The Application of Improved Genetic Algorithm to the Back Analysis of Foundation Pit Construction

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Abstract: The improved genetic algorithm is combined into the foundation pit finite element method. On the basis of the measured lateral displacement data on site, the parameters of the foundation soils were obtained by the back analysis. Then the lateral deformation of the surrounding soil was analyzed on the condition of each different step under the foundation pit excavation according to the inversion parameters, and the calculation and analysis of lateral displacement of cement-soil pile with anchorage retaining structure was did. The results reveal that the calculated value is agreed with to the measured value, which indicates that the improved genetic algorithm is efficient to the related constructions.

1. Introduction
With the characteristics of uncertainty, fuzziness, complexity in geotechnical engineering, therefore, the traditional deterministic method is not fitted to the subject, for a long time, material parameters and constitutive model are the focus of the field of academic research [1].

At present, with the development and application of information construction, the traditional strength control method is gradually replaced with by that of both strength and deformation method in geotechnical engineering. In this process, the inversion analysis methods emerge as the times require, which uses the collecting information as known quantity, material parameter for geotechnical was obtained by back analysis through the constitutive relationship[2]. The properties of both maintenance structure and soil in period of the next working conditions is predicted by collecting relevant information of the next stage on the base of the calculated parameters, this method is the new focus of foundation pit back analysis[3].

According to the basic principle of optimum back analysis, if the numerical solution of positive problem is solved, using the error of calculated value from forward problem and observed value as the driving force of evolution, then the inversion analysis of geotechnical engineering is implemented[4]. As a new type of searching method for global optimization, Genetic algorithms have some merits such as intelligence searching, parallel mode, robust and wide application [5]. It is fit to solve the extreme value of the objective function. The improved genetic algorithm combined with the FEM is used to calculate the excavation inversion analysis in foundation pit, and has achieved good effect.
2. Improved Genetic Algorithm

2.1. The content of improved genetic algorithm

Aiming at the problems of the basic genetic algorithm, considering the merits of geotechnical engineering, some improvements were conducted to achieve the parameter identification method of optimization back analysis for geotechnical engineering problems.

(1) The multi-parameter cascade real number coding mode is used to the genetic algorithm. A set of parameters is inversed as a vector, which is regarded as an individual, each parameter in the individual with independent definition and with corresponding range according to the actual situation.

(2) In the paper, the population size (M) is regarded as variable parameter, using larger population size if the finite element model is smaller, whereas using in smaller scale, at the same time, the inching technique is employed, which can keep the diversity of population to maximum limit, and, can effectively avoid the common defect of early convergence.

(3) In displacement back analysis of geotechnical engineering, the relative error (1) of calculated values and measured values is regarded as the objective function, and the fitness function is transformed into formula (2) by the power law scaling, writing as following:

\[
 f = \sum_{i=1}^{k} \left( 1 - \frac{s_i}{s_{i}^{\text{ref}} \} \right)^2
 \]

Where, \( k \) is the total measured values, \( s_i^{\text{ref}} \) refers to the measured value, such as displacement, stress, strain and so on. \( s_i \) is the calculated value from forward analysis.

\[
 \text{fitness} = \frac{1} {f^2 + \varepsilon}
 \]

where, \( f \) is the objective function, which established by formula (1), \( \text{fitness} \) is fitness function, which employed to solve minimum problem, \( \varepsilon \) is very small positive number, which avoids the denominator is not zero.

(4) According to fitness value of each individual, the crossover probability of each individual (\( p_c \)) and mutation probability (\( p_m \)) are determined by employing the adaptive thoughts. If an individual fitness value is greater, the individual is close to the optimal individual, the probability of individual’s involved in crossover operation is bigger and mutation probability is smaller, its excellent performance can maintain to maximum. Crossover probability (\( p_c \)) and mutation probability (\( p_m \)) writing as follows:

\[
 p_c = \frac{\text{fitness}(x_i)} {\sum_{i=1}^{k} \text{fitness}(x_i)}
 \]

\[
 p_m = 1 - \frac{\text{fitness}(x_i)} {\sum_{i=1}^{k} \text{fitness}(x_i)}
 \]

Where, \( \text{fitness} (x_i) \) is the fitness function of individual \( x_i \), established by formula (2), \( k \) is the population size, ie, the total individual of population size.

