Single Planet Fracture Grouting Model Test Research with Rapid Setting Cement-Based Grouts under Hydrostatic Conditions

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Abstract

Rapid setting cement-based grouts, cement-silicate grout and polymer modified grout, are widely used in water gushing disaster control. Single planet fracture grouting model test with different volume ratio of the grouts were carried out under hydrostatic conditions. Visual model test system were consisted by five parts, test frame, grouting system, fiber optic monitoring system, hydrostatic system and real-time video recording system. By the system, grout diffusion process was recorded, grouting pressure changes at different points were measured. Based on the analysis of test results, diffusion law under hydrostatic conditions and temporal and spatial distribution law of grouting pressure with rapid setting cements based grouts were researched. It was concluded that the two grouts, cement-silicate grout and polymer modified grout, had similar diffusion behavior and pressure distribution, but the diffusion pressure of polymer modified cement grout was obviously smaller than that of cement-silicate grout

Keywords

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

1. Introduction

With rapid growth of urban economy and concentration of population, there is urgent need to construct urban tunnel and underground projects. In the construction of underground engineering, the most common and conspicuous problem is the complicated geological environment, the tunnel often pass through water-enriched and soft stratum, which exhibit poor self stability and lower medium cementation strength.Landslides, water-inrush, and mud outburst of the stratum structure are the usual disasters induced from the action of underground water and engineering excavation [1-3], besides in field environment, it easy to cause urban pavement cracking, collapse, resulting in the underground pipeline damage and cracking in the buildings in the construction of municipal underground engineering [4-7]. However, all kinds of disasters happen to the underground engineering lead to great structure damage, even cause personnel casualties and economic loss.

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 [8-9], 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.

Chemical grout and cement based quick-setting grout are two kinds of mainly used quick-setting grouting materials[10-11]. 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.

Cement water glass slurry and polymer modified cement slurry cement quick setting slurry is typical, with the wide application of[12-17] in water plugging and rock rapid reinforcement etc.. However, due to the rapid solidification characteristics of slurry, the grouting diffusion law is more complex, and the related theoretical and experimental studies are rarely reported. In this paper, a test system of slab crack model is developed, which is used to carry out grouting diffusion test for two kinds of slurry.

2. Model Test

2.1 Model test system

The static grouting model test system is divided into 5 parts: the visual test bench, the grouting system, the optical fiber monitoring system, the static water system and the real-time video recording system.

2.1.1 Test bench

The test bed is the main body of the model test, as shown in Figure 1, the net area of the test bench is (2m * 4m), which is composed of the upper part of the fracture, the lower bottom surface and the sealing system, which is composed of three parts:

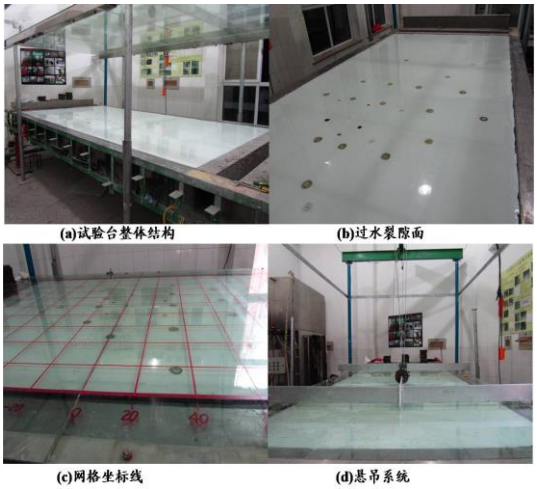

Fig.1 Visual Test-Bed

(1) The upper surface: the use of transparent toughened glass plate production, to achieve the visualization of the grouting, thickness 19mm. In order to obtain a convenient slurry diffusion trace, coordinate grid lines marked on the surface of the toughened glass plate (200mm * 200mm). Toughened glass plate with a total weight of about 0.5T, lifting hoist lifting and landing. Toughened glass surface is equipped with explosion-proof membrane, prevent the grouting pressure is too high toughened glass plate brittle fault, can withstand the maximum grouting pressure 3Mpa.

(2) The bottom surface: the main load-bearing beam, steel frame, steel plate, filling layer and the horizontal layer. The filling layer for embedding various sensors and monitoring of the original. The horizontal layer consists of 4 layers, respectively is: 1) epoxy resin mortar layer; 2) self leveling epoxy varnish layer; 3) background color layer, white color contrast, outstanding; 4) scratch resistant surface paint layer, colorless, prevent scratching in deformation test.

