Study on Correlation of Physical and Mechanical Properties Indexes of Cohesive Soil in Hilly and Plain Region along the Yangtze River in Anhui Province

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Abstract. In this paper, a large number of geotechnical engineering survey data are collected in hilly and plain region along the Yangtze River in Anhui Province. Based on the statistical analysis and calculation of the experimental data of physical and mechanical properties of cohesive soils (the main quaternary soil layers in the area), the correlation between the liquidity index and water content and other physical and mechanical properties indexes are analyzed, and the fitting regression is carried out respectively. The results show that the liquidity index (I_L) and water content (w) are highly correlated with cohesion (C), compression modulus (E_s), compression coefficient (α), natural density (ρ), void ratio (e), and the regression equations have high goodness of fit and good fitting effect. In addition, the fitting regression equations of water content, void ratio and natural density are compared with the theoretical calculation formula, it is found that the calculation results are close, which proves that the fitting regression equations are reliable and can be used in engineering practice.

Keywords. Hilly and plain region along the Yangtze River in Anhui Province; Cohesive soil layer; Physical and mechanical property index; Correlation analysis; Empirical formula

1. Introduction

The physical and mechanical properties indexes of soil are the basis of analysis, evaluation and design calculation in geotechnical engineering. In engineering practice, the physical and mechanical properties indexes of soil can be obtained directly by indoor geotechnical tests, in-situ tests or back analysis. However, any test or analysis method needs a certain period, and some test methods have high cost. Especially in the preliminary survey and design stage of some small and medium-sized projects, sufficient effective data often can not be obtained in time. According to the relationship between the physical and mechanical property indexes, it is also an indirect method commonly used in engineering to determine the parameters which are difficult to obtain in time by using some easily obtained parameters. At the same time, it is of great significance to study the relationship between the physical and mechanical property indexes and master their internal laws for the reasonable selection of geotechnical property parameters and the study of geotechnical engineering reliability.

Domestic and foreign scholars have done a lot of research on the correlation between the physical
and mechanical properties of soil. Azzouz A S et al.[1] used statistical methods to analyze and evaluate more than 700 consolidation test data of undisturbed soil, and established regression equation. Collotta T et al.[2] discussed the correlation between residual friction angle and physical and mechanical properties of cohesive soil. Anthony T. C[3] discussed the method of establishing the correlation relationship between physical and mechanical property indexes of soil by using neural network. Kang X et al.[4] established the relationship between undrained shear strength and plasticity index, and compared it with the existing empirical formula. Li Feifei et al.[5] and Wu Linian et al.[6] respectively conducted statistical analysis and regression on the cohesive soil in Hefei City, and discussed the correlation between the physical and mechanical property indexes of the soil. Jiang Jianping et al.[7,8] respectively analyzed and studied the correlation between the physical and mechanical properties of clay soil at the site of Nanjing Metro and Sutong Bridge. Liu Jia et al.[9] analyzed and studied the correlation between the compression index and physical property indexes of clay soils in Dalian City.

Due to the differences in sedimentary times, environment, material composition and structure of soil layers in different regions, their properties also vary greatly. Therefore, it is necessary to strengthen the research on the properties of regional soil layers[10]. The hilly and plain region along the Yangtze River in Anhui Province is a part of the middle-lower Yangtze Plain. The river terrace geomorphic units are developed in the region, and the Quaternary cohesive soil layers with different thickness and states are widely distributed on the surface[11,12]. This paper collects a large number of geotechnical engineering investigation reports in the study area, makes statistical analysis and calculation of physical and mechanical properties test data of cohesive soil layers in the area, and studies the correlation between the indexes.

It is found that the physical and mechanical properties indexes of cohesive soils in hilly and plain region along the Yangtze River in Anhui Province have different degrees of correlation. For cohesive soil, the moisture condition is the most important factor affecting its engineering properties, and the parameters representing the moisture condition of cohesive soil are mainly liquidity index and water content. Due to limited space, the paper focuses on the correlation between the liquidity index and water content of the cohesive soil in the study area and the commonly used soil property parameters such as the natural density, void ratio, cohesion, compression coefficient and compression modulus.

