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The Electrical Resistivity Characteristics of Cement-Soil and Flyash-Lime-Soil

Yu Xiaojun Miao Linchang Liu Songyu

(Institute of Geotechnical Engineering, Southeast University, Nanjing 210096, China)

Abstract: The electrical resistivity characteristics of cement-soil and flyash-lime-soil are investigated in the laboratory and the field. It is shown that the electrical resistivities of the cement-soil and flyash-lime-soil are sensitive to water content, degree of saturation and unconfined strength. The cement-soil and flyash-lime-soil with higher water content, greater degree of saturation, lower unconfined strength has lower electrical resistivity. Electrical resistivity is also correlated with additives. Based on the tests, it is concluded that the electrical resistivity method is available for checking the effectiveness of the soil improvement by the cement-soil and flyash-lime-soil mixing pile in terms of engineering practice.

Key words: electrical resistivity, cement-soil, flyash-lime-soil

There exists soft soil layer widely in the coast regions in China, especially in those downstream regions nearby Yangzi River, Qiantang River and Zhujiang River, the soft soil layer in these regions has high compressibility and void ratio, low natural strength. As a result, cement mixed pile is often used as a means of soft soil improvement for expressway. However, we have only known some about the characteristics of the cement-soil and flyash-lime-soil. The design theory and detecting method of cement mixing pile are imperfect consequently. Electrical resistivity survey, one geophysical method, can be conducted rapidly and nondestructively. This paper focuses on the electrical resistivity research of the cement-soil and flyash-lime-soil, in order to do some contributions to the design and constructions of the cement-soil mixing pile.

1 The Electrical Resistivity Model of Cement Soil

1.1 Electrical resistivity model of cement soil

Electrical resistivity is a kind of basic parameters representing conductivity. Electrical conduction in electrolytic solution, moist soils, and water-bearing rocks occurs as a result of the movement of ions. The ability of transmitions is governed by the electrical resistivity, a basic property of all materials. The lower the electrical resistivity is, the better the conductivity is. For soils, electrical resistivity depends on many factors such as porosity, electrical resistivity of the pore fluid, composition of the solids, particle shape and orientation, and pore structure[1]. The formula of soft soil's electrical resistivity is as follows[2]:

$$\rho_{sw} = \left(\frac{1}{\rho_s}\frac{1}{1+e} + \frac{1}{\rho_w}\frac{e}{1+e}\right)^{-1} \tag{1}$$

where ρ_{sw} is the electrical resistivity of soft soil; ρ_s is the electrical resistivity of soil skeleton; ρ_w is the electrical resistivity of pore water; and e is void ratio.

The cement-soil and flyash-lime-soil is acquired when we mix natural soil with cement powder. As the soil particle (solid phase) is incompressible, the pore ratio of cement soil will become less after adding cement powder into soil. Thus the formulae of the electrical resistivity of the cement soils are as follows[3]:

$$\rho_{sg} = \left(\frac{1-\sigma}{\rho_{sgs}} + \frac{\sigma}{\rho_{sgp}}\right)^{-1} \tag{2}$$

$$\rho_{sgs} = \left[\frac{1}{(1+e)\left(1-\frac{\lambda}{100}\right)^2}\frac{1}{\rho_s} + \left[\frac{1}{1-\frac{\lambda}{100}} - \frac{1}{(1+e)\left(1-\frac{\lambda}{100}\right)^2}\right]\frac{1}{\rho_w}\right]^{-1} + \frac{\lambda}{100}\rho_g \quad \text{(serial)} \tag{3}$$

$$\rho_{sgp} = \left[\frac{1}{1+e}\frac{1}{\rho_s} + \left(\frac{e}{1+e} - \frac{\lambda}{100}\right)\frac{1}{\rho_w} + \frac{\lambda}{100}\frac{1}{\rho_g}\right]^{-1} \quad \text{(parallel)} \tag{4}$$

$$\lambda = \frac{n}{100}\frac{\alpha}{100} \times 100 \tag{5}$$

where ρ_{sg} is the electrical resistivity of cement soil; ρ_{sgs} is the electrical resistivity of serial model; ρ_{sgp} is the electrical resistivity of parallel model; σ is parallel model's percentage in cement soil; ρ_g is the electrical resistivity of cement; λ is mixture ratio of cement; n is

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* Born in 1969, female, lecturer, graduate.

void ratio; and α is volume percentage of cement powder compared with the pore volume.

1.2 Electrical resistivity measuring method of cement soil

Natural soil or cement soil is different from metal in structure, water content and sodium chloride concentration, therefore its detecting method is not the same as that of metal. On the basis of the above principle, we choose a kind of high-sensivity resistance box equipped with direct electrical power and micro-ampere meter and other auxiliary equipment to measure the electrical resistivity of cement soil. The measuring method is shown in Fig.1.