(3) Sealing system: rubber strip is embedded in the periphery of the test bench, and the toughened glass plate is a stainless steel clamping groove. The thickness of the dielectric layer can be adjusted by using different thickness of the slot.

The test bench has the following advantages: the visualization of grouting process is realized. The test table switch is convenient, and can be used to observe the filling diffusion after grouting. Test bench is note the thickness of the dielectric layer is adjustable, can be carried out in different gap width crack grouting simulation; simulation test can be performed with high pressure, high flow rate and high pressure grouting indoors; convenient burying various original monitoring.

2.1.2 Double liquid grouting system

Double liquid grouting system, is divided into 4 parts: grouting pumping device, power device, stirring device and slurry conveying device.

2.1.3 Monitoring system

Optical fiber monitoring system by the optical fiber pressure sensor, speed sensor, optical fiber temperature sensor and data acquisition software, see Figure 2, the embedding method is shown in figure 3.

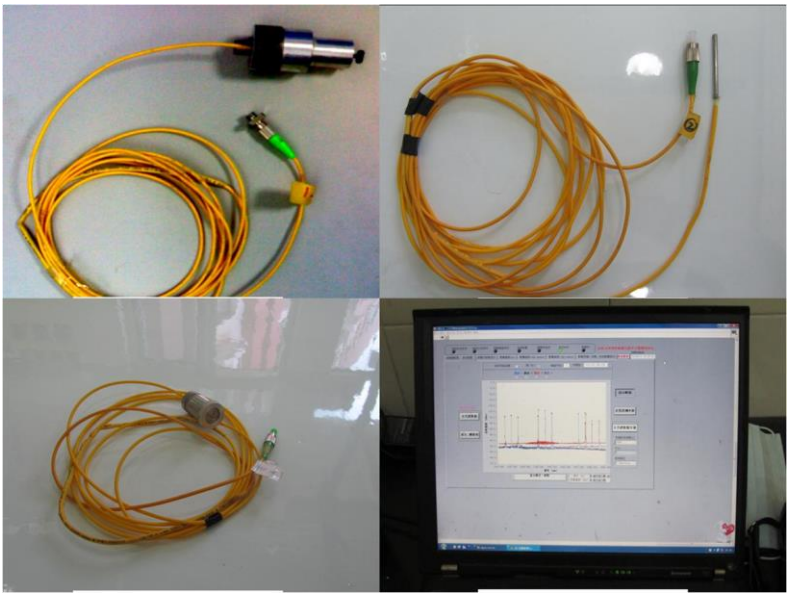

Fig. 2 KBG sensors

Due to the particularity of the grouting model test, the monitoring element must have the characteristics of high precision, sensitive change, easy to clean, water resistance and anti-jamming. According to the characteristics of grouting model test, a new type of optical fiber pressure sensor is developed. The new sensor has high measurement accuracy, good repeatability, small volume, the utility model has the advantages of good waterproof, prevent water and grout into the internal damage to the sensor element, which overcomes the traditional resistance strain gauge signal is easy to creep, susceptible to electromagnetic interference, poor sealing ability. Optical fiber grating pressure sensor is designed based on the principle of fiber grating strain sensor, when the diaphragm is subjected to uniform pressure, displacement of diaphragm center, through the special structure of the rod type diaphragm displacement into the axial strain, through monitoring the change of the center wavelength, measuring the pressure.

2.1.4 Lentic system

The water supply system consists of a water tank, pressure pump, water supply pipeline and pressure discharge device, can provide stable 0.2Kpa pressure model test of hydrostatic environment.

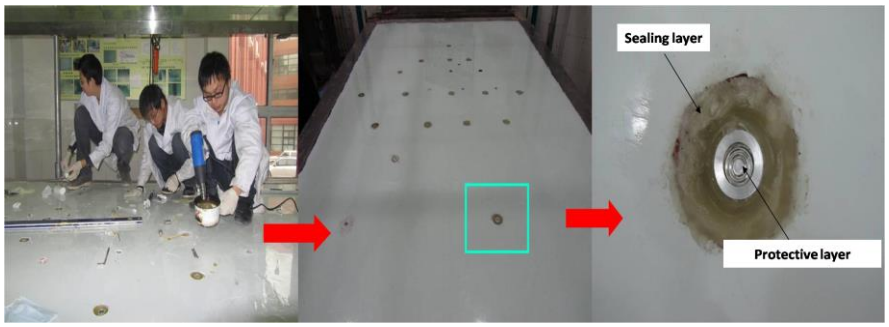

Fig.3 Installing procedure of KBG sensors

2.2 Test material

The slurry used in the test is cement water glass slurry (C-S slurry) and GT-1 slurry, in which GT-1 slurry is polymer modified slurry. The test materials involved in the test are as follows:

(1) Cement slurry

The cement used in the test is 42.5R ordinary portland cement produced by Shandong shanshui cement factory, and the quality of the cement is in accordance with the standard of Portland cement and ordinary portland cement (GB175 - 99). The test cement water cement ratio is 1:1.

