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Simulation Study of Loess Split Grouting based on Discrete Element Method

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Abstract

Split grouting is a common method of stratum reinforcement. However, due to the concealment of grouting itself, it is difficult to observe the slurry diffusion of split grouting. Therefore, this paper uses PFC2D software to simulate the split grouting in loess to study the diffusion law of slurry and the change of formation porosity. The research results show that the number of fracturing cracks increases with the increase of time. The porosity of soil mass changes obviously after the first fracturing, and the change rate of porosity increases after the second fracturing. With the increase of the initial grouting pressure, the number of splitting cracks is increasing, and the change rate of soil porosity is also accelerating.

Keywords

Split Grouting; PFC2D; Numerical Simulation.

1. Introduction

Loess is a kind of sediment formed under Quaternary arid and semi-arid climatic conditions. Loess has large pores, which is easy to reduce its strength due to the increase of water content caused by rainfall and other factors [1]. In various engineering construction, it is necessary to reinforce the loess.

Grouting is a common method of stratum reinforcement. It refers to injecting the prepared uniform slurry into the formation through a certain pressure, so that the slurry can cement the loose soil particles or cracks together in the form of filling, infiltration and compaction.

The grouting project is a concealed project, and the actual situation of different projects is very different, and it is difficult to collect and compare accurate data [2]. The discrete element method is a dynamic calculation method based on discrete particle aggregate or rigid discrete element. Zhou, et al. [3-4] first used PFC2D software to simulate seepage. Sun et al. [5] studied the occurrence and development of grout pressure diffusion and splitting cracks under different grouting pressures and different soil properties during splitting grouting through PFC2D software. Zheng [6] used PFC2D to simulate the fracturing grouting process, and established a particle flow model that can simulate the whole process of fracturing grouting to observe the crack generation, slurry invasion and crack development. However, although some studies have been carried out on the grouting process of split grouting, the overall research on split grouting in loess is relatively small.

2. Model Parameter Calibration

In PFC software, the mesoscopic parameters used are not directly related to the physical and mechanical parameters of the soil itself, and the parameters need to be calibrated through corresponding mechanical tests. Based on the triaxial test results of soil, this paper uses trial

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and error method to calibrate the parameters of loess [7]. The physical and mechanical parameters of loess are shown in Table 1.

Table 1. Physical and mechanical parameters of loess

Water content w/%	Density ρ/g·cm^{-3}	Cohesion c/kPa	Angle of internal friction φ/°
18	1.78	32.1	26.08

Through a large number of triaxial test simulations, the stress-strain curves close to the test results are obtained. Figure 1 shows the stress-strain curves of the test and simulation under different confining pressures.

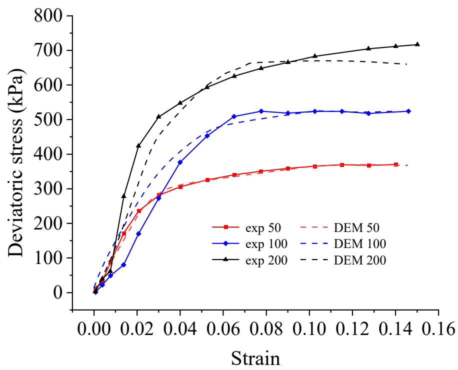

Figure 1. Comparison of stress-strain curves under different confining pressures

When the stress-strain curve obtained by simulation is close to the results of the indoor triaxial test, it is considered that the calibration results can better reflect the physical and mechanical properties of the real soil mass. The mesoscopic parameters such as the calibrated particle size, contact bond modulus, particle stiffness ratio, friction coefficient, particle normal bond strength and tangential bond strength are shown in Table 2.

Table 2. Meso-mechanical parameters of loess

R_{min}/mm	R_{max}/R_{min}	emod/Pa	kratio	fric	tensile/Pa	shear/Pa
0.35	1.43	3.5×10^7	1.0	0.4	1×10^6	1×10^6

3. Simulation and Result Analysis of Split Grouting

3.1. Model Establishment

references at a time may be put in one set of brackets [3, 4]. The references are to be numbered in the order in which they are cited in the text and are to be listed at the end of the contribution under a heading *References*, see Figure 1.

