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Current Research Status of Split Grouting Theory

Bian Liu

Civil Engineering Department, Henan Polytechnic University, Jiaozuo, Henan 454000, China

Abstract: Splitting grouting is currently the most widely used grouting method. Based on a comprehensive analysis of domestic and foreign literature, this paper introduces the theory of split grouting in response to the current research status of grouting theory. Study the theory of split grouting from the aspects of hole expansion theory, splitting pressure, diffusion law, propagation process, and grouting pressure; And suggestions were put forward for the current problems and future research directions of grouting theory.

Keywords: Theory; Overview; Diffusion law.

1. Introduction

With the continuous development of urban construction, there are more and more underground projects such as subways and rail transit. During the construction process of underground projects, the soil is prone to varying degrees of disturbance or damage, causing strata movement and deformation. According to construction practice experience, grouting reinforcement technology is the preferred strata reinforcement technology, and split grouting is currently the most widely used grouting method, but theoretical research lags far behind engineering applications.

The emergence of grouting theory and grouting technology was accompanied by the emergence and development of grouting technology. The grouting theory mainly studies the flow law of slurry in the injected medium, revealing the interrelationship between geological conditions, grouting technology, and slurry material characteristics. The obtained laws provide reference data and scientific basis for grouting design and on-site construction. The grouting theory is established and developed on the basis of solid mechanics and fluid mechanics. The main research content is to establish the relationship between grouting parameters such as grouting volume, pressure, grouting time, and diffusion radius by analyzing the flow form of slurry. Due to the interdisciplinary nature of theoretical research, it is highly complex, which has been the main reason for the slow development of grouting theory.

Due to the complex and variable pore structure in the rock and soil layers, the slurry usually moves in various forms in the rock and soil layers. This article focuses on the current research status of grouting theory at home and abroad, and analyzes the splitting grouting theory in detail from different aspects.

2. Splitting Grouting Theory

Splitting grouting is currently a widely used grouting method, but its theory lags far behind its application. According to the experiment, splitting grouting is a process of first compacting and then splitting. The flow of slurry in soil can be divided into three stages: bubbling compaction stage, splitting flow stage, and passive soil pressure stage.

Based on the theory of split grouting, many scholars analyze it from several aspects such as hole expansion theory, splitting pressure, diffusion law, propagation process, and grouting pressure.

2.1. Dilation theory

At the beginning of grouting, due to the limited energy possessed by the slurry, it cannot split the formation. Therefore, the slurry accumulates near the grouting port, forming spherical or cylindrical slurry bubbles with the grouting port as the main body. With the continuous injection of grout and the continuous increase of grouting pressure, the grout bubbles will gradually expand to the surrounding areas and the soil will also be further compressed and eventually yield, which is regarded as the process of circular hole expansion.

Vesic [1] first introduced the theory of hole expansion into the initial stage of grouting, assuming that the soil material is an ideal elastic-plastic material. Based on the Mohr Coulomb yield condition, analytical solutions for the expansion of cylindrical holes (two-dimensional problem) and spherical holes (three-dimensional problem) were provided. Yu and Houlsby [2] also introduced the concept of shear dilation angle to describe the shear dilation characteristics of soil under the Mohr Coulomb yield criterion. They used the theory of large deformation to analyze the plastic zone and obtained a unified solution for the expansion of cylindrical and spherical pores without any limit on the number of deformations. Zhou Mingru [3-4] combined the general strength criteria of cohesive soil (SMP criterion, Lade Duncan criterion, M-C criterion) and derived the estimated formula for splitting grouting pressure under different theoretical undrained conditions in loess areas. Due to the consideration of the factor of central principal stress in the Land Duncan criterion and SMP criterion, the calculation results of the model are more accurate than those of the traditional Mohr Chunlomb model. Analysis of the pressure mechanism of loess grouting shows that when the pressure is not high, the slurry mainly exerts a compaction effect on the soil. When the splitting pressure is exceeded, the soil will experience splitting.