(2) Water glass

Commonly used water glass, modulus M=3.0, water glass concentration of Be '=40, density of 1.38g/cm^3.

(3) Polymer modified materials

The polymer modified solution is made up of high polymer additives and a composite solution containing a quick setting agent. The polymer additives are mainly polyvinyl alcohol, ethylene glycol and sodium polyacrylate. Polymer additives are commonly used in the modification of polymers, the viscosity properties of polymer modified materials are representative. The main properties of polymer modified grouting materials can be seen as references.

2.3 Test plan

Two kinds of slurry grouting technology are used in plate and double liquid grouting test, cement slurry and slurry (by adding water glass or polymer modified slurry) mixed volume ratio (Vc:Va) of 1:1, 2:1 and 3:1, the grouting rate is 0.2m/s. In the course of the experiment, the morphology and the change of grouting pressure at different points were recorded by video recording system and monitoring system

3. Test results and analysis

3.1 Diffusion law

According to the real time video recording system in the course of grouting test, the change of grout diffusion in the condition of static water is recorded, as shown in figure 4.

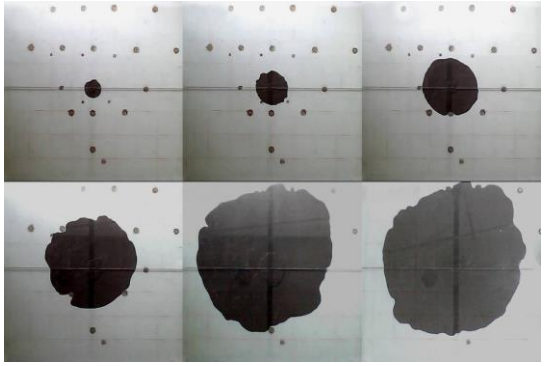

Fig. 4 Diffusion profile under hydrostatic condition

(1) By slurry diffusion grouting pressure, the hydrostatic pressure effect, fracture resistance in still water, all of these forces are symmetric in horizontal cracks in the fluid and slurry can be considered as an isotropic diffusion, so the trace slurry is circular, the center of the circle is the grouting holes.

(2) The two viscosity increased rapidly and the material has anti dispersion properties, so the diffusion process of water hydrostatic interface is clear, does not appear due to water mixed slurry dilution causes.

(3) Diffusion in the early grouting, the viscosity of the slurry is relatively small, the slurry properties of grouting slurry diffusion effect is not significant, showing good circle axisymmetric diffusion; with the passage of time, the slurry gradually thickening, viscosity and viscosity increase grouting, existing space uneven distribution, the impact on the slurry diffusion, slurry only keep the diffusion of similar round or oval.

3.2 law of pressure distribution

3.2.1 Analysis of pressure variation

When the grouting rate is constant, the hydrostatic pressure is constant 0.2Kpa, and the variation law of the pressure of the different slurry ratio with the different measuring points (measuring point 0, the measuring point of 1, the measuring point of 2, the measuring point of 3) is shown in figure 5.

