Study on Mechanism of Groundwater Plugging in C-S Grout

Zizheng Sun

Geotechnical and Structural Engineering Research Center, Shandong University, Jinan 250061, China

narthil_sword163.com

Abstract

In order to study the mechanism of groundwater in C-S grout, single planet fracture grouting model text under hydrostatic conditions were carried out using cement-silicate grout and polymer modified grout with different proportions. The diffusing behavior and the pressure variations in different measuring points were recorded to study the laws of hydrostatic diffusion of rapid setting cement-based grouts and the pressure distribution of grout diffusion. Results showed that cement-silicate grout and polymer modified grout are similar in diffusing behavior and variation of pressure distribution, while the diffusing pressure of the cement-silicate grout is obviously higher than cement-silicate grout polymer modified grout, which has a relatively longer condensate and solidifying time and is conducive to improve the diffusing distance.

Keywords

Rapid Setting Cement-Based Grouts; Grouting Model Test; Diffusion Behavior; Grouting Diffusion Pressure; Field Test.

1. Introduction

In the aspect of curing water damage in underground engineering, grouting is believed to be a very useful technology means due to its good applicability. after years of development, grouting technology has been widely used in engineering areas, such as water resources and hydropower engineering, highway and railway engineering, sea traffic engineering, mining engineering, for their construction and operation, which plays a significant part in the safety, environment and energy conservation in underground engineering construction. Grouting construction is achieved by the diffuse of the grout, through the pores and the fractures in stratum. Water blocking is completed on condition that grout diffuse to the boundary of the fracture and consolidate. As a result, the hydro-geological disasters are mitigated or even eliminated and the engineering conditions are improved. The process of grout diffusion is a combined effect of the grouting parameters, the property of the grout and the influence of the underground water. Consequently, underground water could be blocked only when all the parameters meet a certain condition, that is blocking criterion.

Chemical grout and cement based quick-setting grout are two kinds of mainly used quick-setting grouting materials. A proper grouting material should be chosen according to the field condition.

Chemical grout can achieve good effect under certain conditions, but the high price and toxicity limited its widely use. By contrast, cement based quick-setting grout, mainly including cement-waterglass grout and polymer modified grout, has been widely used in grouting engineering for its widely source of material, relatively low price and environmentally friendly property.

Studies on cement based quick-setting grout have mainly focused on material modification, grouting technology and grouting effect. Little work has been done about basic study, which caused an

insufficient guide to grouting construction. Many crucial parameters, such as routing pressure, diffusion radius and grouting volume could only be determined by experience.

This paper analyzed the water blocking mechanism of the quick-setting grouting material, according to the cement based quick-setting grout. Then we proposed a blocking criterion for this material.

According to theoretical analysis, model test and engineering practice, the process of grouting fracture cross section is studied and put forward the water plugging criterion, this criterion is carried out based on the mechanism of water grouting. The relationship between groundwater head loss, static pressure head and flow rate head in the process of grouting water plugging is studied. According to the interface characteristics of slurry and water, the influence mechanism of phase boundary on the cross section of slurry seal is analyzed qualitatively. It is obvious that the research on the mechanism and the criterion of the water plugging mechanism of cement based quick setting slurry in grouting engineering is of great significance to improve the accuracy of grouting parameters and grouting plugging efficiency.

2. Mechanism of plugging

The process of grouting under water-flowing conditions is essentially a special form of diffusion under a combined influence of the a variety of factors such as underground water (flow, pressure, etc.), rock media (fracture aperture, inclination, distribution, etc.), grouting parameters (grouting pressure, grouting volume and grouting materials, etc.) , which utilizes the blocking on the flow section of underground water, and changes the flow field and the excretion path of the underground water Grouting under water-flow conditions is a very complex physical and chemical process, for the reason that the grouting pressure, the underground water pressure and the viscous shear force of the grout belongs to the mechanical area and condensing and solidification of the grout under these conditions belongs to the chemical area.

Therefore, how to characterize the chemical properties by physical quantity and applying it to waterproof mechanism.

2.1 Grouting process of the cement based quick-setting material

2.1.1 Effective diffusion

During the process of water blocking, the grout diffuse in the fracture as an effect of the movement of underground water and grouting pressure. The part which is in favor of water blocking is called effective diffusion and the opposite is called ineffective diffusion, which can be divided into five sorts as follows:

(1) Parts of the grout lose on account of washing and transport of the underground water.

(2) The grout loses its condensing and solidification ability after spread into water containing and conducting structure, since it is overly diluted.

(3) The grout fails to fill all room of the water containing and conducting structure. Thus the underground water cannot be blocked thoroughly.

(4) The grout condense and solidifies quickly after diffusing into water containing and conducting structure, leading to a limited spread range and blocking effect.

(5) Even if the grout fill all room of the water containing and conducting structure, it can not remain staying in the rock and soil mass after the grouting cases.