3. Splitting Pressure

The initiation pressure is a key aspect of studying the mechanism of fracturing. During the splitting grouting process, the slurry first gathers near the grouting pipe to form slurry bubbles, and the soil receives a compaction effect. When the grouting pressure is greater than the initial splitting

pressure, the soil undergoes splitting, and the slurry diffuses along the splitting cracks.

Pater [5] conducted split grouting tests on loose and dense sand under different confining pressures, and obtained the relationship curve between split pressure and confining pressure. It was also found that under the same sand sample conditions, the split pressure of dense sand was higher than that of loose sand. Yun [6] considered the infiltration effect that occurs during the splitting grouting process, provided an analytical solution to determine the splitting pressure, crack length, and thickness, and verified the correctness of the theory through indoor experiments on weathered granite. Zou Jinfeng [7-8] derived the initial splitting grouting pressure calculation formula (1-1, 1-2) based on the stress, strain, and volume change relationship of the soil in the energy consumption zone under the action of grouting pressure and static soil pressure during the grouting process, as well as the energy and volume change conservation principle during the grouting expansion process and the yield criterion of the soil. And assuming that the fractured rock mass follows the nonlinear Hoek Brown strength criterion, a fracture mechanics analysis model is used to analyze the splitting pressure of the fracture, and a method for determining the splitting grouting pressure in the fractured rock mass is derived.

$$\Delta u_{zhu} = c_u \left[2ln \frac{r_p}{a_u} + \left(1.73A_f - 0.58 \right) \right] \quad (1)$$

$$p_{shu1} = \frac{(\Delta u_{zhu} - \sigma_t)(1+sin\varphi)+2ccos\varphi}{(1-sin\varphi)} + p_0 \quad (2)$$

In the formula: Δu_{zhu} represents the initial excess pore water pressure generated by the expansion slurry of cylindrical pores; p_{shu1} is the pressure when the expansion slurry of the cylindrical hole vertically splits the soil; a_u is the radius of the enlarged hole; r_p is the radius of the plastic zone; c_u is the undrained strength of the soil; A_f is the pore pressure coefficient; σ_t is the tensile strength of the soil; φ is the internal friction angle; c is the cohesive force; p_0 is the initial stress acting on the soil.

4. Diffusion Law

Based on the flat narrow slit model, Li Chao [9] assumed that the slurry was a Newtonian fluid and derived a formula for calculating the maximum diffusion length of the slurry as a function of the grouting pressure when it splits a single crack in the rock. Zhang Junxian [10] derived the formula for calculating the maximum diffusion radius of power-law fluid splitting grouting. Zhang Zhongmiao [11] derived the calculation formulas for the slurry flow rate, flow rate, grouting pressure difference, and maximum diffusion radius during split grouting based on the power-law slurry flat narrow slit flow model. And analyze the influence of grouting pressure on the maximum diffusion radius under the influence of slurry consistency, rheological properties, and crack height. Li Shucai [12] established a single plate dominant splitting grouting diffusion model based on the generalized Bingham fluid constitutive equation, and derived the dominant splitting grouting diffusion control equation considering the rheological characteristics of the slurry.

Based on the consideration of the stress coupling characteristics of slurry and soil, Zhang Lewen [13] introduced the foundation coefficient method, taking into account the size effect and differences in different soils, and analyzed the splitting grouting process of different soils. Derived equations for the variation of diffusion radius of slurry, spatiotemporal variation of slurry pressure, and spatiotemporal variation of crack width. Zou Jinfeng [14] assumed that the flow of grout in cracks conforms to Darcy's law, and that the crack width formed by split grouting in soil is a uniform crack width. He derived the maximum diffusion radius of grout under a certain split grouting pressure, the attenuation law of grouting pressure, and the theoretical calculation formula for grouting amount in a single crack.

