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Effect of grout pressure and grout flow on soil physical and mechanical properties in jet grouting operations

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ABSTRACT

Jet grouting is a method for improving soil characteristics. In this method, grouting of cement slurry with high pressure and velocity causes damage to soil structure. Excavated grains of soil are then removed from the borehole and are replaced with cement slurry. The grains that remain around the borehole mix with cement slurry and produce an improved soil mass of soil. This mass is called "soilcrete". Soilcrete has special characteristics such as high strength, low deformability and very low permeability. The jet grouting process and its results are affected by various parameters of the soil material and jet grouting system. This paper discusses the effects of jet grouting process on the soil properties before and after the operations, and the effects of grout pressure and grout flow on soilcrete's uniaxial compression strength (UCS). For these purposes, five types of the laboratory tests have been done on the jet grouted soil: uniaxial compression, triaxial compression, direct shear, Brazilian indirect tension, and Schmidt hammer tests. According to the numerical results obtained from experiments, by increasing the grout pressure and flow, the UCS (MPa) of soil increases logarithmically. In addition, jet grouting dramatically increases properties such as cohesion and friction angle.

1. Introduction

The jet grouting is a very attractive method, and has been effective in many instances. One of the most important advantages of jet grouting is that different types of soils can be used in such a method. Also, the resistance and permeability can be designed by means of this method. This method is a suitable substitution for the methods of the common injection, chemical injection, trenching (plastic concrete and grab), piling system, foundation and/or using compressed air in the freezing method in tunnel building. In this method, the grouting mixture penetrates into the pore space, joints, cracks and voids of rock/soil structures, and improves the physical and mechanical characteristic of these structures. Thus, the penetrably and deformability of layers will become low, and the strength of these layers will increase [1]. The jet grouting method is frequently used as a mean for ground improvement, especially in shield tunneling, and also in all sorts of foundation treatment in recent years [2].

Jet grouting starts with drilling a borehole, usually 100–150 mm in diameter, to the required lower end of the section to be treated. After completion of drilling, the jetting pipes (or monitors) are inserted into this hole. The next step consists of applying a jet emitted from a nozzle under very high pressure to erode the soil adjacent to the borehole wall. This process enables the slurry to penetrate the soil adjacent to borehole and mix with it (Fig. 1). Jet grouting systems are classified into three types depending on the delivery mechanism (Fig. 2) [5–16].

In a single fluid system, the fluid injected is grout. This system is used mainly for horizontal jet-grouting, for example, in tunnel support systems. In a double fluid system, grout and compressed air are injected. The combined effect of the high-pressure grout and air results in a greater percentage of soil being removed and replaced with grout, and the remaining soil-grout mixture is called soilcrete. In a triple fluid system, grout, air, and water are jetted. This triple combination enables an even higher percentage of soil to be removed, and the system can be used for almost complete replacement of the soil with grout. The triple fluid system offers better control over injection rates and results in better quality of soilcrete. Although the single and double fluid systems can be used in loose sandy soils, the triple fluid system can be used in most types of soil [1,6,8,9,11,13,14,16,17].

Generally, the most important parameters which affect the designing of jet grouting are soil type, mixture influx between soil and grout, exiting jet energy from the nozzle, grout flow rate, rotating speed and lifting speed [13]. The parameters that should be assigned in single fluid system include grout pressure, number and dimensions of nozzles, W/C rate, rotating speed and lifting speed. In double fluid systems, in addition to the parameters that have been mentioned for single fluid systems, air pressure and air

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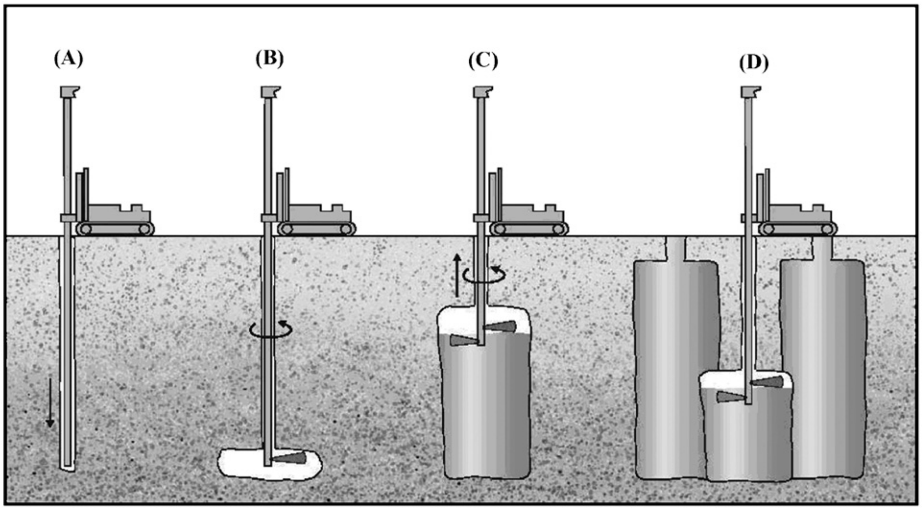