The size of the numerical simulation model is 4m × 4m, filled with dense particles to simulate the actual formation structure, generating a total of 2096 particles. The "servo system" in PFC software is used to adjust the lateral constraint of the model, and the force between particles is changed by the lateral constraint to simulate the initial stress of soil. The lateral restraint force of this simulation is 100kPa. Establish the model and initial force chain diagram, as shown in Figure 2 and Figure 3.

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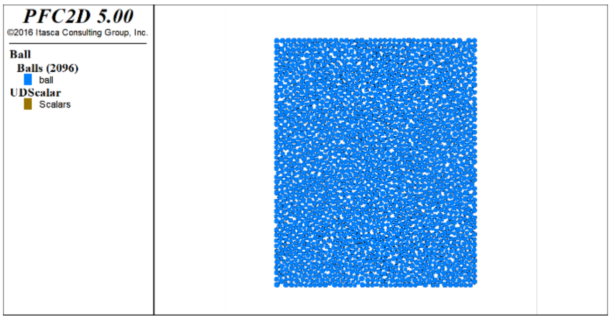


Figure 2. Model established by PFC2D

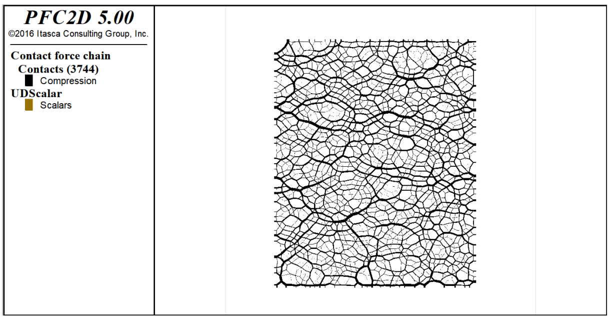
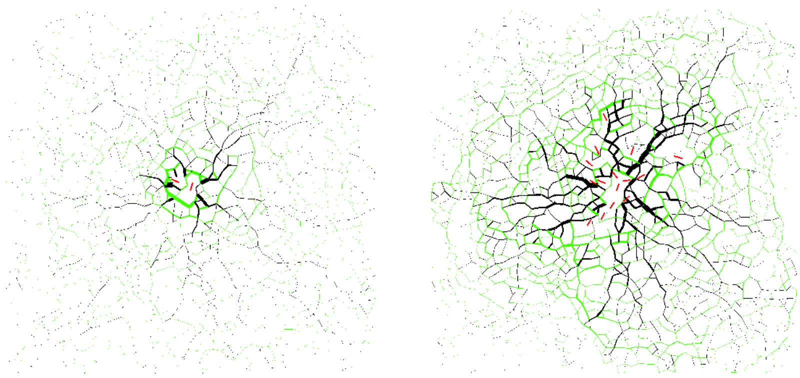


Figure 3. Initial force chain diagram of PFC2D model

3.2. Loess Splitting Grouting Process

In this numerical simulation, keeping the test model and mesoscopic parameters unchanged, the effect of grouting time on the diffusion of loess splitting grouting slurry is considered by calculating the number of steps. Figure 4 is the schematic diagram of slurry diffusion in the process of splitting grouting. The red line segment in the diagram indicates that the bond between particles is broken, forming cracks in splitting grouting.

It can be seen from Figure 4 (a) that at the initial stage of grouting (step=5000), under the action of grouting pressure, tensile stress appears around the grouting hole, but the slurry does not split the soil. As can be seen in Figure 4 (b), when the grouting time increases (step=10000), the grout starts to split the soil mass and produce cracks under the effect of grouting pressure. As the grouting time continues to increase (step=15000), as shown in Figure 4 (c), the first crack continues to expand, and secondary splitting occurs around the grouting hole, resulting in the second crack. As the grouting time continues to increase (step=19000), as shown in Figure 4 (d), the two cracks are gradually expanded, and when filling, a third split crack is generated around the grouting hole, and finally the distribution of grout veins similar to "Y" shape is formed.



