clay          | 3.5           | Moore-Cullen   | 10                    | 0.25             | 19.3                  | 23.2           | 9.9               |
| Coarse sand         | 3             | Moore-Cullen   | 18                    | 0.3              | 20                    | 0              | 35                |
| Silty clay2-1       | 2             | Moore-Cullen   | 12                    | 0.26             | 20                    | 15.9           | 9.4               |
| Coarse sand3-1      | 1             | Moore-Cullen   | 22                    | 0.3              | 20                    | 0              | 35                |
| Strongly weathered granite | 50          | Moore-Cullen   | 45                    | 0.25             | 20                    | 8              | 40                |
| Concrete C30        | /             | Elasticity     | 31000                 | 0.2              | 23                    | /              | /                 |
| Concrete C25        | /             | Elasticity     | 29500                 | 0.2              | 23                    | /              | /                 |
| Reinforcement       | /             | Elasticity     | 210000                | 0.3              | 77                    | /              | /                 |

Figure 1. Horizontal Displacement of Foundation Pit Support Structure and around the foundation pit

It can be seen from the deformation of the soil layer of the model that the horizontal displacement curve around the foundation pit is parabolic, and the displacement value is about 12m away from the foundation pit. The upper part of the support structure has a larger displacement, and the lower part has a reverse displacement, but is smaller. The maximum horizontal displacement of the foundation pit support structure is 5.43mm, and the reverse maximum horizontal displacement is 3.72mm, which is less than the alarm value of 30mm in the specification. The maximum horizontal displacement around
the foundation pit is 6.66mm, and the maximum horizontal displacement in the reverse direction is 0.84mm, which is less than the alarm value of 20mm. Explain that the foundation pit is safe.

2.2. Analysis of inversion results of subway foundation pits

The soil parameters obtained by the inversion are input into the Midas GTS for calculation, and the obtained subway support structure simulates the horizontal displacement and the surrounding settlement value cloud map. The simulated value and the measured value are compared as shown in the following table.

![Inverse displacement cloud](image)

**Table 2. Comparison between simulated and measured values of support structure deformation**

| distance (m) | 0   | 4   | 8   | 12  | 16  | 20  | 24  | 28  | 32  | 36  |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Measured value (mm) | -0.80 | 4.97 | 6.58 | 7.06 | 6.36 | 5.16 | 4.54 | 3.44 | 2.32 | 1.25 |
| Inversion value (mm) | -0.84 | 4.48 | 6.05 | 6.36 | 5.84 | 4.92 | 4.26 | 3.49 | 2.49 | 1.30 |
| Relative error (mm) | 0.04 | 0.49 | 0.54 | 0.70 | 0.52 | 0.23 | 0.27 | -0.06 | -0.17 | -0.04 |
| Absolute error (%) | 5.07% | 9.91% | 8.18% | 9.97% | 8.16% | 4.54% | 6.06% | 1.61% | 7.26% | 3.41% |

3. Analysis of the influence of soil parameters

3.1. Principle of orthogonal analysis

Orthogonal test design is a multi-factor and multi-level design test method. According to the orthogonality, some representative points are selected from the comprehensive test. For the analysis of orthogonal test results, two methods are generally used: one is visual analysis or range analysis; the other is analysis of variance. The following symbols $i$ indicate factor level numbers, and subscripts $j$ indicate different factors. The formula for calculating the range $R_j$ of factors $j$ is as follows:

$$R_j = \max_i \{K_{ij}\} - \min_i \{K_{ij}\}$$

Assume that the test result is a random variable that follows a normal distribution. The sum of the squares of the deviations of the blank columns of the orthogonal table is not caused by any factor, and is therefore caused by the error. Check the F distribution table to get $F_{f_2}^{-1}(\alpha)$. So under the significant level, the test for H0 is:
Discarding $H_0$ means that the effect of factor $A$ on the test results is significant; the effect of factor $A$ on the test results is considered without abandoning $H_0$.

### 3.2. Soil parameter level selection

Through the previous analysis, we can get the influence of the elastic modulus $E$, Poisson's ratio $\mu$, cohesion $c$ and friction angle $\phi$ on the deformation of the foundation pit; the change of the elastic modulus has obvious influence on the deformation of the foundation pit, especially the bottom. The strong weathered granite, but can not compare the effect of the elastic modulus $E$, Poisson's ratio $\mu$, cohesion $c$ and friction angle $\phi$ on the edge shape of the foundation pit. The following factors select the elastic modulus $E$, Poisson's ratio $\mu$, cohesion $C$ and friction angle $\phi$ of the strongly weathered granite. According to the orthogonal experimental design table, the 4 factor 3 level $L_9(3^4)$ orthogonal test is selected. The selection of the parameter level is shown in the table below.

