

EFFECTIVENESS AND POTENTIAL OF FIBER-REINFORCEMENT FOR CEMENT REDUCTION

Okumura Corporation Regular Member ○Jakhongirbek Ganiev
Nagoya University Regular Member Takayuki Sakai
Okumura Corporation Regular Member Yasumasa Sotokoba
Nagoya University Fellow Member Masaki Nakano

1. INTRODUCTION

Soil improvement is a crucial aspect of geotechnical engineering aimed at enhancing the mechanical properties and stability of soils for various construction applications. Cement stabilization is one of the most common techniques used to increase bearing capacity and reduce susceptibility to external factors such as erosion and weathering. Furthermore, cementation is considered an economical method to achieve the required strength in soil structures. However, in recent years, there has been an increasing demand for more sustainable and eco-friendly soil improvement techniques due to growing environmental concerns associated with cement application. One of the primary issues is the significant carbon dioxide (CO_2) emissions generated during cement production, compounded by on-site challenges related to the release of hexavalent chromium Cr^{6+} and alkaline substances into the surrounding soil. In some cases, particularly when the soil contains pesticides or fertilizers, achieving the desired strength requires a higher amount of cement or the use of specialized cement types, resulting in generation of excessive cement-treated soil. Proper management and disposal of this excess soil, through landfilling at designated disposal sites, pose additional environmental and economic burdens. Given these concerns, an alternative soil improvement method using fiber reinforcement (Estabragh et al., 2012; Chen et al., 2015; Li et al., 2023) was investigated through an experimental study and a possible reduction of cement amount compensated by fiber inclusions to improve soil strength was considered.

For this purpose, a soil from a construction site was collected and examined, where cementation works took place and concerns about generation of excessive cement-treated soil was observed. Also, a deformation mechanism (crack propagation) due to loading described through failure mode comparison. Moreover, limitations of practical application of fiber-reinforcement regarding fiber-soil mixing issues was also presented.

2. MATERIALS AND METHODS

The host soil used in this study was a clayey silt soil collected from the site, characterized by low strength properties based on boring data, with an N-value distribution ranging from 0 to 4 (Fig. 1). Additionally, the soil exhibited medium moisture content, low to medium viscosity, and, in some areas, contained humus and organic matter.

The reinforcing materials were cement (ordinary Portland cement) and discrete polyvinyl alcohol (PVA) fibers. Based on a laboratory mixing test conducted on-site, a cement content of 200 kg/m^3 was determined to achieve the design strength of the cement-treated structure. Using this amount as a reference, additional cases with reduced cement contents of 160, 120, 80, and 40 kg/m^3 were also investigated and fibers added at proportions of 0.25% and 0.50% of the dry weight of the soil. Fibers (length $l_f=12\text{mm}$, diameter $d=0.04\text{mm}$) possess a specific gravity of $G_f=1.3$, a tensile strength of 1560MPa , and an elastic modulus of $E_f=41\text{GPa}$.

The laboratory experiments were divided into two parts. The first part aimed to understand the relationship between cement content and unconfined strength, and the second is to examine effectiveness of fiber inclusions in cement reduced samples. Cement-treated specimens with varying cement contents ranging from 40 to 200 kg/m^3 , where 200 kg/m^3 cement content corresponded to that determined on-site following the power-blender method for cement treatment and fiber/cement treated samples with 0.25% and 0.5% for selected cement contents (120 and 160 kg/m^3) investigated through unconfined compression test (UCT). The UCT were performed in accordance with the JGS 0511 standard, using a shearing rate of 1% per minute.

3. TEST RESULTS

Fig. 2 shows the results of UCT performed on cement-treated soil with varying cement contents without fibers reinforcement. Results verify necessity of 200 kg/m^3 cement to reach a design strength. It can be observed that even relatively small decrease in cement content results in significant reduction in peak strength. It is obvious that applying fiber-reinforcement to samples with 40 kg/m^3 and 80 kg/m^3 cement content is quite challenging, therefore, cement-treated soils with 120 kg/m^3

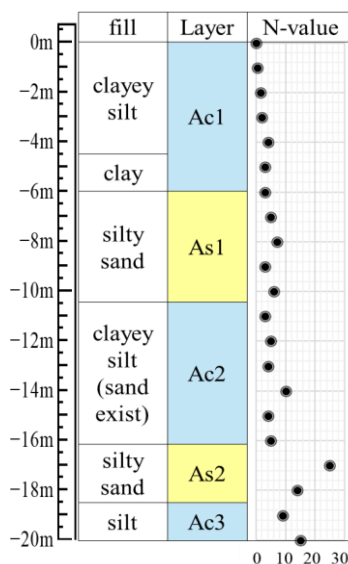


Fig. 1. Boring data

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Contact address: 5-6-1 Shiba, Minato-ku, Tokyo, 108-8381, Japan, Tel: +81-3-5427-8260

and 160 kg/m³ cement content was primarily examined.

Figs. 3-4 show the results of UCT a comparative analysis of UCT between cement-treated specimens without fiber reinforcement and fiber/cement-treated specimens containing 0.25% and 0.5% fiber contents. For specimens with 120 kg/m³ cement content (Fig. 3) a compressive strength of 0.5% fiber/cement treated soil exceeded design strength with peak strength of 450 kPa. In case of 160 kg/m³ cement content (Fig. 4), improvement effect of strength by 0.5% fiber inclusions was even more effective than single cement-treatment with 200 kg/m³.

