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Discussion on the Application of Grouting in Underground Engineering

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Abstract: With the development of China's economy, in some large cities, surface transportation alone can no longer meet people's needs today, and the development of underground engineering is increasingly catering to the needs of the public. During the excavation process of subway tunnels, it is inevitable that they may be threatened by groundwater, and grouting technology is one of the effective methods for preventing and controlling water in underground engineering. The mechanism of slurry flow and diffusion varies depending on the soil conditions. When underground projects such as subway tunnels pass through poor geological conditions, it is highly likely to cause significant surface subsidence, and even engineering disasters such as water inrush and collapse may occur. To ensure the safety of underground engineering construction in the geological strata, it is often necessary to carry out advanced grouting in the strata to achieve the purpose of reinforcement or water blocking. Advanced grouting reinforcement belongs to concealed engineering, and the existing advanced grouting construction mostly relies on experience and on-site grouting tests, making it difficult to achieve the expected grouting effect. Therefore, it is of great theoretical and engineering significance to conduct in-depth research on the diffusion mechanism of slurry in geological grouting reinforcement engineering, as well as the influence of factors such as slurry water cement ratio and geological characteristics on the diffusion form of slurry.

Keywords: Underground engineering; Slurry diffusion mechanism; Grouting technology; Grouting theory; Strengthening and blocking water.

1. Introduction

Underground engineering refers to the underground civil engineering projects built deep below the ground to explore and utilize underground space resources. It also generally refers to various projects and facilities built in the soil or rock layers below the surface, mainly including underground factories, subways, highway tunnels, railway tunnels, underground civil defense engineering and facilities, underwater tunnels, underground commercial streets, street crossing underground passages, underground parking lots, and various underground pipelines. There is a clear difference between ground engineering and underground engineering construction. During underground construction, adverse geological conditions and unknown risks may be encountered that urgently need to be addressed.

Grouting method is a technique used for ground reinforcement and water blocking in underground engineering. It is the preparation of materials with filling and bonding properties into a slurry, which is injected into the pores, cracks or voids of the formation using grouting equipment. After diffusion, solidification, and hardening, the slurry reduces the permeability of the rock and soil, increases its strength and stability, and thus achieves the purpose of sealing water or strengthening the formation.

Grouting construction can be used in civil engineering to:

(1) In water conservancy construction, anti-seepage treatment of the foundation strata of reservoir embankments is carried out to reduce the leakage of stored water;

(2) Reinforcement treatment of various building foundations and excavation support for deep foundations of high-rise buildings;

(3) Various underground projects (mountain tunnels, mining tunnels, underground oil and gas storage, underground nuclear waste storage, etc.);

(4) Strengthening and anti-seepage treatment of various geological layers in urban subway construction;

(5) Reinforcement treatment of various railway, highway embankments and bridge foundations;

(6) Reinforcement and formation of various pile foundations;

(7) Soft soil foundation reinforcement treatment;

(8) Ground treatment for various port engineering projects.

Using grouting construction to improve the performance of rock and soil layers

2. Grouting Theory

2.1. Permeation grouting

Infiltration grouting is the process of hydraulic injection of grout into cracks or pores of rock and soil through a grouting pump. The grout is used to squeeze out water and air from the cracks or pores, allowing the grout to combine with the soil and seal or fill the pores or cracks, thereby strengthening the rock and soil, and reducing or making the permeability of the rock and soil less permeable. Infiltration grouting does not change the structure of the original soil, and the grouting pressure is relatively low. It can only be achieved in sandy soil above medium sand and rock masses with loose filling materials in cracks. For formations with certain permeability such as fractured rock layers, sand and gravel layers, medium to fine sand layers, and silt layers, medium to low pressure is used to inject slurry hydraulic pressure into cavities, cracks, and pores in the formation. After solidification, the rock, soil, or soil particles are cemented into a whole to improve the stability and strength of the formation.