2. General Situation of the Study Area
The hilly and plain region along the Yangtze River in Anhui Province is located in the south of Anhui Province with an average altitude of about 20 m, including Wuhu City, Ma’anshan City, Anqing City and some areas of Chuzhou City, etc. It belongs to the humid monsoon climate in the northern subtropical, with clear four seasons and mild climate. The annual average precipitation is 1 200 ~ 1 400 mm.

The surface water system in the study area is well developed and belongs to the Yangtze River system. The types of microgeomorphology in the study area are floodplain, first class terrace, second class terrace and erosion residual hill. Except for erosion residual hill, the cohesive soil layers of different thickness and state are distributed on the surface of the other three types of microgeomorphic units, which mainly include Quaternary Holocene mucky silt, mucky soil, clay, silty clay, etc.[11,12]

3. Correlation Analysis and Fitting

3.1. Data Sources and Processing
The data used in the paper are all from several large survey and design institutes with decades of engineering experience in Anhui Province, and the data are accurate and reliable. Through the statistics of the data, a total of 125 projects are obtained for analysis and research, which basically covers the cities and counties under the jurisdiction of the hilly and plain region along the Yangtze River in Anhui Province, making the research results reliable and extensive.

In this paper, the main physical and mechanical properties of the cohesive soil layer in the study area are statistically calculated. After eliminating the data with large deviations, the correlation
analysis between the liquidity index and water content and other common physical and mechanical properties indexes is carried out, and the linear and nonlinear methods are used to fit one by one to seek the optimal fitting regression equation.

3.2. Correlation of Liquidity Index, Water Content and Mechanical Properties Indexes
The commonly used mechanical property indexes of soil mainly include cohesion, angle of internal friction, compression modulus, compression index and compression coefficient, etc. which are the necessary soil property parameters for the design and calculation of geotechnical engineering. Therefore, how to obtain the mechanical properties of foundation soil economically and quickly is an important issue for engineering and technical personnel. In this paper, it is found through fitting that the liquidity index and moisture content of the cohesive soil layers in the study area have good correlations with cohesion, compression coefficient and compression modulus. The specific results are shown in table 1 and shown in figure 1, but the correlation with other mechanical indexes is poor, so those fitting results are not given.

| Table 1. Fitting formulas of liquidity index, water content and mechanical properties of cohesive soil. |
| --- |
| The independent variable | The dependent variable | Fitting equation | Good fit $R^2$ | Dependent variable range |
| --- | --- | --- | --- | --- |
| Liquidity index | Cohesion | $C = 42.43(I_L)^2 -122.12(I_L) + 101.43$ | 0.769 | 5~139kPa |
| | Compression modulus | $E_s = 4.15(I_L)^2 -12.61(I_L) + 13.32$ | 0.670 | 2.45~21.15MPa |
| | Compression coefficient | $\alpha = 0.36I_L + 0.09$ | 0.740 | 0.021~0.89MPa$^{-1}$ |
| Water content (%) | Cohesion | $C = 237945w^{-2.55}$ | 0.658 | 5~139kPa |
| | Compression modulus | $E_s = 4702.69w^{1.92}$ | 0.671 | 2.45~21.15MPa |
| | Compression coefficient | $\alpha = 0.03w - 0.49$ | 0.835 | 0.08~1.49MPa$^{-1}$ |

![Figure 1. Scatter diagram and fitting curve of the relationship between liquidity index, water content and mechanical properties of cohesive soil in the study area.](image-url)
The moisture condition of cohesive soil is the main factor affecting its mechanical properties. When the water content increases, the strength decreases while the compressibility increases; when the water content decreases, the strength increases while the compressibility decreases. All the fitting regression equations reflect this law. It can be seen from table 1 and figure 1, the goodness of fit $R^2$ of each empirical formula is relatively high, ranging from 0.67 to 0.835, indicating the good fitting effect.

