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Investigating the effect of Portland cement and Nano-clay on the collapse potential and consolidation indexes of the collapsible soil

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ABSTRACT: Collapse refers to a sudden decrease in the soil volume upon wetting which is attributed to a loss in the strength of the inter-particle bonds. Collapsible soils can be founded in vast areas around the word and subtropical areas of Iran. Collapse characteristics contribute to various problems to infrastructures that are constructed on loess soils. For this reason, the collapse behavior of loess soils has been the subject of interest. In this study, stabilization of Semnan loess which is composed of fine sand and silt bonded by weak clay bonds, has been investigated. The loess was mixed with Portland cement in the order of 0.5%, 1%, and 2.5% for and with nano-clay in order of 0.05%, 0.1%, and 0.25%. The specimens were prepared to achieve a dry density of 14 kN/m3 and a water content of 5%. Oedeometer tests were performed to determine the collapse potential according to ASTM D5333 after 7, 14, and 28 days. Results showed that both Portland cement and nano-clay could reduce collapse potential. Improvement performance was significantly dependent on the binder content and curing time. The best improvement performance was observed at low nano-clay content and it was reduced by increasing nano-clay content. Unlike the cement stabilization, treatment process with nano-clay was relatively fast that terminated when soil moisture content was evaporated. In addition, in this study, micromechanical soil behaviors were investigated by scanning electron microscopy (SEM) image of the treated and untreated specimens.

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1.INTRODUCTION

Loess is a collapsing soil with a high void ratio, low relative density, unsaturated status, and weak inter-particle cementation. These soils are relatively stiff and suffer substantial stress due to the inter-particles bond and matrix suction. However, the porous and metastable structure of loess is susceptible to sudden settlement or collapse upon wetting [1, 2]. More than 10% of the global land area is composed of collapsible soil, primarily in arid and semi-arid regions [1].

Depending on the depth of the collapsible soil, mechanical approaches (e.g., surface or deep compaction) or chemical stabilization (e.g., Portland cement, lime, acid, salt) can be performed through different improvement techniques.

In recent decades, a wide variety of chemical additives such as ammonium sulfates [3], potassium chlorides [3], Portland cement [4], and lime [5] have been used for stabilization of the collapsible soil. Among these materials, good improvement efficiency has been observed at cement and lime stabilized soils via soil mixing method. The in situ treatment methods by cement and lime are limited to compaction grouting or soil piles due to the low permeability of losses.

Improvement in the hydro-mechanical behavior of fine-grained soil using nano-materials has received much attention in recent years [1]. Iranpour and Haddad performed an experimental study to investigate the effect of four nano-materials (nano-clay, nano-copper, nano-alumina, and nano-silica) on the behavior of collapsible soil from a subtropical area of Iran. A considerable reduction in collapse potential was observed in specimens mixed by nano-clay because of the larger specific surface in comparison with other nano-materials [1].

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Reviewing relevant literature shows that OPC and lime are the most favored material in geotechnical engineering projects because of adequate mechanical properties, availability, and cost. However, internal sulfate attack is a serious problem in soil stabilized with OPC [6]. Also, Portland cement industries have several environmental concerns, including large CO2 emission, natural resource depletion and dust generation [7]. New additives, such as nano-materials, geo-polymers and bio-polymers, have been developed that show good performance for soil treatment and have fewer environmental problems.

This study compares the collapse potential of the treated soil with NC and OPC. For this purpose, loess samples were treated by different binder concentrations of OPC and NC. After that, an oedometer was performed after at 7, 14, and 28 days after treatment to evaluate improvement performance over time. Furthermore, microstructure analysis was done by using SEM images of the treated specimens.

Table 1. Physical properties of the untreated soil

e_0	γ_d (kN/m^3)	ω_0	LL	PL	PI	Gs
0.914	13.7	5	23	20	3	2.68
0.991	13.9	5	26	21	5	2.69
0.960	14.1	4	21	18	3	2.71

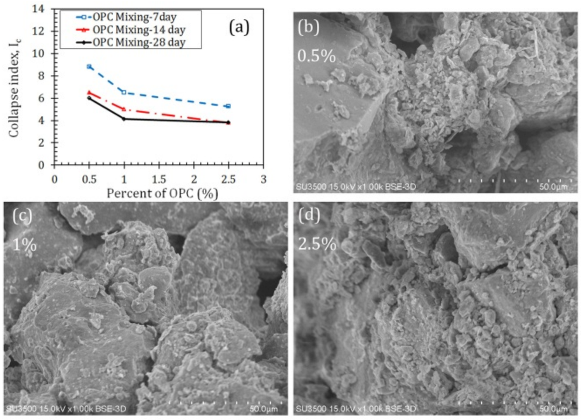

Fig. 1. Collapse index of the mixed soil with OPC; (b) 0.5 wt% OPC, (c) 1 wt% OPC, (b) 2.5 wt% OPC