Yang Ping [1] analyzed and determined that the main hidden factor affecting the diffusion radius of grout is grouting pressure through indoor simulation grouting experiments combined with Bingham fluid model. The effects of grouting pressure, porosity, permeability coefficient, water cement ratio of grout, grouting amount, grout diffusion radius, and stone strength were studied, and their relationships were summarized and quantitative formulas were derived. Li Shengang explained the spherical and cylindrical diffusion patterns of power-law grout and Bingham grout in sandy soil based on the Darcy permeability law, and obtained a quantitative relationship between grouting pressure and grout diffusion radius. Using a cylindrical permeability grouting test device, the functional relationships between soil parameters, grouting pressure, cement slurry water cement ratio, diffusion radius, grouting amount, and stone strength were determined [2].

2.2. Splitting grouting

Splitting grouting [3,4] overcomes the initial stress state and tensile strength of the injected medium by increasing the grouting pressure to a certain value, leading to splitting failure of the soil structure. The soil splits along the minimum principal stress surface, forming a network crack. The slurry enters the network crack to form a slurry vein, which reinforces the soil by squeezing the surrounding soil and supporting the skeleton of the slurry vein. Compared with other grouting methods, split grouting damages the original geotechnical structure and may also cause new damage, leading to a decrease in soil strength. Splitting grouting was first applied to weakly permeable formations. For impermeable clay formations with finer particles, high-pressure slurry is used to forcefully compress the periphery of the hole. Under the action of grouting pressure, the surrounding soil under the action of the slurry is split and cracks are formed. Through the grouting vein like consolidation effect formed in the soil, the clay layer is compressed and reinforced, and the high-strength interlayer is increased to improve its strength and stability.

The mechanism of split grouting is developed from the principle of hydraulic splitting. When the static water pressure of the soil exceeds the sum of the minimum principal stress in the local area and the tensile strength of the soil, hydraulic splitting occurs. Its essence is that the pore water pressure of the soil exceeds the initial stress state, resulting in splitting [5]. The flow of slurry in soil can be divided into three stages : bubbling compaction, splitting flow, and passive soil pressure.

2.3. Compression grouting

Pressure grouting is the process of injecting extremely dense inert materials that are not easily flowing into the soil, while forming grout bubbles, to compact the surrounding soil and reinforce the soil layer. At the beginning of grouting, the grout bubbles are still relatively small, and the grouting pressure first expands along the grouting aperture. As the slurry bubbles expand and compress the soil, a significant upward force will be generated, causing the ground to rise. Research has shown that changes in slurry bubbles can cause mechanical changes and deformation in soil. The foam area is a plastic deformation zone, where the density of the soil is relatively small due to disturbance, while the soil far from the foam undergoes elastic deformation due to compression by the foam, resulting in a relative increase in soil density [6-8]. The difference between compaction grouting and infiltration grouting and splitting grouting is that it uses grout bubbles to squeeze adjacent soil and compact the surrounding soil. There is a clear interface between the grouting body and the soil. Pressure grouting is a process in which the grout cannot penetrate the rock and soil, and can only accumulate at the grouting port to form grout bubbles. As the grouting pressure increases, the grout bubbles also become larger, squeezing the surrounding soil. The radius of the grout bubble increases with the increase of grouting pressure. The effect of compaction grouting is related to the thickness, load size, soil type, compactness, and water content of the upper soil layer.

2.4. High pressure spray grouting

Under high pressure, a high-speed slurry jet is sprayed out from a special nozzle at the bottom of the grouting pipe, promoting the soil particles to be cut and broken under the effects of impact, centrifugal force, and gravity. As the grouting pipe is withdrawn outward, it mixes with the slurry to form a columnar consolidation body, achieving the goal of reinforcement.

3. Small Duct Grouting

3.1. Information management Principle of Small Tube Grouting

Small tube grouting [9,10] uses a grouting pump to provide pressure, and the slurry is directly injected into the rock mass through the small hole on the small tube under the pressure of the grouting pump. Therefore, the decisive factors in grouting construction include grouting pressure, injection speed, grouting amount, and the properties of the rock mass. The effectiveness of small conduit grouting largely depends on its grouting process and the reasonable use of various grouting parameters. The grouting process and parameters used vary depending on the geological conditions and grouting objectives.