(5) Set the maximum iterative algebraic \( T \) as one of the termination conditions, making average values of objective function of the population as the convergence criterion, if value satisfies the formula (5), then the algorithm terminates.

\[
 \frac{1}{k} \sum_{i=1}^{k} f_i \leq \varepsilon
 \]
Where, $f_i$ is the $i$th individual’s values of objective function among in the population, calculated by formula (1), $\varepsilon$ is convergence criterion i.e. very small positive number.

3. Back Analysis for Foundation Pit Excavation

3.1. Mechanical mode

The excavation width of foundation pit is 30 meters, maximum depth reaches 10 meters, using manual hole digging pile, its diameter of 1.2 meters and length 17.5 meters respectively. Employing tow bolts to support the construction, it’s with length 21 meters and the dip 15°, and the pretested stress of anchor is 120 kN. The soil clays mainly include silt clay ①, silt ②, silty clay ③ and weathered muddy sandstone ④.

The excavation section is axisymmetric problem, using 1/2 model to analyze, the impacted range of ground lateral subsidence of foundation pit excavation was set to 40 meters, [5], and the bottom scope was set 10 meters below the pile. Both surrounding boundary for horizontal restraint and the bottom boundary for the vertical constraint were applied, and the finite element mesh as shown in figure 1.

3.2. Construction steps and inversion parameters

The main construction steps for finite element calculation process is as follows: the self weight stress field; the first step excavation for 3 meters (named step1), layout the first anchor (Step2); second step excavation for 3 meters (Step3), layout second anchor (Step4); third step excavation for 4 meters till to the bottom of the foundation pit (step5).

Only the parameters that play an important influence on the soil deformation such as elastic modulus ($E$), cohesion ($C$), and frictional angle ($\Phi$) were analyzed during the back analysis in foundation excavation, and the constitutive mode of soil employed Drucker-Pracker criterion, the inversion analysis range of parameters for soil as shown in table 1. Inversion parameters of the soils were conducted on using the monitoring lateral displacement of 1# pile (as shown in Figure 2). The population size was set to 100, the maximum number of iterations was 200, the crossover probability was 0.9, mutation probability was 0.2, and total parameters of soils were 12, the results of inversion parameters as shown in table 2.
Table 1: The range of the inversion parameters

| Soil clay name | Cohesive $c$ (kPa) | Friction angle $\Phi$ (°) | Elastic modulus $E$ (MPa) |
|----------------|---------------------|--------------------------|--------------------------|
| 1              | 4-6                 | 10-20                    | 4-5                      |
| 2              | 5-10                | 10-20                    | 4-6                      |
| 3              | 25-35               | 15-20                    | 5-6                      |
| 4              | 450-550             | 40-50                    | 400-550                  |

Table 2: The results of the inversion parameters

| Soil clay name | Cohesive $c$ (kPa) | Friction angle $\Phi$ (°) | Elastic modulus $E$ (MPa) |
|----------------|---------------------|--------------------------|--------------------------|
| 1              | 4.95                | 14.6                     | 4.04                     |
| 2              | 5.32                | 10.27                    | 5.18                     |
| 3              | 28.31               | 18.80                    | 5.36                     |
| 4              | 498.26              | 40.57                    | 476.47                   |

3.3. Back analysis of results

The FEM analysis for foundation excavation was performed using soil parameters from inverse analysis, obtaining the results for every excavation step with bolt based on the lateral displacement of the pile 1#, as shown figure 3. It is shown that the calculation values agree well with the monitoring data, the top anchor plays an important role on lateral displacement of pile pole, however, the effect on the lateral displacement of pile due to the anchor near the middle of pile is insignificant.
4. Conclusions

(1) An improved genetic algorithm is adopted for the inversion analysis of foundation excavation in this paper, obtaining the soil parameter by inversion and the relevant results are reliable.

(2) Taking the lateral displacement of the pile as basis for parameter inversion analysis, which grasp the key points of foundation engineering, and it plays a decisive role on both construction quality and safety, and the employed index is reasonable.

(3) Compared to the measured value, the improved genetic algorithm is effective, applicable, and can satisfy the engineering requirements.

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