To sum up, effective diffuse refers to a process in which the grout can fill all room of the water containing and conducting structure, condense and solidifies in the rock and soil mass while influenced by underground water, and finally complete blocking water. Effective and ineffective diffusion are not separate, but coexist in most inflowing water control process in underground engineering. Consequently, one of the main aims of this study is to improve the utilization ratio of the grout by select proper grouting materials and modifying grouting methods.

2.1.2 Grouting process under water-flowing conditions

In the study of grouting process and mechanism under water-flowing conditions, the specific reacting process needs a increasing dynamic shear force to sustain a constant shear rate when the condensing and solidifying process are characterized by a viscosity-time function. In an actual project, however, the specific reacting process shows a decrease in viscosity, when the dilution and discondensing are characterized by a modified viscosity-time function.

（1）Fluid diffusing phase

During this phase, the grout condenses and solidifies successively, with a flow-plastic property. However, the motion of the grout can still be described by Newton's hydromechanics theory and satisfy the hypothesis in hydromechanics in the grouting defusing theories. The motion rules of the grout can be studied by hydromechanics theory if the viscosity is considered as a function of time.

（2）Condensing and solidifying phase

During this phase, condensing and solidifying actions have been accumulated to a limit point, causing a phase transition of the grout: first fluid, then plastic and finally into a rigid body.

The motion rules of this phase are very complicated, since fluid, plastic body and rigid body coexist in the defusing range. In the range of flow-plastic body, the grout follows plastic fluid viscosity time-varying constitutive equation (generalized Bingham fluid equation), then it turns to follow plasticity theory after losing its fluidity and turning into plastic body and finally, it follows elasticity theory after losing its plasticity and turning into plastic body. In each phase of the grout, the corresponding forces are viscous shear force, plastic shear force and sliding friction, which play a controlling role in impeding the motion of the grout. In this study, the grout is supposed as generalized Bingham fluid. The viscous shear force and plastic shear force are only considered at a certain degree. During the plastic phase of the grout, the same constitutive equations are applied to characterize the shear stress on the unit body.

（3）High-pressure compacting phase

After the grout solidifies to plastic body and rigid body in a large range, the resistance of grouting increase greatly, marking the diffusion of grout turns to the compacting phase. During this phase, the grout takes place of the room of underground water, and grouting is completed when grouting pressure reaches the designed final pressure. During this process, injection of grout may split the solidified grout, which causes generation of new diffusion path. This phenomenon needs a further study, which is not considered in this paper.

To sum up, the motion patterns of the grout in the period of (1) and (2) play a controlling role in water plugging. In this process, the grout diffuses to edge of the cross section, solidifies into plugging body and blocks flow of underground water, so that the plug of flowing water is completed. The plugging body may be plastic, rigid or a mixture of both. The strong blocking capability restricts plugging body's flowing ability, only allowing a elastoplastic deformation. As time goes by, the amount of plugging body increases, allowing no movement in this area, so that water plugging is completed.

Additionally, in the period of (3), compacting and solidification on water containing and conducting structures is completed, the effect of water plugging is consolidated and the long-period stability of effect of engineering governance is improved greatly.

After water plugging, the hydrostatic pressure in the water containing and conducting structure will rise significantly, the osmotic pressure will increase and the volume of the grouting material will change slightly during its solidification. Therefore, it is crucial point weather the plugging body can remain stable under the pressure of the hydrostatic pressure. As a result, the importance of the third period on the final effect of water plugging is important, which determines whether secondary water inflow would happen.

2.2 Flowing-water plugging mechanism of cement-based quick-setting grout

For flowing-water plugging mechanism of cement-based quick-setting grout, the primary task of the study on is to find out the form of interaction between the grout and water, which mainly reflected in the

characteristics of the phase interface. According to the results of the study on the phase interface, the two kinds of materials in this paper(C-S grout and GT-1grout) can be divided into three parts: in the inner area of the interface, it is pure grout; in the outer area of the interface, it is pure underground water; in the vicinity of the interface, it is a mixture of both.

In this area, the interface between the water and the grout change gradually, the rule of which obeys a function of height. The grout is beneath the function line and the water is above it, since the density of grout is higher than water. The grout solidifies after injected into rock and soil mass, which impedes the mixing of the grout and water. The velocity of the underground water increases in pace with the diffusion opening causing a heavy loss of the grout near the interface, which should not be accounted in the range of the interface, leading to a decline of the retention rate of flowing water.

The diffusion and plugging mechanism of cement based materials is similar to driving-replacing mechanism, but the transition of the peak face in the phase interface is a gradual change, not a sudden change, which differs from the plugging mechanism of cement grout and polymer chemistry grout. The following part of this paper will have a comprehensive discussion on it.

