Effect and Mechanism of Quicklime on Stabilized Loess

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Abstract. Lime is a cheap and easily available building material, which can greatly change the physical and mechanical properties of soil and is widely used in engineering construction. This article summarizes the effect and mechanism of quicklime in improving loess mechanical properties. The changes of physical and mechanical properties of loess after lime added and the internal mechanism of lime-improved soil are summarized, also, the factors affecting lime-soil improvement are analysed.

Keywords: Effect and Mechanism, quicklime, loess stabilization.

1. Introduction

Loess is a kind of special soil, which is widely distributed in north western China. The loess in the Northwest Loess Plateau is characteristic of continuous distribution, complete stratum, accumulation thickness, and relatively continuous time [1]. In recent years, loess and compacted loess are widely used in the construction of embankments, airports, waste landfill sites, etc. with the large-scale development of engineering construction in the loess area. However, because of the special properties of loess, such as large porosity, water sensitivity, and collapsibility, there will be a series of engineering geological problems such as roadbed subsidence, uneven settlement of buildings, and destruction of bridge and culvert structure. This requires research on improving the properties of loess.

At present, a lot of work has been carried out at home and abroad on the subject of loess improvement, and the improved soil has been applied to the actual engineering. There are two kinds of methods of loess improvement: physical improvement and chemical improvement. The physical improvement is mainly to add coarse-grained materials (such as soil replacement, sand mixing, reinforcement, etc.) to the filler soil, which strengthen the engineering properties of the filler by changing the particle size gradation. Chemical improvement is mainly mixed with cement, lime, fly ash and other solidifying agent in the poor soil. The solidifying agent will have a series of physical and chemical reactions with the soil, which can change the particle composition and structure of the soil, and thus the strength and stiffness of the soil, water stability and other engineering properties of the
soil have been improved. The chemical soil improvement method in China is mostly used. The improved soil can be divided into lime improved soil, fly ash-improved soil, cement-improved soil, cement or lime-fly ash-improved soil, etc. according to the different curing agent materials. Osula [2] proposed that the improvement effect of lime and cement-improved laterite is affected by age. HORPIBULSUK S, etc. [3] pointed out that a specific age and water-cement ratio have a greater impact on the shear strength of cement-soil, and proposed corresponding empirical formulas. Zhang Junli et al. [4] used a triaxial apparatus to study the mechanical properties and deformation characteristics of cement loess with different cement mixing ratios, different sample moisture contents, and confining pressures. Yang Guangqing and Guan Zhenxiang [5] found that the strength of each modified soil increased with the increase in the dosage of the admixture by conducting laboratory tests. The content of cement has a significant effect on the strength of cement soil. When the lime content is low, it mainly plays a stabilizing role, reducing the plasticity and expansibility of the soil, and making the soil initially have water stability, and stabilizing the density and strength. As the content increases, the strength and stability are improved. But when the content of lime further increases and exceeds a certain amount, too much lime will be deposited in the soil pores without participating in the reaction, which will cause decrease of the strength of lime soil [5]. Lime soil is widely used in soil improvement due to its wide range of sources, low price, easy access to nearby materials and lower cost, and easy construction. Therefore, lime is widely used in soil improvement [6,7].

2. Influence of quicklime on physical and mechanical properties of loess

2.1. Influence of quicklime on the consistency limits of loess
The consistency limits of soil are related to its particle composition, mineral composition and the degree of soil-water interaction. The consistency limits have a great influence on the engineering properties of fine-grained soil. Previous studies have shown that after adding lime, the liquid plastic limit of loess is significantly increased, and plasticity is reduced [8], which can effectively improve the adhesion of soil particles and facilitate backfill construction. The change of the consistency limits is closely related to the amount of lime added and the curing age.

2.2. Influence of quicklime on the maximum dry density and optimum moisture content of loess
The optimal moisture content of the soil increases, and the maximum dry density decreases after adding lime [9]. It can be seen from the compaction curve of loess and lime-improved soil in the literature [10] that the compaction curve of plain loess is steeper and has a significant peak value. Only by controlling the moisture content in a relatively small range can the dry density be as close as possible to the maximum dry density. However, after adding lime to the loess, the compaction curve is smoother and the peak value is not so obvious, so the moisture content can be controlled in a larger range to achieve the required dry density.

The optimal moisture content and maximum dry density of loess are changed after mixing with quicklime. The reason is that after lime is added to the soil, the cement in the soil increases, the connection between soil particles changes, and the soil particles are more likely to condense into aggregates. The resistance to displacement of soil particles increases, and the particle size increases, which has an impact on soil compaction. At the same time, the addition of lime in the soil will also absorb the water in the soil.