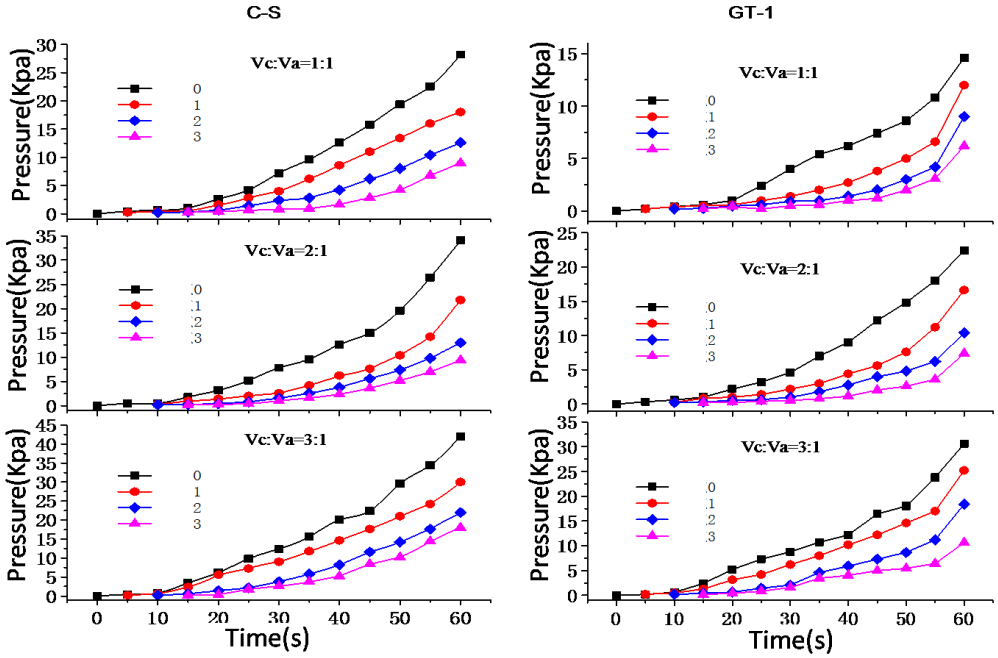

Fig. 5 Pressure -time curves of grouts under different volume ratio

Based on the experimental data:

(1) The grouting pressure increases with time, and the growth rate becomes larger.

(2) The higher the grouting pressure, the higher the grouting pressure is, the higher the grouting pressure is.

(3) The pressure of C-S slurry and GT-1 slurry at the same measuring point increases with the increase of the mixing volume ratio.

(4) At the same measuring point, under the same time and the same mixing volume ratio, the pressure of GT-1 slurry is obviously less than that of C-S slurry.

3.2.2 Analysis of grouting diffusion pressure distribution

The pressure distribution law of two kinds of slurry is obtained through the grouting pressure monitoring data, that is, the variation of grouting pressure with diffusion radius and grouting time, see Figure 6.

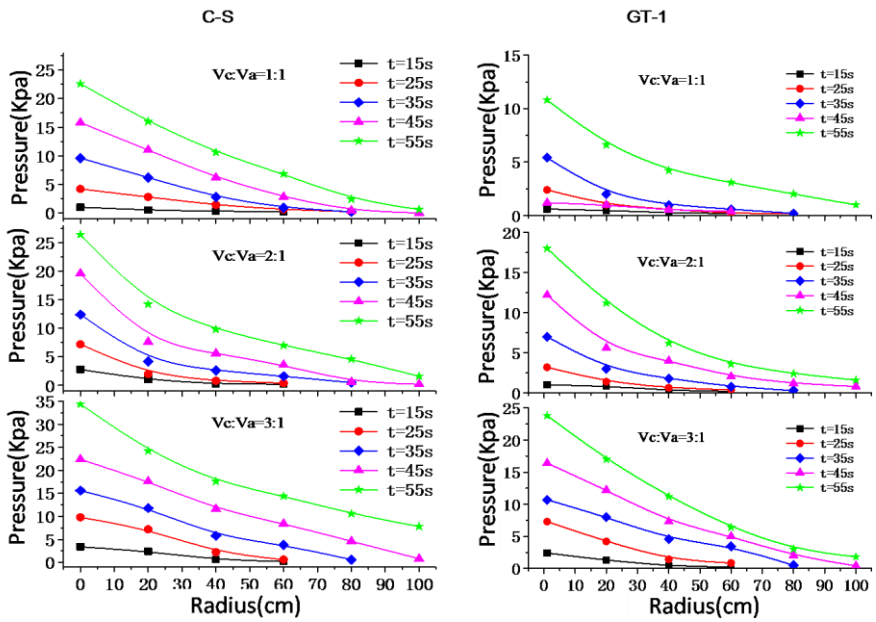

Fig. 6 Pressure curves with diffusion distance under different volume ratioAnalysis of the above data:

(1) The grouting pressure at the same time gradually decreases with the increase of the diffusion radius, and the attenuation exhibits nonlinear characteristics. Near the grouting hole area, the pressure attenuation is the most significant, and the pressure attenuation away from the grouting hole gradually slows down.

(2) In different time, the pressure increases with the increase of time, and the closer the grouting hole is, the more obvious the trend is.

(3) The variation rule of GT-1 slurry pressure distribution is similar to that of C-S slurry, and the variation of grouting pressure varies with time. GT- slurry viscosity resistance is small, the same conditions, the pressure is small; but the material initial viscosity, and the need to increase the grouting pressure; therefore the slurry pressure distribution of the initial stage is out of more complex rules. But after 30s, the pressure is generally lower than the C-S slurry.

4. Conclusion

(1) Visual model test system by visual test bench, grouting system, optical fiber monitoring system, real-time video system and hydrostatic system which can satisfy the quick setting slurry hydrostatic diffusion study demand, record the diffusion of slurry, monitoring the mixing volume ratio of different measuring points of grouting pressure.