Fig. 1. Sequence of jet grouting method: (A) drilling, (B) jetting test, (C) jetting, forming a column, and (D) completion [3].

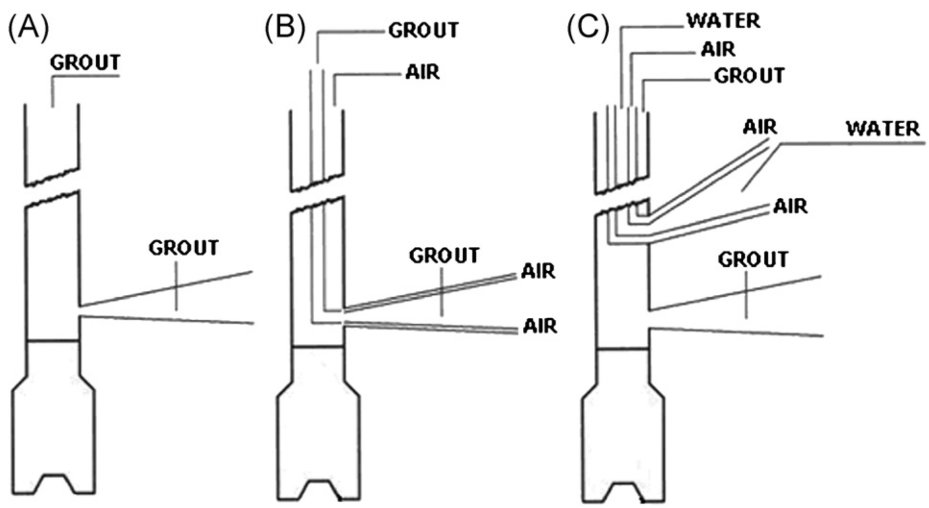

Fig. 2. Three basic systems of jet grouting: (A) single fluid, (B) double fluid, and (C) triple fluid [4].

flow rate should also be assigned. But in triple fluid systems, in addition to the seven parameters that have been mentioned, the number and dimension of water and air nozzles should also be assigned [8].

In discussion of the effects of soil material properties on the jet grouting process, many investigators have described the soil's behavior, using various parameters. Xanthakos [8] and Greenwood [13] showed that in soft ground and in ground with high cohesion, the effective diameter of soilcrete will decrease with increasing the standard penetration test '*N*' values. Greenwood [13] suggested a nozzle with 4 mm diameter to prevent obstruction. Yahiro [8,13] showed that the soil slicing efficiency can be improve with a compressed air cone around a water jet. Increasing pressure or decreasing lifting speed caused an increase in the soilcrete diameter [8]. In granular and argillaceous soils the soilcrete diameter will decrease with increased the lifting speed.

2. Site specification

The location under investigation is the Shahriar dam, a double-curvature concrete arch dam that is under construction near the town of Mianeh in northwest Iran. The alluvial sediments in the riverbed of the dam are underlain by low-strength clay, and therefore are likely to cause slope stability failures.

The foundation of the Main Dam requires excavation of the alluvial deposits down to competent bedrock. The average ground elevation of the alluvial plain is about 975 m asl. The elevation of the bedrock at its deepest point is about 920 m asl. Hence, about 55 m of alluvium needed to be excavated at the deepest section of the valley. Excavation of approximately 55 m of alluvium is not possible without some strengthening and support measures (Fig. 3). The reasons for these measures are the presence of a basal clay layer with relatively low shear strength and the limited space between the upstream cofferdam and the main dam, requiring relatively steep excavation slopes.

There are two approaches to ensure the stability of an excavation pit. One is strengthening the soil either by mixing it with some material (lime, cement) to increase its shear strength (mainly its cohesion component) or reinforce it with some mechanical device (e.g. net, grid, strips, etc.), mainly to increase the friction angle. Another approach is to support the potentially unstable mass of earth materials by engineered structures such as retaining walls with or without anchoring. Often a combination of