(1) The small pipe grouting technology has been widely used in underground and tunnel construction. It is suitable for advanced pre reinforcement of various weak, fractured, and fault surrounding rock formations, and can be used for complex collapse treatment in small section construction conditions;

(2) The main ways to change the mechanical properties of surrounding rock through small conduit grouting are through the reinforcement of the surrounding rock by the small conduit itself and the reinforcement of the surrounding rock with grouting slurry. The principle of anchor rod action for small conduits is mainly based on their own reinforcement principle, including connection principle, combination principle, and overall reinforcement principle. In different situations, their emphasis varies, but both functions coexist.

(3) The effect of small conduit grouting can be reflected in the following two aspects: on the one hand, changing the mechanical parameters of the rock mass to make E, C φ Value increase, μ Reduce the value and improve the self stabilization ability of the surrounding rock itself; On the other hand, the action of the slurry can serve as a water stop and consolidation. Through these two aspects, the safety of the tunnel during excavation is ensured.

(4) The selection of slurry, construction equipment, and parameters is crucial in small pipe grouting technology. Before grouting, it is necessary to select slurry, construction equipment, and reasonable construction parameters according to the actual situation

3.2. Layout and installation of small conduits

(1) Before installing the small conduit drilling, concrete

with a thickness of 5-10cm should be sprayed to seal the excavation surface and the tunnel within a 5m range.

(2) Small conduits are generally made of 32mm welded pipes or 40mm seamless steel pipes, with a length of 3-6m. The front end is made into a pointed cone shape, and the front pipe wall is drilled alternately every 10-20cm, with an eye diameter of 6-8mm.

(3) The drilling diameter should be more than 35mm larger than the pipe diameter, and the circumferential spacing should be determined according to the geological conditions, generally using 35-50cm; The external insertion angle should be controlled between 3 ° and 15 °.

(4) Double row pipes can be used when dealing with extremely fractured surrounding rock or collapse; For soft layers with abundant groundwater, multiple pipes with double or more rows can be used; When the cross-section is large or the grouting effect is poor, double row pipes can be used.

(5) After inserting the small catheter, it should be exposed for a certain length to connect the grouting pipe, and the pores around the catheter should be tightly sealed with plastic mud.

3.3. Small tube grouting

(1) The grouting equipment should have good performance, the working pressure should meet the grouting pressure requirements, and on-site test operation should be carried out.

(2) The maximum pressure at the opening of the grouting hole for small pipes should be strictly controlled within the allowable range to prevent pressure cracking and opening of the excavation surface. The grouting pressure is generally 0.5-1.0 MPa, and the grout stop plug should be able to withstand the grouting pressure. The grouting pressure is related to the geological conditions and grouting range requirements. Generally, it is required that a single pipe of grouting can diffuse to a radius range of 0.3-0.5 meters around the pipe.

(3) To control the injection volume, it can be completed when the specified injection volume has been reached in each conduit; If the pressure at the orifice has reached the specified pressure value but the injection amount is still insufficient, grouting should also be stopped.

(4) After the grouting is completed, a certain number of boreholes should be checked or the grouting effect should be checked using a sonic detector. If the requirements are not met, supplementary grouting should be carried out.

(5) After grouting, it is necessary to wait for 4 hours (cement water glass slurry) to 8 hours (cement slurry) depending on the type of slurry before excavation. The excavation length should not be too long to retain a fixed length of grout stop wall (i.e. the shortest advance amount of advance grouting)

3.4. Grouting effect testing

(1) Statistically calculate the amount of grouting. The automatic flow and pressure curves during the grouting process can be used for analysis to determine the grouting effect.

(2) Using static cone penetration testing to determine the changes in soil mechanical indicators before and after reinforcement, in order to understand the reinforcement effect.

(3) Conduct pumping tests on site to determine the permeability coefficient of the reinforced soil.

(4) Using on-site static load tests, determine the bearing capacity and deformation modulus of the reinforced soil.