A comparative evaluation of fiber reinforcement effect on compressive strength reveals that it is more visible for specimens with lower cement content (120 kg/m³). For instance, for a cement content of 120 kg/m³ the compressive strength of specimens containing 0.25% fibers increased by 1.5 times compared to single cement-treated soil, while those containing 0.5% fibers exhibited a 2.5 times strength improvement. In case of 160 kg/m³, a compressive strength increased by approximately 1.2 times when 0.25% fibers were used and by 1.5 times when 0.5% fibers were added. This trend indicates that the reinforcement effect of fibers is more pronounced when the cement content is limited, likely because the fiber contribution becomes less significant when the cementation effect dominates the overall strength. Notably, even with a relatively small amount of fiber inclusion, the introduction of fibers into a host soil not suitable for cement improvement like humus soil and so on, compressive strength significantly enhanced in case of both 120 kg/m³ and 160 kg/m³ cement-treated specimens. In addition to the strength improvement, the inclusion of fibers contributed to an enhancement of the specimens' ductile and resilient.

Cementation generally enhances peak strength, while a brittle behavior characterized by a sharp increase and a sharp drop in compressive strength in the post-peak region is still present. For a single cement-treated specimens strength loss occurred within 1-2% after a peak strength (Fig. 2). A fiber-reinforced specimens experienced a prolonged peak strength phase and the reduced drop in strength within the post-peak region which continued even at compressive strain more than 6-7%.

4. CONCLUSIONS

In this research the effect of fibers in improving cement-treated soil with potential reduction in cement content was investigated. Examination of effect of fibers to improve the strength of cement-treated soil showed a positive trend. The addition of even a small amount of fibers (0.25% and 0.5%) proved effective in compensating for strength loss in cement-reduced specimens. Also, fiber-reinforced cement-treated soil exhibited a more ductile and resilient behavior compared to traditional cement-treated soil. By using less cement while maintaining strength, fiber/cement treatment supports environmentally responsible construction without decreasing performance, making it a promising option for resilient infrastructure.

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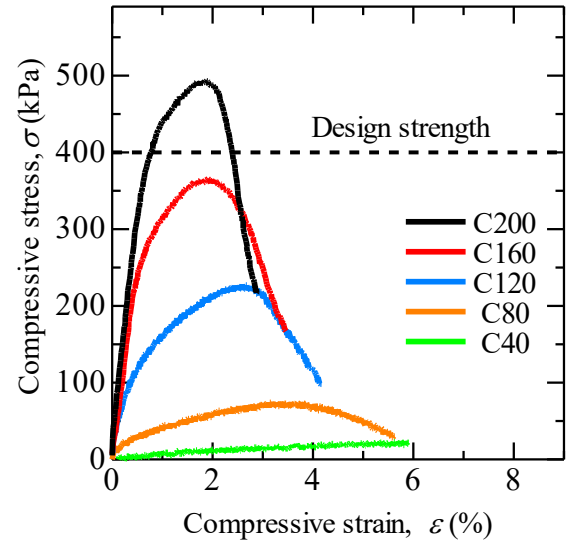


Fig. 2. UCT results performed on cement-treated specimens (legends show cement content)

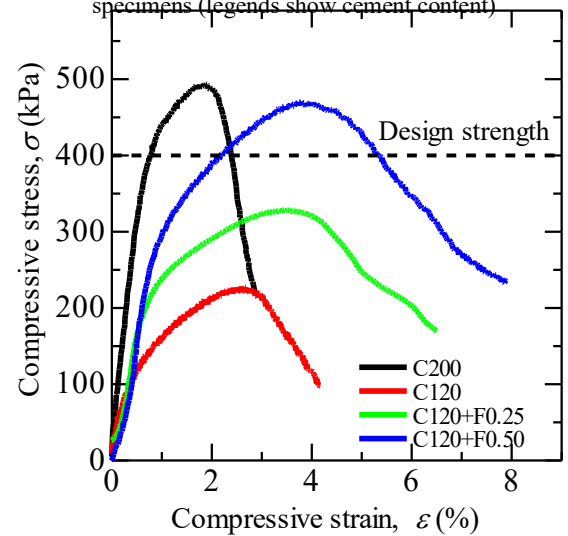


Fig. 3. UCT results performed on fiber/cement-treated specimens with 120 kg/m³

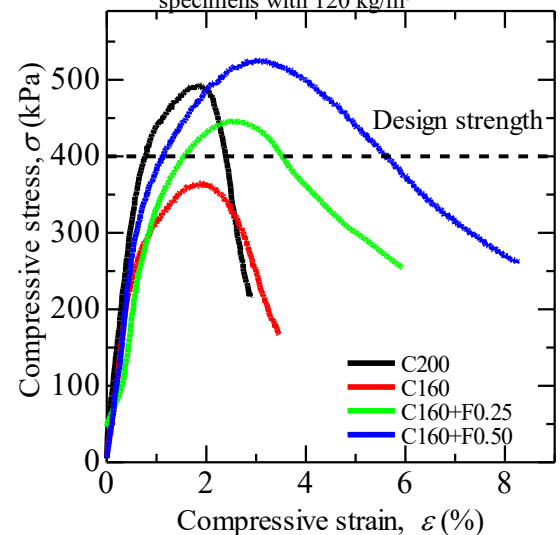


Fig. 4. UCT results performed on fiber/cement-treated specimens with 160 kg/m³