사질토지반에서의 그라우트체 형상에 관한 실험 연구
Experimental Study on Grout Shape in Sandy Soils

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요지

지반을 보강 또는 지하수를 차단하기 위해 실시되는 그라우팅과 같은 공법이 제대로 효과를 발휘하기 위해서는 bulging 또는 sheet 형태의 그라우트체 형상의 조절이 필수적이다. 본 논문에서는 이러한 그라우트체 형상에 영향을 끼치는 인자를 찾기 위해 포화된 사질토지반에서의 그라우트 실험을 다수 실시하였다. 그라우트의 주입속도와 점성의 크기, 사질토의 상대밀도와 입도크기의 인자를 사용하여 실험을 사용한 결과, 비교적 느린 주입속도와 작은 상대밀도, 그라우트의 점성과 입자가 클수록 bulging 형상의 그라우트체가 형성이 되었다. 이와는 반대로 빠른 주입속도와 높은 상대밀도, 그리고 그라우트의 점성과 흙 입자가 작을수록 sheet 형상의 그라우트체가 형성이 됨을 확인하였다.
주요어 : 그라우트체 형상, bulging 형상, sheet 형상

1. Introduction

The main purpose of the grouting is to reinforce the ground and prevent ground water seepage through opening such as tunnel. The function of grout in many applications such as fracture grouting to reduce settlement of the foundation mainly depends on its form with respect to injected hole of axis. The difficulty of grouting in soils is that it is not easy to predict and control the shape and direction of grout propagation. This leads to the necessity for controlling grout propagation and it is vital for a safe and effective design method.

Grout can be mechanically considered as a hydraulic fracture as cement paste fluid is used for fracturing into soil or rock. While the mechanism of hydraulic fracturing in rock is well understood, that in soil is not. The formation of hydraulic fracture is complicated and is affected by many factors and parameters. Table 1 summarizes the relevant parameters in fracturing process proposed by Rutger (2004).

Table 1. Influential parameters in grouting performance (Rutger, 2004)

Mechanical parameters	Grout parameters	Sand (soil) parameters
Injection rate (Q) Injection time (t) Injection pressure (p)	Yield point (t_y) Plastic viscosity (μ_p) Permeability (k) Porosity (n)	Minimum soil stress (σ_{min}) Water pressure (u) Angle of internal interaction (ϕ) Cohesion (c) Permeability (k) Elastic modulus (E) Poisson's ratio (v)

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The two main fracture types such as sheet and bulging fractures are generally expected. Sheet fracture is capable of sealing and preventing from leakage while bulging fracture is useful for soil densification. Control of the formation of hydraulic fracture is the interest of many researchers (Murdoch, 1993, 2002; Suat et al., 2002; Hong, 2004, Soga et al., 2004) because of its uncertainties such as a wide range of soil properties in grouting performance. In this paper, several grout tests are experimentally performed to investigate the effect of influential parameters on grout shape (i.e., bulging or sheet type) in saturate sandy soil.

2. Experimental setup and procedure

Figure 1 shows the experimental setup. A chamber of consolidometer type is made of acryl, and is 15 cm in diameter and in height. A copper injection tube is inserted at the bottom of the consolidometer. The loading plate is made of acryl and there are four holes for drainage purpose since the tests require fully saturated conditions. The dial gauge with the resolution of 0.01 mm is placed on the top of the loading plate to measure the vertical displacement that happens during tests, the heave induced by injection is controlled with maximum allowance uplift. A shut-off valve is attached ahead of injection tube in order to stop the injection. The grout is stored inside the steel chamber and the pressure meter is used to measure the fluid pressure.