(5) Measure the dynamic elastic modulus and shear modulus of reinforced soil using borehole elastic wave tests.

(6) The mechanical properties of reinforced soil are measured using dynamic probing methods such as standard penetration test or lightweight probing. This method can directly obtain the strength of the in-situ soil before and after grouting, and compare it.

(7) Conduct indoor experiments. Determine the reinforcement effect by comparing the physical and mechanical indicators of the soil before and after indoor reinforcement.

(8) Adopting γ X-ray density meter method. It belongs to a type of physical detection method, which can measure the density of soil on site to illustrate the grouting effect.

(9) Use the resistivity method. Compare the electrical resistivity measured on the soil before and after grouting, and explain the presence of slurry in the soil pores based on the difference in electrical resistivity.

Among the above methods, the indoor static penetration test is the most convenient and practical [11].

4. Numerical Simulation

Grouting engineering belongs to concealed engineering, and the actual situation of different projects varies greatly, making it difficult to accurately collect and compare data; Indoor model testing can accurately simulate the grouting situation in specific soil samples, but it requires high time and economic costs. Moreover, the soil samples used in model testing are all disturbed soil, which damages the original structure of the soil and still has significant differences from the natural state of the soil.

The numerical simulation methods used in the study of grouting mechanism and grouting laws mainly include finite element method and discrete element method. The discrete element particle flow software PFC3D is used to simulate grouting, in which the grouting material and soil are regarded as composed of several small particles. The interaction between the slurry and soil is simulated through the contact between particles, and a three-dimensional grouting micro model is established for numerical simulation. Study the influence of factors such as grouting pressure, grouting volume, and confining pressure on the diffusion of grout, analyze the changes in grout diffusion, soil stress, and porosity throughout the grouting process, and verify and improve the model grouting results.

PFC software simulates materials with different properties through particle interactions and mechanical transfer. The forces and physical changes between particles are transmitted through different contact models. By defining the contact stiffness model, sliding model, and bonding model, as well as their different model parameters, particle aggregates can exhibit different properties [12].

5. Conclusion and Outlook

The underground engineering structure has strong practicality and has been using the method of "experience design and experience construction" for a long time; It is closely related to the development of geotechnical mechanics. The stability of the surrounding rock mass in underground engineering determines the safety and normal operating conditions of the project. The geological conditions of underground engineering are complex and varied, and there are many unexpected situations that have a significant impact on ground buildings. The material properties consider the rock mass as the building material for underground structures.

The rock mass is generally heterogeneous, discontinuous, nonlinear, and has rheological properties. The design is still mainly based on empirical criteria and simulation methods. The working face is narrow, the construction period is long, and excavation is carried out in the rock mass. The surrounding rock and support jointly form the bearing body, and the stress structure is unclear. The original rock stress and boundary conditions are not clear, and the support pressure is not a fixed value, but a variable value; It is not only related to the properties of the surrounding rock, but also to the properties of the supporting structure. Calculating parameters often requires in-situ testing and experimentation.

With the continuous progress of society, underground engineering is also constantly developing. With different needs in materials, surveying, construction, monitoring, and other aspects, engineers and researchers are constantly researching and developing more practical and advanced technologies, equipment, and software systems. Continuously developing towards intelligence, informatization, greening, systematization, industrialization, and mechanization. The grouting method is gradually finding a balance between theory and practice, with a more complete theory rather than relying solely on experience for construction. From various aspects such as grouting materials, construction objects, engineering conditions, construction techniques, grouting methods, and grouting effects, the goal of strengthening or blocking water, reducing settlement or water reduction can be achieved. In the future, the grouting process will be more advanced and intelligent, and the detection methods will be more convenient and intelligent. The theory will be more complete, combining big data and computer technology for prediction, detection, and design. The small pipe grouting technology is widely used in tunnels and underground engineering, but compared to other pre reinforcement methods for strata, there is a lack of in-depth theoretical research, so the theoretical research in this area still needs to be improved; The confirmation method for grouting effect also needs to be developed and improved.

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