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An experimental study of the effect of cement and chemical grouting on the improvement of the mechanical and hydraulic properties of alluvial formations

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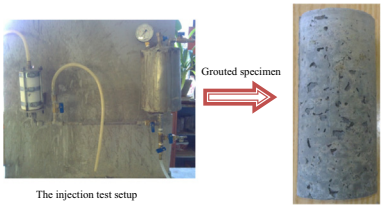
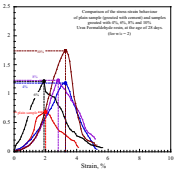
GRAPHICAL ABSTRACT

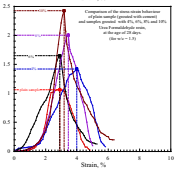
Alluvial formations in Iran are often encountered on many civil engineering project sites (especially subway projects), which lack sufficient strength to support the loading either during construction or throughout the service life. To improve the strength and stiffness of those less competent formations, soil stabilization with cementitious and chemical materials has been practiced. In this study, the effectiveness of grouting on improving the strength characteristics and hydraulic properties of alluvial formation at different curing ages was established with the help of experimental results.



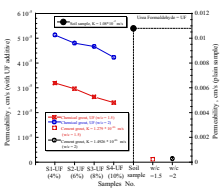
The injection test setup



Unconfined compressive strength of injected specimens.



Stress -strain behavior of stabilized specimens, injected with different percentage of urea - formaldehyde.



Reduction in permeability with cement and urea formaldehyde content.

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ABSTRACT

One of the most common methods of ground improvement is grouting. This study mainly focus on the influence of the injected urea-formaldehyde resin as an additive to cement grout forming mixed cement-chemical slurry on the improvement of mechanical and hydraulic properties of alluvial formations. For this reason, using the laboratory grout injector, the slurry from a mesh pipe located in the middle part of the specimen was injected into the specimen. The curing time, water/cement ratio (w/c) and the percentage of urea-formaldehyde resin were among of parameters have been studied. At the end, after 28 days of curing, unconfined compressive strength was performed on the specimens. Based on the results obtained, it was observed that in specimens injected by the mixed slurry with the w/c of 2, the highest amount of compressive strength was obtained when the slurry contained 10% urea formaldehyde resin. The strength of the injected specimen with the mixed slurry after 28 days of curing was increased by 150%, as compared to the case in which the cement based slurry was injected. Also, an

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increase in urea-formaldehyde resin in the mixed slurry led to an increase in the failure strain, the modulus of elasticity and the secant modulus. Permeability test results on the cured specimens within 28 days also indicated that injecting the cement based slurry with w/c = 1.5 and 2 resulted in 98% reduced permeability.

1. Introduction

One of the most common ways for ground improvement is a kind of injection in which the injected fluid known as the grout enters the ground through borehole. It is a procedure involving grout injection into fissures, discontinuities, voids and cavities in soil or rock formation in order to improve their properties, especially to reduce permeability and increase the strength and modulus of the formations [1,2].

Among various materials used for grouting, cement is one of the most common. Chemical compounds such as silicates, lignin, acrylic, and urea or epoxy resins and polyurethanes complying with environmental laws may be used in geotechnical injection projects. Berigny was the first person who used injection technology for soil improvement in 1802, marking the first successful applications of the injection technology [3].

The earliest uses of Portland cement as a grout have been variously credited to Marc Brunel in 1838, who used it for the first Thames tunnel in England, W.R. Kinipple in 1856, who introduced the injection process in England, and Thomas Hawksley in 1876, who employed this procedure to reduce rock mass water flow and deformability [4].

Cement grout is widely applied because of its inexpensiveness, ready sources, and high strength. However, since it is a particulate material, disadvantages such as poor injection ability (penetration into tiny fractures and silty sand layers can be difficult), and poor ductility confine it practical applications. Chemical grout workswell because of its good injection ability, its adjustable gel time, and its flexibility after solidification. Although chemical grout has special functions, it does not have wide applications due to expensiveness and the lower solid strength [5].