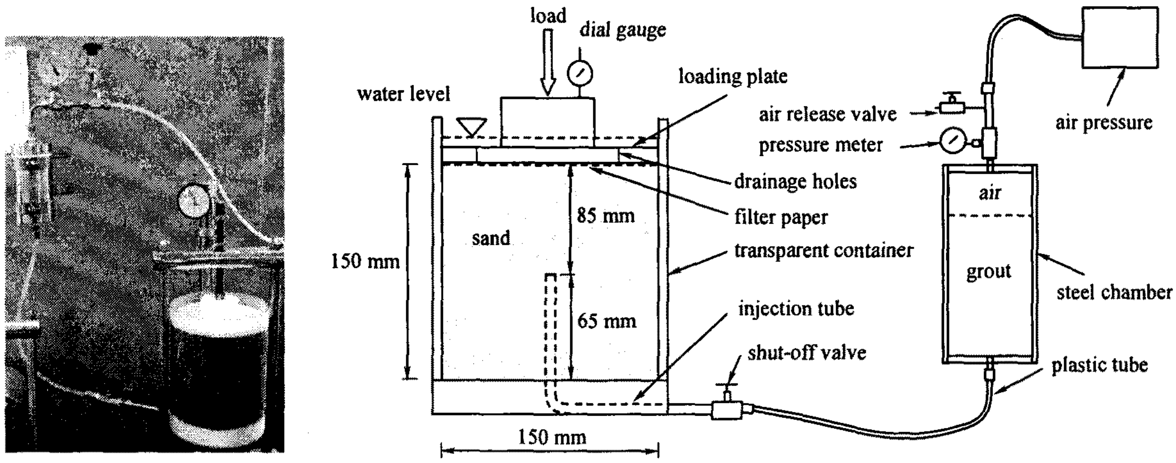


Figure 1. Experimental apparatus

Several grouting materials (grouts) are used in the test such as epoxy, silicone sealant, and gypsum solution. Each grout has different viscosity so that the effect of viscosity to fracture formation can be investigated.

The soil specimen used in experiment tests are yellow and black sand. Sands are put in the oven to make them dry at 100°C. In our tests, the sand which passes through No. 60 sieves is used. The density of the sand is controlled by measuring the weight of sand, water and the volume of the sand and water before compaction. Water and sand are well mixed together to ensure the uniformity of moisture content of the specimen.

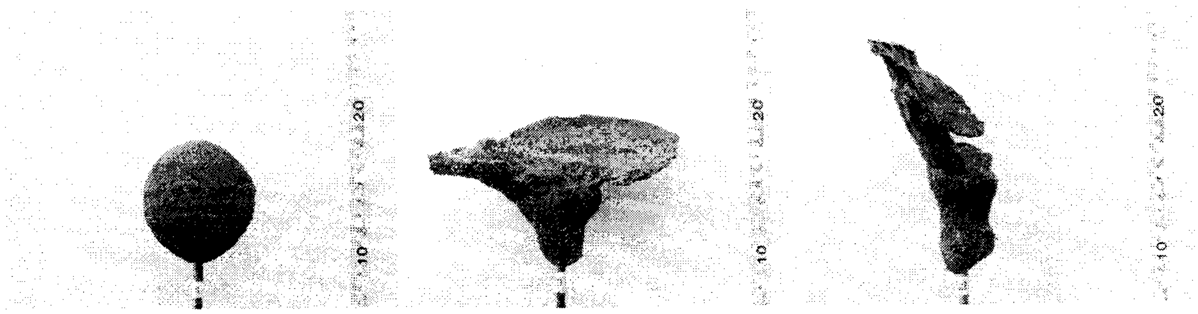
After the specimen is prepared, it is placed into the load frame of the consolidometer. At the next step, we saturate the soil specimen with water in 6 hours to ensure it is fully saturated. The dial gauge is then set up and we measure the initial displacement of the specimen. Later, we connect the injection tube with the shut-off valve, injection pipe, steel pressure chamber, pressure control panel, pressure transducer, and nitrogen pressure tank.

During the injection, the injection pressure inside the tank is measured with pressure transducer, plotted for pressure-time curve, and stored into computer. While conducting the injection process, the applied pressure is controlled, so we can have an effective and safe handling. The heave of the sand is measured and observed during and after the test. The first step after injection is to remove the loads from load frame and then drain water from the specimen. After being cured inside of the consolidometer, the hydraulic fracture is carefully excavated from the specimen.