3.3. Correlation of Liquidity Index, Water Content and Physical Properties Indexes

The commonly used physical properties indexes of cohesive soil mainly include water content, void ratio, liquid limit, plastic limit, natural density, liquidity index, plasticity index, etc. Through fitting, it is found that the liquidity index and water content of the cohesive soil layers in the study area have good correlation with natural density and void ratio. The specific results are listed in table 2 and shown in figure 2, but the correlation with other physical properties indexes is poor, so those fitting results are not given.

It can be seen from table 2 and figure 2 that the goodness of fit $R^2$ of each empirical formula is relatively high, ranging from 0.763 to 0.975, indicating that the correlation between the liquidity index and water content and the above physical properties is relatively high.

### Table 2. Fitting formulas of liquidity index, water content and physical properties of cohesive soil.

| The independent variables | The dependent variable | Fitting equation | Good fit $R^2$ | Dependent range |
|---------------------------|------------------------|------------------|----------------|----------------|
| Liquidity index           | Water content          | $\omega = 12.84I_L + 21.24$ | 0.795           | 18.3–46.4%     |
|                           | Natural density        | $\rho = -0.17I_L + 2.01$   | 0.768           | 1.64–2.06g/cm$^3$ |
|                           | Void ratio             | $e = 0.35I_L + 0.61$       | 0.763           | 0.554–1.403    |
| Water content (%)         | Natural density        | $\rho = 0.01w + 2.26$      | 0.925           | 1.7–2.06g/cm$^3$ |
|                           | Void ratio             | $e = 0.03w + 0.04$         | 0.975           | 0.554–1.819    |

![Figure 2](image-url). Scatter diagram and fitting curve of the relationship between liquidity index, water content and physical properties of cohesive soil in the study area.

4. Comparison Between Empirical Formula and Theoretical Formula

The theoretical conversion formula of void ratio and water content is as follows:
According to the experimental data of cohesive soil collected from the study area, the specific gravity of soil particles ($G_s$) and soil saturation ($S_r$) are relatively stable, where $G_s$ is generally about 2.73 and $S_r$ is generally about 97%. It can be obtained by substituting them into Equation (1):

$$ e = w \cdot G_s / S_r $$

(1)

The theoretical conversion formula between the natural density of soil, water content and void ratio is as follows:

$$ \rho = \frac{\rho_s + e \rho_w}{1 + e} = \frac{G_s + w G_s / S_r}{1 + w G_s / S_r} $$

(2)

Similarly, taking $G_s = 2.73$, $S_r = 97\%$ into Equation (3), it can be obtained that:

$$ \rho = \frac{264.8 + 2.73w}{97 + 2.73w} $$

(4)

In Equations (1)(2)(3)(4), $\rho$ is the natural density of soil (g/cm$^3$); $\rho_s$ is the soil particle density (g/cm$^3$); $\rho_w$ is the density of water (g/cm$^3$); $e$ is the void ratio; $G_s$ is the specific gravity of soil particles; $w$ is the water content (%); $S_r$ is the saturation (%).

The regression equations of water content and soil void ratio and natural density in Table 2 are plotted with Eq. (2) & (4) respectively (as shown in figure 3 (a) & (b)). It can be seen from the figures that the regression equations obtained in the paper are close to the theoretical formula, indicating that the regression equations obtained in the paper are reliable and can be applied to engineering practice.

![Figure 3. Comparison of fitting regression equations in table 2 and theoretical formula Eq. (2) & (4)](image)

5. Conclusions

(1) In this paper, the physical and mechanical properties indexes of cohesive soil layers in the study area are statistically analyzed and fitted. The results show that the correlation between the liquidity index, water content and cohesion, compression modulus, compression coefficient, natural density, void ratio and other common physical and mechanical properties indexes of cohesive soil layers in the study area is good, and the goodness of fit is up to 0.975;

(2) It is found that the goodness of fit between water content and physical and mechanical properties indexes is generally higher than that between liquidity index and physical and mechanical properties indexes. That is, the correlation between water content and physical and mechanical properties indexes is higher, which can more directly characterize the properties and state of cohesive soil;

(3) The regression equations of water content, void ratio and natural density are compared with the corresponding theoretical formulas. It is found that the regression equation is close to the theoretical formula, indicating that the regression equation is reliable and can be applied to engineering practice.
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