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# Effect of chlorine salt on the physical and mechanical properties of inshore saline soil treated with lime

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**Abstract**

Salt in saline soil has adverse effects on the stability of treated soil. In this study, the grain size, the Atterberg limits, the compaction, the strength, and the microstructure were measured successively to analyze the effects of the chlorine salt content on lime-treated saline soil. Chlorine salt had obvious effects on the structure of the lime-treated soil; it increased the quantity of coarse soil particles and decreased the total surface area of the soil. An approximately linear relationship was found between the salt content and the microstructure's parameters, such as the bone area, the aspect ratio, roundness, etc., while the salt content reduced the degree of homogenization of the treated soil. Additionally, the liquid limit, the plastic limit, and the plasticity index decreased with an increasing salt content. The salt content had little effect on the maximum dry density or the optimum water content, and its effect on in situ compaction was negligible. Importantly, the chlorine salt did not react with the lime, and adsorbed only onto the soil surface or into the pores. Moreover, the chlorine salt induced engineering problems in the lime-treated soil, which affected its stability, especially when the salt content was more than 3.0%. Thus, waterproofing measures should be applied to treated saline soil.


*Keywords:* Treated saline soil; Chlorine salt; Lime treatment; Physical properties; Strength; Microstructure

## 1. Introduction

Saline soil, formed by marine deposits and seawater immersion, is distributed widely on the surface of soil in Bohai Bay and the southeast coastal areas of China (Li et al., 2012). Saline soil is a conductive system with a chlorine salt content of $>3\%$ (Gao and Wang, 2011). Along with water migration, salt ions enter into charged porous media and then react with the soil particles (Koniorczyk, 2012). Chlorine ions also have a higher hydration radius and can absorb water (Flatt, 2002; Konyai et al., 2006). Engineering problems, such as salt expansion, dissolution, and water absorption, result in such media failing to meet the appropriate strength and anti-deformation requirements for use in construction without treatment (China Standard GB50021, 2001).

$Cl^-$ not only affects the microstructures of treated soil, but also the strength (Modmoltin and Voottipruex, 2009). $Cl^-$ has a negative effect on the strength of treated soil in the short and

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long term (Calvello et al., 2005; Carteret et al., 2014). Salt decreases the unconfined compressive strength and is closely related to the shear strength (Zhang et al., 2012). A rich $Cl^-$ content in soils and groundwater can react with hydration products and hinder increases in its strength (Xing et al., 2009). Brittle fractures intensify with an increasing salt content (Carteret et al., 2014). Furthermore, some analysts have suggested that there should be a salt content threshold, below which the strength of treated soil increases due to the solute salt's crystallization and expansion, and above which the strength decreases due to structural destruction caused by excessive crystallization and expansion (McRobert et al., 2008). Hygroscopic softening, induced by salt after treatment, has also been proposed (Modmoltin et al., 2004). Therefore, the effects of salt on treated soil should be investigated to guide engineering practices.

Lime treatment is commonly used because of its overall low cost and ease of application, along with the simplicity of its technology that provides an added attraction for engineers (Wilkinson et al., 2010). Soil-lime reaction products resulted in the growth of soil particles and a subdued shrink/swell propensity (Rajasekaran and Rao, 1997). Lime treatment changed the behavior of the soil from normally consolidated to overconsolidated (Kamaluddin and Buensuceso, 2002). The compaction and mechanical properties of saline soil with lime satisfy the requirements for highway specifications and are suitable for use in treatment in coastal areas (Wang and Chai, 2011).

To evaluate the effects of the salt content on the physical and mechanical properties of lime-treated soil, a series of experiments investigating the grain size, the Atterberg limits, and the conductivity were carried out. Compaction tests were then used to study the impact of the salt content on in situ compaction. Compressive strength and triaxial compression tests were developed synchronously from a mechanical perspective. In addition, microstructures were scanned and analyzed using Leica QWin 5000 software to establish the quantitative relationship between the microstructure's parameters and the salt content. The results can provide technical guidance for the construction and application of salty soil, such as in situ compaction control, strength growth prediction, the prevention of salt damage, etc.

## 2. Test materials and methods

### 2.1. Test materials

#### 2.1.1. Saline soil in inshore areas

The saline soil used in this investigation was collected from the surface of Binhai New Area, Tianjin, China. The soil is mainly silty clay containing quartz, feldspar, and mica minerals. The physical and chemical properties of the saline soil used here are presented in Table 1. The saline soil was air dried, sieved (2 mm), and then set aside until it was used.

#### 2.1.2. Lime

The bagged lime powder used in this study was purchased directly from a lime plant in Tianjin China. The properties of the lime powder are shown in Table 2. Prior to its use, the lime was sieved (2 mm) to remove impurities.

Table 1
Physical and chemical properties of saline soil.

| No. | Parameter index | | Value |
|---|---|---|---|
| 1 | Particle size distribution | < 0.005 mm | 11.39 |
| | | 0.074–0.005 mm | 88.61 |
| 2 | Consistency index | Liquid limit, $W_L$, % | 34.4 |
| | | Plastic limit, $W_p$, % | 20.5 |
| | | Plasticity index, $I_p$ | 13.9 |
| 3 | Maximum dry density, g/cm$^3$ | | 1.84 |
| 4 | Optimum water content, % | | 15.2 |
| 5 | Specific gravity | | 2.70 |
| 6 | Salt content, % | | 2.65 |
| 7 | Salt ionic content, nmol/L | $SO_4^{2-}$ | 24.17 |
| | | $Cl^-$ | 798.31 |
| | | $Ca^{2+}$ | 13.50 |
| | | $K^+$ | 10.26 |
| | | $Mg^{2+}$ | 82.5 |
| | | $Na^+$ | 704.48 |

Table 2
Properties of lime powder used.

| No. | Properties | Value |
|---|---|---|
| 1 | Available calcium and magnesium content | 82% |
| 2 | No digestion residue (residue weight after 5 mm screen) | 5% |
| 3 | Water content | 2% |
| 4 | $CO_2$ content | 6% |

The lime itself has neither appreciable friction nor cohesion (Kavak and Akyarlı, 2007). However, there is a lime content threshold, in excess of which will be adverse to soil strength (Bell, 1996; Khattab et al., 2007). A lime content of 12% by weight of dry soil was chosen for testing in this study based on previous investigations by our group (Chai et al., 2009; Wang and Chai, 2011).

### 2.2. Test methods

#### 2.2.1. Desalinization of saline soil

Prior to investigating the effects of the salt content on lime-treated soil, the saline soil was desalinated. To accomplish this, sieved saline soil and water were mixed at a 1:5 ratio (mass of soil to distilled water), and the supernatant was removed after the solution became clear. This process was repeated until the electrical conductivity and salt content were < 1000 s/cm and 0.3%, respectively (ASTM D2487-11, 2011).

Changes in the electrical conductivity, salinity, total dissolved solids (TDS), and pH of the soil–water system were determined according to ASTM D4972 (2007) using a DDSJ-308 conductivity meter and a PHS-3C pH meter. The PHS-3C pH was standardized with two standard buffer solutions (pH of 4.0 and 9.2). The test temperature was 20 °C.

The electrical conductivity, salinity, and TDS decreased rapidly with increasing desalination times, but the pH remained stable (Fig. 1). The salt was completely removed after eight rounds of desalination.