(2) Under hydrostatic condition, two kinds of slurry diffusion of similar shape, water mixing zone diffusion boundary can be ignored. In the initial stage, the circular diffusion of the axial symmetry was observed, and the slurry performance changed significantly with the time.

(3) The variation rule of GT-1 slurry pressure distribution is similar to that of C-S slurry, and the pressure of the measuring point increases nonlinearly with the grouting time. The grouting pressure produced by GT-1 slurry is significantly smaller than that of C-S grout.

References

[1] GUAN Baoshu. Deformation of Tunnels with Soft Surrounding Rocks and its Control [J]. Tunnel Construction,2011,(01):1-17. (in Chinese)

[2] DENG Zhiyou, PENG Limin, LIU Zhengchu. Study on Progressive Failure Mechanisms of Rock Mass of Asymmetrically-loaded Tunnel under Shallow Cover[J]. Tunnel Construction, 2012,(02): 150-155. (in Chinese)

[3] SHE Linhui. Causes for Water Inflow/Bursting in Tunneling and Its Prediction Methods[J]. Tunnel Construction,2012,(02):164-168. (in Chinese)

[4] Wang Yuqin, Ji Huanjun, Yang Yongli. Practices on dynamic water grouting and sealing in coal mine [J]. Coal Science and Technolo,2007,35(2):30-33. (in Chinese)
[5] FENG Zhiqiang, KANG Hongpu, YANG Jinghe. Discussion on grouting technology for crack rock mass[J]. Coal Science and Technology,2005,33(4):63–66. (in Chinese)
[6] Zhang Xiao. Study On Mechanism Of Slurry Diffusion And Sealing At The Process Of Underground Engineering Moving Water Grouting And Its Application[D],Shandong:Shandong University,2011. (in Chinese)
[7] Zhang Xiao, Li Shucai, Zhang Qingsong, et al. Filed test of comprehensive treatment for high pressure dynamic grouting[J]. JOURNAL OF CHINA COAL SOCIETY, 2010,35(8):1314-1318. (in Chinese)
[8] RUAN Wen-jun. Spreading model of grouting in rock mass fissures based on time-dependent behavior of viscosity of cement-based grouts [J]. Chinese Journal of Rock Mechanics and Engineering, 2005,24(15): 2709−2714. (in Chinese))
[9] RUO Ping-ping, LI Zhi-ping, FAN Bo, et al. Theoretical study on flow model for tilted single fracture Binghamian grout[J]. Journal of Shandong University of Science and Technology, 2010, 29(1): 43−47. (in Chinese)
[10] Li Shucai, Zhang Xiao, Zhang Qingsong, et al. Research on mechanism of grout diffusion of dynamic grouting and plugging method in water inrush of underground engineering[J]. Chinese Journal of Rock Mechanics and Engineering,2011,30(12):2377-2396. (in Chinese)
[11] ZHANG Gai-ling, ZHAN Kai-yu, SUI Wang-hua. Experimental investigation of the impact of flow velocity on grout propagation during chemical grouting into a fracture with flowing water[J]. JOURNAL OF CHINA COAL SOCIETY, 2011,36(3): 403-406. (in Chinese)
[12] LI Hujun, WANG Qi. Journal of Functional Polymers,1999,12(3):276-280. (in Chinese)
[13] FENG Ai-li, QIN Wei-zu, WANG Zong-yu. Comparison of some kinds of wadding congeal that influence the property of non- scattering concrete[J]. Petroleum Engineering Con-struction, 2002, 28(4): 6-10. (in Chinese)
[14] Costas A. Anagnostopoulos,Laboratory study of an injected granular soil with polymer grouts[J]. Tunnelling and Underground Space Technology,20(2005):525-533.
[15] LIU Jin,ZHANG Fengjun, CHEN Xiaoming, et al. Study on the soil hardening properties and mechanism of a new water soluble polymeric soil hardening agent[J]. Materials Science and Engineering,2001, 19(4): 62–65. (in Chinese)
[16] YANG Xiaohua, YU Yonghua. Application of cement-silicate double solution grouting in loess tunnel construction[J]. China Journal of Highway and Transport, 2004, 17(2): 68–72. (in Chinese)
[17] LIU Rentai, LI Shucai, ZHANG Qingsong, et al. EXPERRIMENT AND APPLICATION RESEARCH ON A NEW TYPE OF DYNAMIC WATER GROUTING MATERIAL[J]. Chinese Journal of Rock Mechanics and Engineering, 2011, 30(7): 1454–1459. (in Chinese)