**Table 3.** Range of parameter values of severely weathered granite

| level | Elastic Modulus $E1$(Mpa) | Poisson ratio($\mu$) | Cohesion(kpa) | Friction angle$\phi$( °) |
|-------|---------------------------|----------------------|---------------|-------------------|
| 1     | 22.5                      | 0.125                | 4             | 20                |
| 2     | 45                        | 0.25                 | 8             | 40                |
| 3     | 67.5                      | 0.375                | 12            | 60                |

According to the $L_9(3^4)$ orthogonal test table, 16 sets of different levels of parameters were obtained, which were input into the Midas GTS for calculation, and the maximum horizontal displacement of the support structure was output as a result. The specific results of the orthogonal test design are shown in the table below.

**Table 4.** Orthogonal test plan design

| Column number | 1 Elastic Modulus $E1$(Mpa) | 2 Poisson ratio($\mu$) | 3 Cohesion(kpa) | 4 Friction angle$\phi$( °) | Support structure horizontal displacement(mm) | result |
|---------------|-----------------------------|------------------------|-----------------|----------------------------|---------------------------------------------|--------|
| 1             | 23                          | 0                      | 12              | 60                         | 14                                          | 14     |
| 2             | 45                          | 0                      | 4               | 60                         | 7                                           | 7      |
| 3             | 68                          | 0                      | 12              | 20                         | 3                                           | 3      |
| 4             | 68                          | 0                      | 4               | 40                         | 2                                           | 2      |
| 5             | 23                          | 0                      | 8               | 40                         | 16                                          | 16     |
| 6             | 68                          | 0                      | 8               | 60                         | 5                                           | 5      |
| 7             | 23                          | 0                      | 4               | 20                         | 14                                          | 14     |
| 8             | 45                          | 0                      | 8               | 20                         | 4                                           | 4      |
| 9             | 45                          | 0                      | 12              | 40                         | 8                                           | 8      |
The range analysis was performed on the orthogonal test results, as shown in the table below.

| factory | 1 | 2 | 3 | 4 |
|---------|---|---|---|---|
| Column number | Elastic Modulus E1(Mpa) | Poisson ratio(μ) | Cohesion(kpa) | Friction angle φ(°) |
| K1 | 43.40 | 26.88 | 22.76 | 20.41 |
| K2 | 18.66 | 25.52 | 23.92 | 26.61 |
| K3 | 9.99 | 19.65 | 24.61 | 25.03 |
| k1 | 14.47 | 8.96 | 7.59 | 6.80 |
| k2 | 6.22 | 8.51 | 7.97 | 8.87 |
| k3 | 3.33 | 6.55 | 8.20 | 8.34 |
| R | 33.41 | 7.23 | 1.85 | 6.2 |

From the results of the range analysis table, it can be seen that R₁>R₂>R₄>R₃, R₂ is up to 33.41, and R₃ is at least 1.85, indicating that the most important influence in the strongly weathered granite layer is the elastic modulus, followed by Poisson. Specific μ, cohesion c, friction angle φ.

Since the sensitivity of cohesion is the lowest, cohesion is selected as the error column for analysis of variance. Take the F distribution to a significant level of 1 to 0.1, respectively.

| factory | Sum of squared deviation | Degree of freedom | Mean square | F ratio | F-threshold | Significant |
|---------|--------------------------|------------------|-------------|---------|-------------|-------------|
| Elastic Modulus | 200.385 | 2 | 100.192 | 175.775 | 9.00 | √ |
| Poisson ratio | 9.842 | 2 | 4.921 | 8.633 | 9.00 |
| Cohesion | 1.14 | 2 | 0.57 | 1.000 | 9.00 |
| Friction angle | 6.92 | 2 | 3.46 | 6.070 | 9.00 |
| error | 1.14 | 2 | 0.57 | | |

From the analysis in the table, it is known that among the factors causing the deformation of the foundation pit, the elastic modulus of the strongly weathered granite, the Poisson's ratio, the cohesion, and the friction angle affect the deformation of the foundation pit.

4. Conclusion
Select four important parameters of soil, elastic modulus, Poisson's ratio, cohesion force and friction angle. By adjusting the different levels of parameters, combined with the orthogonal experimental design scheme, input into the finite element analysis software for numerical simulation. The variation of foundation parameters is obtained by different parameters:

1) The elastic modulus has the greatest influence on the deformation of the foundation pit, followed by the Poisson's ratio, and the cohesion and friction angle have the least influence on the deformation of the foundation pit.

2) By analyzing the range and variance, it is further verified that the most influential is the elastic modulus, followed by the Poisson's ratio, and the cohesion and friction angle have the least influence on the deformation of the foundation pit.
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