5. Communication Process

The above theory is based on the assumption of a flat narrow slit model that the splitting path is formed in one split during the grouting process, and the width remains unchanged, without considering the dynamic characteristics of the propagation of the splitting path.Li Peng [15] proposed four stages through experiments: the transformation of slurry diffusion form, saturation of primary and secondary splitting channels, formation of new splitting channels, and saturation of subsequent secondary splitting regions (see Figure 1). He analyzed the mechanism of soil splitting pressure changes and proposed a method for defining the values of primary and secondary splitting pressures. Wang Qicai [16] studied the causes, mechanisms, stages, displacement of the roadbed soil after grouting under different pressures, and the trend of grouting veins in the formation of split grouting grouting for collapsible loess roadbeds, and derived a fitting formula. It is difficult for secondary splitting to occur under grouting pressure of 0.3-0.5MPa; The main effects in split grouting are filling effect, compression effect, and skeleton effect; The slurry pipeline formed by small slurry in the surrounding soil also plays an indispensable role, and the slurry veins formed belong to open cracks. Fang Xiaobo [17] considered the variation of the height of splitting cracks and established a theoretical model of wedge-shaped splitting grouting. He derived the relationship between the diffusion radius of the slurry and the grouting pressure difference, as well as the thickness of the opening end of the grouting vein. The higher the height of the crack at the open end, the larger the diffusion radius of the slurry, and within a certain range, there is an approximate linear correlation between the two; The larger the grouting pressure difference, the larger the diffusion radius of the slurry, and within a certain range, the two are approximately positively correlated; The higher the height of the crack at the open end, the faster the attenuation of grouting pressure. Figure 1 Distribution of Main Plasma Veins in Different Splitting Regions. The existing splitting expansion model often assumes that only one grouting is performed to form a splitting crack, while actual grouting projects often use "porous and multi sequence". Li Peng [18] established a dynamic diffusion model for multi sequence grouting based on the soil re compression model, and obtained the calculation formulas for the width of the splitting path and the driving pressure of the grout in the subsequent grouting. Due to the influence of pre grouting, the width of the splitting path in post grouting can be reduced by 26.59%, and the driving pressure of the slurry can be increased by 269.00%, proving the necessity of considering the influence of pre grouting.

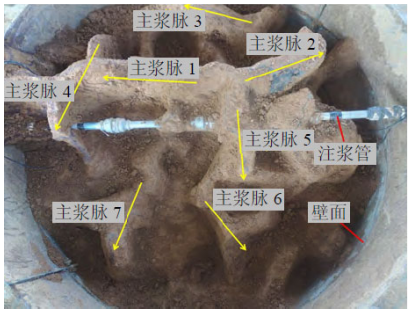

Figure 1. Distribution of Main Plasma Veins in Different Splitting Regions

6. Grouting Pressure

The grouting pressure is a key factor affecting the diffusion mode of grout. When the grouting pressure is greater than the splitting pressure, the soil undergoes splitting, and the slurry diffuses along the splitting cracks. Li Guanqi [19] believes that in dense soil, the grouting pressure obtained by the spherical expansion theory of infiltration grouting does not conform to the actual situation. He establishes a splitting model based on the Tresca yield criterion and calculates the grouting pressure that is more in line with the dense soil. Chen Yue [20] studied the pressure of grouting in soft soil foundation reinforcement. Based on the general form of failure criteria, combined with the formula of excess pore water pressure, expansion and large deformation theory, the theoretical formula of grouting pressure for soft soil splitting was derived. The variation of grouting pressure for soft soil splitting under different failure criteria was analyzed.

7. Conclusion

The research on the mechanism of splitting grouting mainly focuses on the elastic-plastic solution of the initial splitting pressure based on the theory of circular hole expansion, which is only the criterion for the occurrence of splitting grouting. There is a lack of in-depth and systematic research on the internal mode of splitting failure in the initial stage and the microscopic transient starting state. The research on the theory of splitting grouting reinforcement is mostly based on specific model experiments to draw qualitative conclusions, lacking universality, and should be studied in combination with different complex working conditions.

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