(a) step 5000 (b) step 10000

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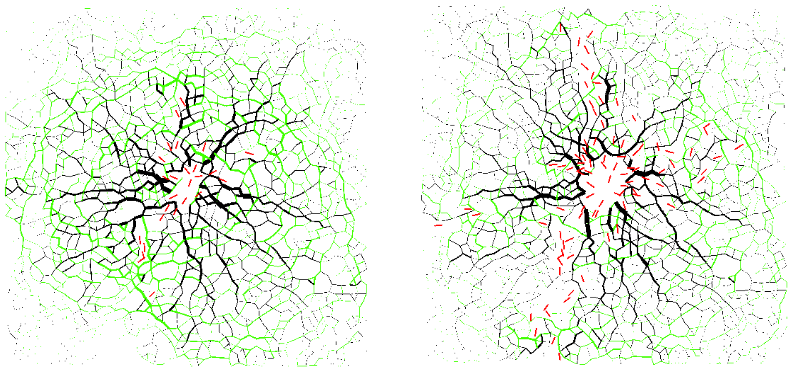

(c) step 15000 (d) step 19000

Figure 4. Schematic diagram of slurry diffusion during split grouting

In order to better study the change of soil mass during grouting, the measurement circle was used to monitor the change of soil mass porosity during grouting. The change of soil mass porosity is shown in Figure 6. It can be seen from Figure 6 that in the initial stage of grouting, the porosity of soil mass only slightly increases. After the initial fracturing, the void ratio of soil begins to increase significantly. When the soil is split twice, the porosity increases more rapidly. The increase of porosity is due to the change of soil structure due to the injection of slurry. The increasing speed of soil porosity indicates that the filling speed of soil by slurry is also accelerating during the grouting process.

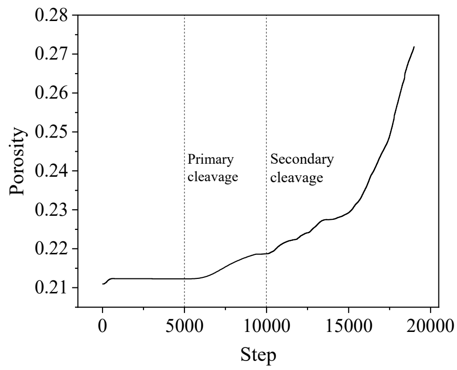

Figure 5. Variation curve of soil porosity during split grouting

3.3. Effect of Grouting Pressure on Split Grouting

In order to study the diffusion law of grout under different grouting pressures, under the same other parameters, change the initial grouting pressure of 0.3MPa, 0.35MPa and 0.4MPa to simulate the diffusion of grout under various grouting pressures.

The slurry diffusion under different grouting pressures is shown in Figure 6. It can be seen from Figure 6 that under the condition of low initial grouting pressure (0.3MPa), the slurry is mainly concentrated around the grouting hole, and no major splitting cracks have been formed. When the grouting pressure increases to 0.35 MPa, the soil around the grouting hole is seriously broken, and there are many split cracks in the soil. When the grouting pressure increases to 0.4MPa, the number of split cracks in the soil continues to increase, and the bond between soil particles begins to weaken. This shows that the increase of grouting pressure promotes the expansion and increase of split cracks, and also leads to more grout can be injected into the soil, which is more obvious around the grouting hole.