Under certain hydro-geological conditions in underground engineering, the diffusion and plugging mechanism are totally determined by grouting material and technology, which are collectively referred to as grouting factors. Grouting factors can be divided into a constant and variable one, according to whether it needs to be adjusted to fit the actual working conditions. The distinction of these two factors is significant, for the variable grouting factor mainly shows a discontinuous property of the time and space during the grouting process.

When grouting rate changes, the velocity and pressure of the grout will be endued with a discontinuous property, and probably a discontinuous property of the grout volume. A change of the sort or a mix proportion of the grout will cause a discontinuous property of the viscosity. Generally, the aim of the adjustment on the grouting factor is to keep the grout staying in the rock and soil mass, in order to complete the plugging of the water containing and conducting structure. Thus, in this paper, we studied the plugging mechanism of the cement based quick-setting grout under two different conditions.

2.3 Differences and similarities in different grout plugging mechanism

(1) Cement grout

Recent studies on the plugging mechanism of cement grout includes drainage consolidation theory and flow deposit theory.

1) Drainage consolidation theory

In this theory, grout is supposed to conduct an water-losing and solidifying process similar to sandy soil, after filling the whole diffusing space. The grout particles access each other and eventually accomplish solidification. But this theory fails to illustrate how the grout consolidates in bad permeable rock fractures, which is why this theory is inadequate for hydrodynamic grouting.

2）Flow deposit theory

In this theory, the flow of the grout is assumed to decrease dramatically with the diffusion of the grout. Thus, the cement grout particles deposit gradually, causing a decrease of the cross section and finally to a blocking. Except for the water for the condensing and solidifying of the grout, the superfluous water flow away as supernatants. The foundation of this theory is based on the deposit effect of the cement particle in water. The depositing rate can be calculated according to the following formula.

Static or laminar flow, Stocks formula

$$v_c = \frac{g(\rho_R - \rho_0)d_R{}^2}{18\mu} = 54.5\frac{(\rho_R - \rho_0)}{18\mu}d_R{}^2 \quad (1)$$

Transition state, Alen formular

$$v_c = 25.8d_R\sqrt[3]{(\frac{\rho_R - \rho_0}{\rho_0})^2}\sqrt[3]{(\frac{\rho_0}{\mu})^2} \quad (2)$$

Newton-Lei Tingge formula

$$v_c = 51.1\sqrt[3]{\frac{\rho_R - \rho_0}{\rho_0}}\sqrt{d_R} \quad (3)$$

This theory can partially explain the deposit effect of cement, but fails to illustrate the fact that the depositing rate of the cement grout is only related to the different phases of the flow pattern of underground water and has nothing to do with specific velocity. According to subjects related to river sediment transportation, the underground water can form eddy current and transport sediment on river bed after changing into turbulent flow. However , the sediment carried by the water deposits only when the velocity of the flow reaches a low level, which is in contradiction with the formula.

In an actual hydrodynamic grouting, the inflow and outflow edge of water containing and conduction fractures is generally finite. In other words, the water containing structures have a certain physical dimension. Therefore, the key point of plugging underground water is whether cement grout can deposit in this area.

(2) Polymer chemistry grout

For polymer chemistry grout, studies on the grouting mechanism are mainly founded on analysis of physical and chemical properties of grout. Few works has been done to analyze the influences on the rules of movement of the grout with different physical and chemical properties. Polymer chemistry grout generally has three periods according to the variation of the reacting time: liquid period, condensing period and solid period. In these periods, grout and the underground water form a special state. The grout may form foams on phase interface, but these foams condense as cross linking action process. After tuning into solid thoroughly, the grout accomplishes the plugging of underground water in cross section depending on its own strength.

After entering water, parts of the polymer chemistry grout generates intermediate product, and then fill up the grout. In this process, grout continues to react, and finally become cross-linking solid with high density (some parts contain foams), and hence this kind of grout cannot be treated as incompressible fluid in studies.

3. Conclusion

The mechanism of cement based quick-setting grout is different from that of cement grout and polymer chemistry grout, mainly reflected in the following aspects:

1) The mechanism of cement based quick-setting grout is an incomplete grout driving-replacing mechanism (considering phase interface), while cement grout follows the particle deposit law of particle two-phase follow. Polymer chemistry grout can be considered as thoroughly driving-replacing mechanism.

2) Cement based quick-setting grout inevitably loses during water plugging, and the losing part no longer plays a role in plugging water. This is distinct significantly with chemical grout. However, in the cement grout deposit solidifying plugging mechanism, grout lose and failure of setting is not considered.

3) Cement based quick-setting grout can be considered as a liquid with time-varying physical and chemical property in studies. To some extent, polymer chemistry grout can also be described by this model. But the expansion of the grout may bring many troubles for the study. In addition, cement grout can hardly qualify this model and more appropriate to particle two-phase flow model.

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