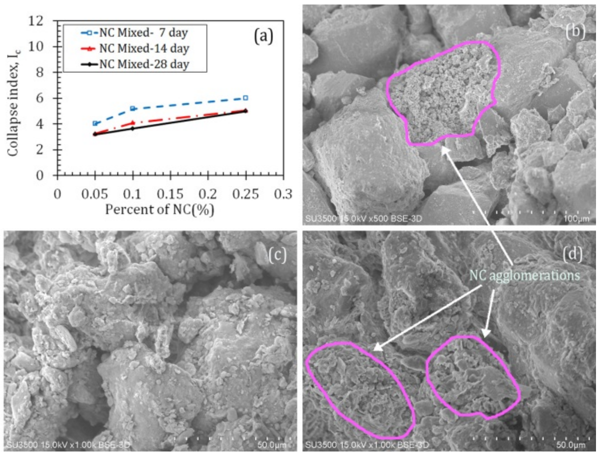

Fig. 2. Collapse index of the mixed soil with NC; (b) 0.05 wt% NC, (c) 0.1 wt% NC, (b) 0.25 wt% NC

2. MATERIALS AND METHOD

The soil used in this study was a typical collapsible soil that is distributed in subtropical areas of Iran and was collected near a railway station in Semnan province, Iran. The basic physical and engineering properties of the collapsible soil are listed in Table 1. Based on the unified soil classification system (USCS), the soil is classified as low plasticity silt (ML).

The oven-dried original soil was homogeneously mixed with the additives and then reconstituted in the oedometer mold with the same dry unit weight and moisture content as in the field (γ_{dry} = 14 kN/m^3 and ω = 5%). The intended moisture content was achieved by adding water to the mixture and the binder content was in order of 0.5%, 1%, and 2.5% for OPC and 0.05%, 0.1%, and 0.25% for NC. The collapse potential of the reconstituted specimens was determined at 7, 14, and 28 days after treatment. ASTM D 5333-03 was implemented in this study for determining the collapse potential of soil. For a given vertical (axial) stress, collapse potential can be determined based on the settlement that occurs when unsaturated soil is inundated with water. For a vertical stress value of 200 kPa, the collapse potential was stated as collapse index I_c

3. RESULTS AND DISCUSSION

Fig. 1 compares collapse index of mixed specimens with OPC for different percentage of additives at 7, 14, and 28 days after treatment. As observed, treatment efficiency was improved by increasing binder content. The collapse index of the untreated soil reduced from 9.1% to 4% after 28 days when the soil mixed by 2.5 wt% OPC. Increasing binder content create not only stronger inter-particle bridges but also fill soil voids which further increase soil shear strength. Figures 1 b to d and incents show SEM image of the OPC treated specimens with different binder content after 28 days. As observed, the soil voids were reduced by increasing OPC content. In addition, more interparticle bridges were created at higher OPC content.

Independent to the binder content, treatment performance was increased in the first two weeks and stopped over time. This is attributed to the soil water content, which was insufficient to provide a suitable medium for cementitious hydration and pozzolanic reactions.

Fig. 2 compares the collapse indexes of the specimens mixed with different percentages of NC at 7, 14, and 28 days after treatment. The best performance was observed in specimens mixed with 0.05% NC, in which the collapse index decreased from 9.1% to less than 4%. Similar to the OPC-mixed specimens, the treatment process in the NC-mixed specimens completed at early stages. However, unlike to the OPC-mixed specimens, increasing NC content reduced improvement efficiency. The shear strength reduction at higher NC content can be attributed to the agglomeration of nanoparticles due to their high reactivity resulted from high spatial surface area.

4.CONCLUSION

This study compared the potential of NC as an environmentally friendly earth stabilizer with conventional OPC for treatment of the collapsible soils. Results showed that the treatment procedure in OPC treated specimens was a time-dependent process. However, insufficient water content in specimens mixed with OPC suppressed the improved performance. For NC-treated specimens, the treatment process was relatively fast which terminated after the first two weeks with the drying of the soil. Considering the environmental concern of using OPC, it could be said that NC treatment is a preferable eco-friendly approach for the treatment of the collapsible soils.

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