3. Results

3.1. Shape of the grout

Figure 2 shows two types of grout shape, bulging (a in Figure 2) and sheet fractures (b and c in Figure 2). In the result, bulging fractures are generally obtained in low relative density and low injection rate. Sheet fractures are obtained by increasing injection rate. The direction of sheet fractures are attributed to the stress regime in the container. In general, higher vertical loading that forms least horizontal principal stress is contributed to the vertical sheet fractures.



(a) Bulging fracture (b) Horizontal sheet fracture (c) Vertical sheet fracture

Figure 2. Shape of the grout

3.2 Effect of relative density and injection rate on grout shape

The two main parameters that have much influence on the behavior of hydraulic fracture are the relative density of the soil and the injection rate of the grout. In Figure 3, three types of fracture "bulging," "intermediate" and "sheet" are denoted. The number beside each symbol represents the test number. In most cases, sheet fractures are easily obtained if the injection rate is higher.

However, the relative densities of the soils somewhat contribute to or affect the fracture type. The tests No. 10 and No. 25 gave the result of intermediate fracture type. In the test No. 25, the relative density of the soil is very low ($D_r \sim 0.23$) and injection rate is high. In the test No. 10 the relative density of the soil is medium ($D_r \sim 0.61$) and injection rate is lower than that of No. 23.

3.3. Effect of grout viscosity and grain size on grout shape

Figure 4 shows the effect of viscosity of the grout and grain size on grout shape. The grain size is closely related to the permeability of a soil. In a common sense, the grout which has lower viscosity has lower resistance to flow or fluid friction between particles. As expected, therefore, the lower viscosity of the grout gives it more chance to make sheet fractures.

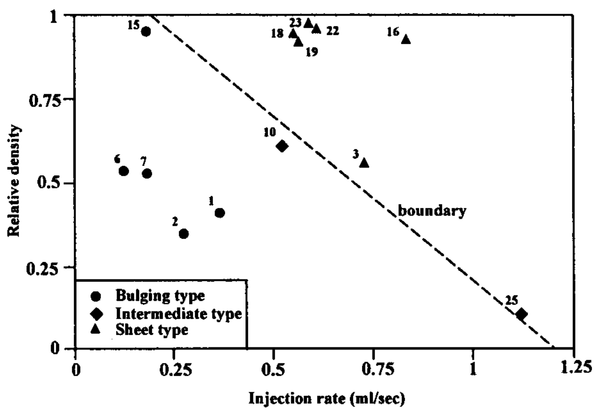


Figure 3. Effect of relative density and injection rate

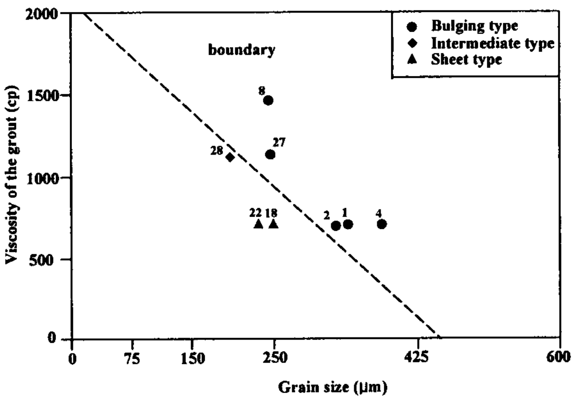


Figure 4. Effect of grout viscosity and grain size

4. Conclusions

In this paper, several grout tests are experimentally performed to investigate the effect of influential parameters on grout shape (i.e., bulging or sheet type) in saturate sandy soil. Stress regime, injection rate, relative density and grain size of the soil, viscosity of the grout are used for influential parameters. In general, bulging fractures are obtained under the lower injection rate. Vertical sheet fractures are obtained by increasing more vertical load on top of the specimen in our horizontally constrained tests. In addition, sheet fractures are easily obtained under the conditions of higher relative density of soil and higher injection rate. Lower viscosity of the grout under smaller grain size gives more chance to form sheet type of grout.

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