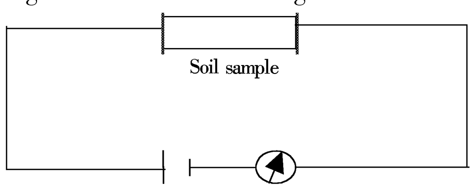

Fig.1 The detecting diagram of electrical resistivity

2 Electrical Resistivity Characteristics of the Cement-Soil and Flyash-Lime-Soil

2.1 Relationship between strength and electrical resistivity

From the detecting results through laboratory and in-situ experiments shown in Fig.2, we can easily see that electrical resistivity of the cement-soil and flyash-lime-soil are relevant to unconfined compressive strength. The larger the unconfined compressive strength is, the higher electrical resistivity is.

Tab.1 shows the range of electrical resistivity and corresponding unconfined compressive strength of various materials (cement content and lime content varies from 5% – 25%; flyash content varies from 10% – 25%; salt content vary from 5% – 15%; days vary from 7 days to 28 days).

Tab.1 Electrical resistivity and corresponding unconfined compressive strength of various materials

Material	Mucky clay	Mucky clay + cement + flyash + salt	Mucky clay + cement + flyash	Mucky clay + lime + flyash
Electrical resistivity/(Ω · m)	0.2	0.3 – 1.5	2.5 – 8.5	2.0 – 8.5
Unconfined compressive strength/kPa	20 – 40	40 – 180	150 – 320	120 – 320

2.2 Relationship between water content and the electrical resistivity

Relationship between electrical resistivity and water content is shown in Fig.3 for the cement-soil and flyash-lime-soil.

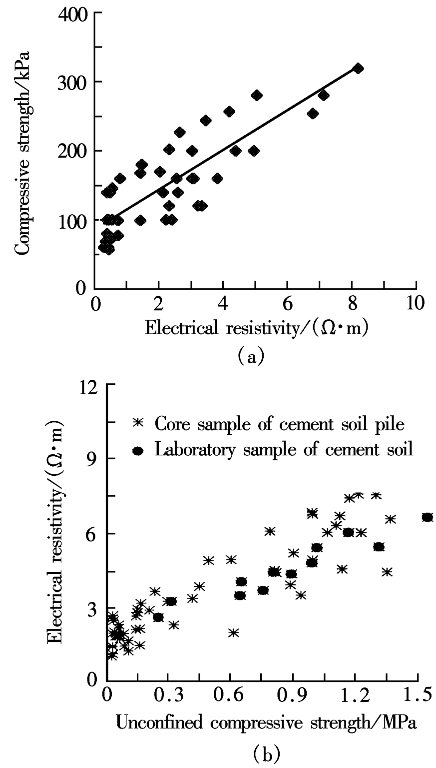

Fig.2 The relationship between electrical resistivity and unconfined compression strength

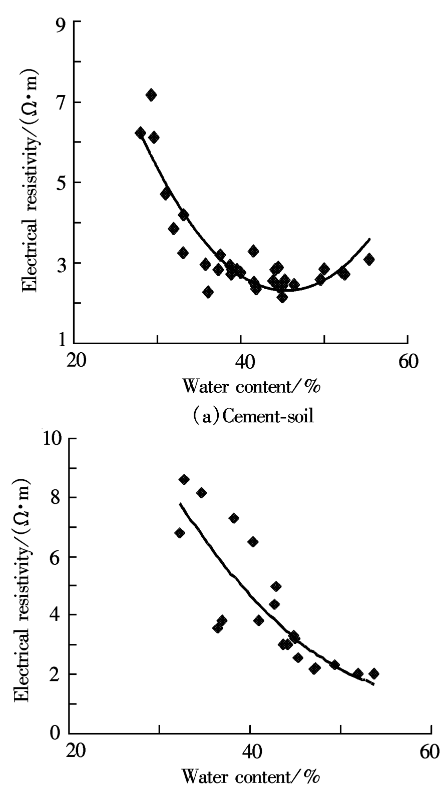

Fig.3 The relationship between electrical resistivity and water content

In both cases a distinct relationship between electrical resistivity and water content exists. The higher water content is, the lower electrical resistivity is. When soils has low water content, the clay clods are difficult to remold, and inter-clod pores are relatively large, many of the pores are filled with air, the particle to particle contact is poor, consequently, conductance is low, electrical resistivity of the cement-soil and flyash-lime-soil increases.

2.3 Relationship between degree of saturation and the electrical resistivity

A change in saturation reflects not only a change in the volume of pores filled with water, but also a fundamental change in the macro- and microstructures of the soils. Higher saturation generally leads to more apparent bridging between particles surfaces and leads to greater particle to particle contact. Consequently, electrical resistivity is lower.