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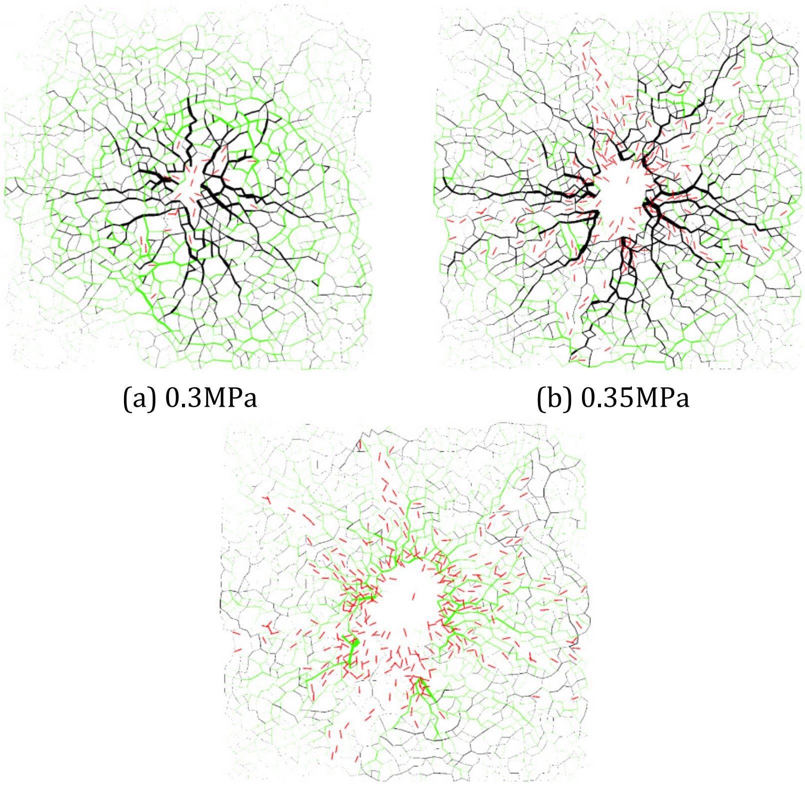

(a) 0.3MPa (b) 0.35MPa

(c) 0.4MPa

Figure 6. Splitting shape of soil mass under different grouting pressures

In order to better understand the splitting of soil mass, the change of soil porosity under different grouting pressures was monitored using a measuring circle. Figure 7 shows the change curve of soil porosity under different grouting pressures. It can be seen from Figure 7 that during the grouting process, the porosity of the soil mass increases continuously, and the change of the internal porosity of the soil mass is also faster in the case of large grouting pressure. When the grouting pressure is 0.30MPa, the porosity of soil mass increases from 21% to 26% within the same grouting time (step=9000). When the grouting pressure increases to 0.40MPa, the porosity of soil increases from 21% to 32%. The porosity increases by 11%, which indicates that the increase of grouting pressure significantly increases the injection volume of grout.

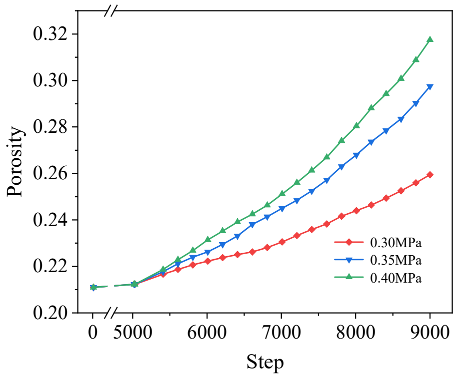

Figure 7. Variation curve of soil porosity under different grouting pressures

4. Conclusion

Through the simulation study of loess split grouting, the following conclusions are drawn

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(1) In the process of split grouting, the slurry first diffuses around the grouting hole. When the first split crack occurs, the slurry rapidly expands in the first split crack, and new split cracks continue to occur.

(2) In the process of split grouting, the porosity of the soil mass changes obviously after the initial split of the soil mass. With the increase of grouting time, the change speed of the porosity of the soil mass continues to accelerate.

(3) The initial grouting pressure has a great impact on the fracturing during the grouting process. With the increase of the initial grouting pressure, the number of fracturing cracks in the soil increases significantly, and the porosity of the soil increases significantly.

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