Jeziorski, in 1887, introduced the use of sodium silicate as the first chemical grout to inject; unfortunately, this method had some problems because the chemicals reacting soon after mixing required very rapid injection, and, all too often, was hardened in the pump and delivery system, restricting their application. To overcome the problem of Jeziorski's method, Hugo Joosten developed a two-shot sodium silicate–based system-in 1925. In this system, the sodium silicate base chemical was first injected into the soil, followed by the injection of a reactant, commonly the calcium chloride, which would cause the silicate to harden [6].

Until the mid-20th century, chemical injection was considered as the injection of sodium silicate and all the grouts used in the course were based on the sodium silicate. In the late 1940s, in Europe, phenoland formaldehyde were used and in the 1950s, urea formaldehyde-based grouts were introduced [4].

In 1990, Levacic and Bravar used urea formaldehyde resin for soil stabilization and investigations of different parameters showed that the resin significantly improved mechanical soil properties [7]. Germishuizen et al. in 2002, have reported on the application of a proprietary urea-formaldehyde (UF) resin as a soil stabilizer. Excellent wet and dry strengths were obtained when the UF resin was used in combination with either Portland cement or bitumen emulsion [8].

Later, in this line of research, Focke and et al. in 2003, used the Indirect Tensile Strength (ITS) to characterize the soil stabilizing; their experimental results suggested that the presence of an appropriate organic matter was critical for effective soil stabilization with UF resin [9].

Hongfei et al. in 2012, formulated a new composite two component grout consisting of modified urea–formaldehyde resin and cement to achieve the advantages and disadvantages of both the cement grout and the chemical grout. The results of the tests showed that gel time was increased with increased water content and urea–formaldehyde resin content and its gel time was decreased at the increased levels of alkaline coagulant. The solid strength was increased over time and became stable by the 28th day after mixing [5].

Mackevicius, in 2013, analyzed possibilities for the stabilization of grounds and foundations of two valuable Ancient Cathedrals on weak soils in Baltic Sea Region with grouting, using urea formaldehyde. The results showed that it was possible to stabilize sandy soil with grouting, but stabilizing peaty and clay ground was not achievable. The addition of active components to carbamide resins also increased density and the alkalinity level of solution, and decreased viscosity. Also, the uniaxial strength of sands stabilized with polymer resins was found to be time dependent [10].

Islam M. Abo Elnaga, in 2014, presented the results of detailed laboratory tests to improve the natural subgrade soils using polymer resins. The urea-formaldehyde resin was used in his study, as a soil stabilizing agent, to improve the characteristics of desert and beach sands. Based on the test result, he has demonstrated that with the addition of the urea formaldehyde resin the compressive strength increase which enables the sands to carry the heavy traffic [12]. Environmental friendly material, can use as an additive material in small percentage in soil. H. Suha Aksoy and Mesut Gor, in 2013, investigated the effect of natural resin on strength parameters of sandy soil. According to their experimental study, it was seen that increasing of astragalus content decreased the internal friction angle on the contrary increasing of astragalus amount supplied higher value of cohesion [13].

In this study, Urea-formaldehyde resin, that was environmentally compatible with nature, was used as an additional substance for cement based groutto createa cement and chemical based mix grout.

The investigation mainly focuses on the influence of chemical grouts and cement content on the mechanical properties alluvial formations. To investigate the performance of UF resin, the unconfined compressive strength, elastic and secant modulus and permeability of injected specimens were determined. The unconfined compressive strength (UCS) test was performed on the samples after 7, 14 and 28 days of curing. The addition of the urea-formaldehyde resin in the mixed grout can significantly improve the compressive strength and deformability of cement stabilized granular soil. The optimal improvement is found at the UF content of 10%. Hence, the analysis for compressive strength is based on the test results of specimens stabilized with less than 10% of urea-formaldehyde resin. The test results indicate that the UF resin perform effectively reactions and improve the mechanical properties of cement and chemical based mix grout.