2.3. Influence of quicklime on the strength of loess
The shear strength of soil is closely related to its particle composition, mineral composition, and pore distribution. When lime is added to the soil, the viscosity of the soil will be changed, making the soil particles easy to form aggregates, enhancing the cohesion of the soil particles, and thus increasing the shear strength of the soil.
3. Improving and strengthening mechanism of quicklime

The main component of quicklime is CaO, which is an air-harden ing inorganic cementing material. Lime has good water stability and freezing stability, and is easy and economical in construction operation. It is widely used in the treatment of expansive soil, collapsible loess area and base and subbase of airport runway or building foundation treatment. The reason why lime can be used for soil improvement is that when lime is mixed into soil, a series of interactions will occur, thereby changing the physical and mechanical properties of soil. After lime is added to the soil, both physical and chemical effects will occur. At present, it is generally believed that lime will have the following effects in the soil:

1. Ion-exchange action. This effect occurs at the beginning of the contact between lime and soil. At this time, lime will react with water in the soil to form Ca(OH)₂ and a small amount of Mg(OH)₂, both of which will be ionized with the action of water in the soil, and the high-priced metal ions generated can easily replace the low-priced sodium and potassium ions originally attached to the surface of the soil particles (see formula (1) and formula (2)), as a result, the attraction between the particles is enhanced and coagulation occurs easily, specific surface decrease. Because the hydrated film of calcium and magnesium ions are relatively thin, the hydrated film of aggregate structure formed by the cementation of soil particles is also relatively thin, so the dispersibility and hydrophilicity are reduced, and the plasticity index is reduced.

\[
\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 \rightarrow \text{Ca}^{2+} + 2\text{(OH)}^- \quad (1)
\]

\[
\text{MgO} + \text{H}_2\text{O} \rightarrow \text{Mg(OH)}_2 \rightarrow \text{Mg}^{2+} + 2\text{(OH)}^- \quad (2)
\]

2. Carbonation function. As equation (3) and (4), Lime soil will further react with CO₂ in the air to produce carbonate compounds - CaCO₃ and MgCO₃. This reaction also needs to be carried out in the presence of water. The newly formed compound has high strength and strong water stability, which will strengthen the connection between soil particles and strengthen the soil. Because the CO₂ content in the air is small, and the lime in the soil has limited contact with the air, and the newly formed carbonic acid compounds form a hard crust on the surface of the soil, which will hinder the further contact between CO₂ and the soil, therefore, the reaction takes a long time. This is the reason why the later period strength of lime stabilized soil increase with the increase of age.

\[
\text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} \quad (3)
\]

\[
\text{Mg(OH)}_2 + \text{CO}_2 \rightarrow \text{MgCO}_3 + \text{H}_2\text{O} \quad (4)
\]

3. Crystallization. The minerals, moisture and CO₂ content in the clay will limit the dissociation and chemical reaction of lime in the soil. Therefore, most of saturated Ca (OH)₂ will absorb water in the lime. soil and crystallize on its own to form a crystal lattice, making the solubility smaller, and further improve the water stability of lime soil (see equation (5)).

\[
\text{Ca (OH)}_2 + n\text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2\cdot n\text{H}_2\text{O} \quad (5)
\]

4. Pozzolanic reaction (the gel reaction). This reaction occurs in the late stage of the ion exchange reaction. The silica and aluminum gel in the cohesive soil further react with lime to produce hydrated calcium silicate and calcium aluminate (see equation (6) and (7)), which form a stable protective film on the surface of the soil particles and fill in the pores between the particles, the soil density increases and the water permeability decreases. It can also be seen from the microstructure photos of lime-improved loess [11] that the content of macropores in the improved soil is reduced, the degree of particle agglomeration increases, the average particle diameter increases, and the structure is denser. This is also an important factor that the lime-improved soil obtains strength and water stability.
It can be seen from the above description that the reaction of quicklime in the soil is accompanied by water absorption, expansion and heat generation. These effects make the soil further compacted and dehydrated, the water content in the soil is reduced, and the strength is enhanced. In general, when lime is mixed into loess, a series of physical and chemical reactions will occur. The soil particles will agglomerate and the pores will be filled with the generated material. The strength of the particles will increase and the water stability will increase, thereby the engineering properties of the loess are improved.

4. Factors affecting lime improvement

The main factors affecting the improvement effect of lime on loess are the proportion of lime addition, the curing conditions and age, and the water content.

The lime content has a significant influence on the effect of lime improvement. When the lime content is low, lime mainly plays a stabilizing effect, and the lime soil initially has water stability; when the lime content increases, more lime participates in the reaction, which further improves the strength and stability of the lime-improved loess; After exceeding a certain ratio, the strength of the improved loess will decrease. This is mainly because there is too much lime in the pores of the soil. The too much lime will be deposited in the pores of the soil and will not participate in the reaction [5].

It can be seen from the third section that the formation process of lime-improved soil strength requires a certain amount of water. However, in the process of engineering construction, soil with more than the optimum water content is not easy to be compacted, and it will also have bed influence on the strength of lime soil.

Improving loess with lime requires certain curing conditions (temperature and humidity). A certain temperature can promote the rate of the reaction, and humidity is to provide the water needed for the reaction. It is a slow process in which lime produces a series of physical and chemical reactions in the soil, and it takes a certain time. Therefore, the curing age is an important factor influencing the strength of lime-improved soil. Existing studies [12, 13] have also verified this point.

5. Conclusions

This article briefly reviewed the relevant theories about lime-improved loess, focused on the influence of lime on the physical and mechanical properties of loess and its internal mechanism, and analyzed the factors affecting the effect of lime-modified loess. Lime can significantly increase the strength of loess, reduce the plasticity of loess, and improve the engineering properties of loess. The reaction of lime on soil involves a series of physical and chemical reactions. The improvement effect of lime is affected by the ratio of ash addition, maintenance conditions, age, and moisture content. In the engineering process, the appropriate moisture content and ash ratio should be selected according to the soil conditions, and a longer curing age should be ensured.

Acknowledgments

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