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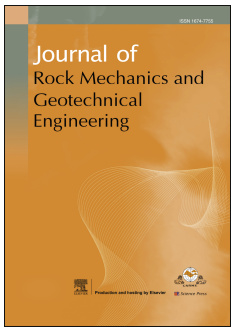

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Soil-cement mixture properties and design considerations for reinforced excavation

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Abstract: soil-cement is a mixture produced by grouting or mixing cement with soils. This paper reviews and discusses the general classifications of grouting techniques and the suitability of their applications. The mechanical properties of soil-cement mixture and the influence of sodium silicate added are discussed. Design considerations for deep soil mixed wall (DSMW) for excavation support and vault arch for tunnelling stabilisation are presented. Parameters for the numerical analysis of soil-cement mixture are evaluated and recommended.
Keywords: grouting; soil-cement mixture; mechanical properties; deep soil mixed wall (DSMW); vault arch

1. Introduction

Soil-cement is a mixture of cementitious chemical material (usually referred to cement) and natural material (usually referred to soils). The product has a significant increase in shear strength to meet strength requirements of different applications. Soil-cement is best described as fine-grained or coarse-grained soil-cement mixture in accordance with soil classifications, and it presents different mechanical properties accordingly. Grouting or mixing is the mechanical action to produce soil-cement. Grouting may be classified according to the mechanical action, such as jet grouting, permeation grouting, compaction grouting and fracture grouting. On the other hand, grouting can also be classified based on the grouts, e.g. chemical grouting, and cement grouting. In practice, additives, such as fly ash and sodium sulfate solution, are admixed with the cementitious materials to meet different needs.

This paper first reviews the general classifications of grouting and the suitability of their applications. Then, the mechanical properties of the soil-cement mixture and the influence of the sodium silicate added are discussed. Finally, design considerations for the two popular methods, i.e. deep soil mixed wall (DSMW) for excavation support and vault arch for tunnelling, are presented.

2. Grouting categories and suitability of application

Grouting is a mature technology used to inject cementitious materials into fine fissures or small pores. Firstly developed in 1802 (Cambefort, 1977), chemical grouting was applied to dam cut-off and tunnel support (Littlejohn, 1985). Table 1 summarises the grouts used and their applications (Cambefort, 1977).

Chemical grouts are in a state of solution when used to fill the voids of soils, while cementitious grouts are in a state of suspension of particles in a fluid medium (EM1110-1-3500, 1995; EM1110-2-3506, 1995). Chemical grouts react to form a solid, semisolid or gel after a predetermined time, and the difference between chemical and cementitious grouts is arbitrary in which some particulate grouts are composed of suspension of superfine cement with particle size less than 10 μm in diameter. The viscosities of chemical grouts can be in a very low level and no solid particles are contained. Thus chemical grouts have been frequently used to penetrate into the very fine cohesive materials to enhance the strength of the material or into the very fine fissures to prevent water infiltration, when cementitious grout cannot be penetrated. Table 2 summarises the properties of five types of chemical grouts in contrast to Portland cement based grout. US Army Corps of Engineers' manual EM1110-1-3500 (1995) stated that chemical grouts are constantly more costly than cement grouts. Moreover, chemical grouts often show significant disadvantages due to potentially toxic effects, and in some circumstances, they are even not allowed to be used in practice. Potential pollution to groundwater by chemical grouts is considered as a main factor that should be avoided in the selection of the type of grouts in many cases. From Table 2, we can see that sodium silicates are among the most widely used chemical grouts due to their safe, environment-compatible nature and relative low costs. In practice, cementitious grout, and sometimes in conjunction with chemical grouts (e.g. sodium silicates), is preferred to grout the large voids.

Grouting can also be categorised by either grouting method or the purpose. For example, jet grouting generates in situ grouted soil body. The jet grout is advanced to the treatment depth, where grout jets (cement grout with optional water and air) are sprayed with high velocity from nozzles under high pressure in the side of the drill chamber. Depending on the application and types of soils, jet grouting can use the single fluid system (slurry grout jet), the double fluid system (slurry grout jet surrounded by an air jet) or the triple fluid system (water jet surrounded by an air jet, with a separate grout port). Different grouting parameters are used for different grouting materials and methods, e.g. grout pressure can be up to 30-50 MPa for single fluid and double fluid (air) systems, higher than 2 MPa for double fluid (water) and triple fluid systems (BS EN 12716, 2001), while some contractors may use 40-70 MPa for single fluid system, 30-70 MPa for double fluid system and 7-10 MPa for triple fluid system, correspondingly with flow rate of grout of 100-300 L/min, 100-600 L/min and 120-200 L/min (Burke, 2004; Wang et al., 2013). With such pressure and velocity, the jets erode and mix the soil in the field as the drill stem and jet grout head are rotated and raised to construct soilcrete panels in full or partial columns, with designed strength and/or permeability.

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