The relationship between degree of saturation and electrical resistivity for the cement-soil and flyash-lime-soil is shown in Fig.4. For both soils, electrical resistivity is correlated with degree of saturation.

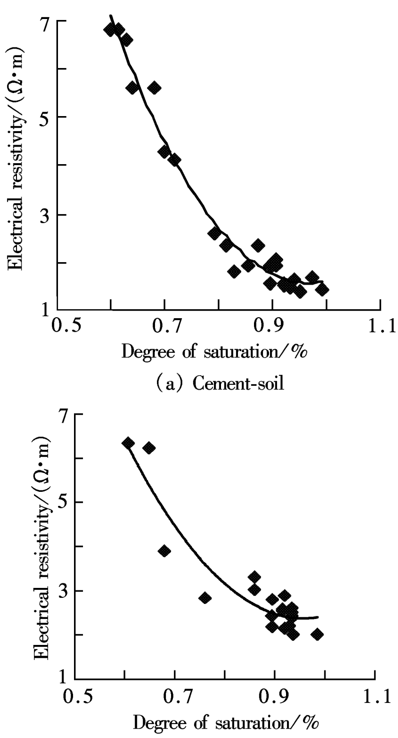

Fig.4 The relationship between electrical resistivity and degree of saturation for the cement-soil and flyash-lime-soil

2.4 The additives impact on the electrical resistivity

Flyash impacts on the electrical resistivity of cement soil. Flyash, as a kind of active mixture material, can produce coagulants after reacted with $Ca(OH)_2$ hydrated from cement for two times. These coagulants include hydrated calcium silicate and calcium aluminum or other similarities, which improve the hydration condition of cement in early period and display the filling effect and grain impact of flyash. It's also helpful to improve the post-strength of cement soil when certain quantity of flyash is added in cement soil.

Experiments show that the flyash has large impact on the electrical resistivity of cement soil (clay + cement + flyash), the more the flyash added, the lower the electrical resistivity is. It is shown in Fig.5.

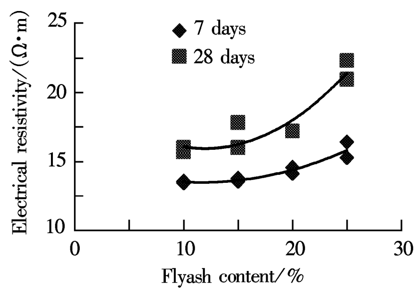

Fig.5 The relationship between flyash and electrical resistivity

Salt content impacts on the electrical resistivity. Salt content is in reverse proportion to the electrical resistivity of cement soil. As we know, high salt content leads to high content of cation sodium and anion chloride in cement soil (clay + cement + salt). This inevitably makes cement soil more conductive whereas its electrical resistivity reduces accordingly. As shown in Fig.6.

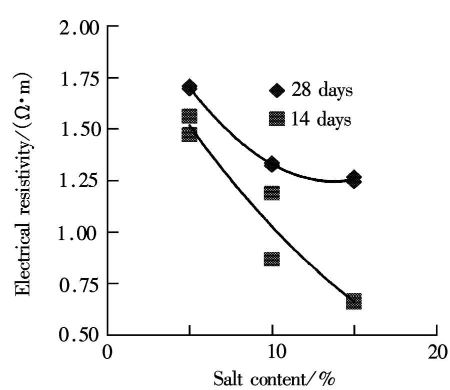

Fig.6 The relationship between salt content and electrical resistivity

3 Conclusions

1) The electrical resistivity is one of the physical parameters of the cement-soil and flyash-lime-soil, which can represent its engineering features.

2) Many factors including unconfined compressive

strength, water content, degree of saturation of cement soil and flyash-lime-soil are relevant closely to its electrical resistivity. Electrical resistivity of cement-soil is also correlated with additives such as flyash and salt content.

3) The cement-soil and flyash-lime-soil with higher water content, greater degree of saturation, lower unconfined strength have lower electrical resistivity. The content of flyash of the cement-soil is in direct proportion to its electrical resistivity. On contrary, salt content of cement soil is in reverse proportion to its electrical resistivity.

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水泥土和二灰土的电阻率特性研究

于小军　　缪林昌　　刘松玉

(东南大学岩土工程研究所, 南京 210096)

摘　要　通过室内试验和现场测试,研究得到水泥土和二灰土电阻率的特性.研究分析表明,水泥土和二灰土电阻率与含水量、饱和度、抗压强度密切相关.含水量高、饱和度大、抗压强度小,电阻率就小.同时,水泥土和二灰土电阻率还与添加剂相关.这些特性表明电阻率法在工程实践中是一种有效监测水泥土桩和二灰土桩加固地基效果的手段.

关键词　电阻率,水泥土,二灰土

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