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Anti-seepage Treatment of Chemical Grouting Material in Civil Engineering

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This study intends to study the properties of chemical grouting materials in civil engineering. For this objective, a flat fracture model under the condition of dynamic water is established, and on the basis of the model, theoretical derivation and the injectivity analysis based on Fluent is made, so as to study the flow characteristics of the slurry, as a supplement to the grouting theory. The results show that the diffusion form of slurry is wide before and narrow behind, which is similar to an ellipse. Groundwater flow is large, grout diffusion area will be narrower and the slurry is more easily diluted, which is not conducive to water grouting. The greater the grouting pressure is, the greater the degree of open fracture will be, the smaller the viscosity is, and the smaller the groundwater pressure is. All of these are beneficial for the slurry diffusion. The grouting pressure is a constant. With the increase of grouting time, the flow velocity of the slurry front decreases and it is gradient. The grouting pressure at the grouting hole is the largest, and with the slurry diffusion, the slurry pressure decreases and decreases gradiently. In a word, the grouting method can well test the properties of chemical grouting materials, which has great practical value.

1. Introduction

The essence of grouting method is to make use of grouting equipment to inject some slurry into the rock and soil and so on medium. The original loose soil or fissure structure is cemented into a new "entity" with greater strength, higher impermeability and better chemical stability. In this way, it can improve the hydrogeological conditions of the engineering geology and geotechnical body, and improve the safety and economy of civil engineering.

At present, because the use of grouting method to treat part of geotechnical engineering defects and disasters is very economical and efficient, it is widely applied in roadway support and foundation pit reinforcement, building lifting and rectification, dam foundation dam seepage control, prevention and control of coal mine water inrush and other fields (Du et al., 2016; Milanović, 2015; Wu et al., 2017; Yan et al., 2016). However, the development of grouting theory, especially the theory of fracture grouting, is relatively backward, and the guidance of grouting technology is of little significance. Therefore, this research has certain engineering significance. This article, from the perspective of slurry flow law, analyses the impact of grouting pressure, slurry flow rate, groundwater velocity, slurry viscosity, aperture, groundwater pressure and other parameters on grouting rules from hydrostatic conditions and hydrodynamic conditions, which is the supplement to the grouting theory, but also has a certain reference value in the engineering field.

2. Condition of penetration of slurry in clay

2.1 Emulsified epoxy grouting material index

The common epoxy resin is a non-aqueous solvent, only dissolved in organic solvents such as aromatic hydrocarbons, ketones and alcohols, while organic solvents are not only expensive, but also volatile and pollute the environment. With the increasingly stringent environmental protection requirements, the research and development of non volatile organic compounds (VOC) or low VOC, or no harmful air pollutants (HAP) slurry system has become an inevitable research direction. As epoxy emulsion and curing technology continues to

develop, the waterborne epoxy resin was developed, which has replaced the solvent type epoxy resin in many applications (Fonollosa, et al., 2016). The research and development for designing waterborne epoxy resin grouting material suitable for treatment of cracks in hydraulic concrete structures has very important significance. The test water soluble epoxy grouting material indicators are shown as follows:
1) viscosity: 100~500mPa.s
2) gelling time: 4~8h
3) substrate bonding strength (MPa) ("8" type): more than 1.0MPa
4) compressive strength: greater than 15MPa
5) impermeability grade: greater than S15
6) toxicity: low toxicity or actually no toxicity

2.2 Condition of penetration of slurry in clay

The necessary conditions for infiltration are described as follows:
1) The slurry must be wetted and spread over the clay surface. The contact angle of the slurry to the clay surface is θ. When θ<90 degrees, it is called wetting; when θ<0 degrees, the slurry can spread on the surface of clay particles.
2) The force between the grout and the clay must be greater than the action of water and clay. In clay medium needs for grouting reinforcement, it is usually in water saturated state. On the soil particle surface, there is always a layer of water film wrapped, and the slurry, through the water layer, can be adsorbed by soil, and make further chemical adsorption or ion exchange reaction (Faramarzi, et al., 2016). In the analysis of soil adsorption of slurry, we have to consider at least three types of forces: force between soil particles and slurry material; forces between soil particles and water molecules; and forces between slurry and water molecules. The result of grout penetration is the total effect of the interaction of these three forces.
3) In order to make the slurry gives permeability of the clay the practical engineering significance, in addition to the above two conditions, it is necessary to make pretreatment of filling body, and properly close the greater fractures and pathway of slurry. At the same time, due to the presence of low permeability and high permeability of fracture or channel and the formation of a strong contrast, it must make pretreatment of filling body, decrease the permeability of the whole filling body, so as to ensure the effective permeability of soil slurry.

3. Permeability of fractured media and injectivity analysis of grouting materials

3.1 Permeability analysis of fractured media

There are two expressions for fracture permeability. One is that it is expressed by the permeability coefficient K or the permeability tensor K; the other is that it is expressed by the unit water absorption w or Lv Rong value Lu obtained by the water pressure test. The main parameters affecting the permeability of fractured media include fracture group number, fracture width, fracture spacing, fracture connectivity, fracture filling and fracture surface roughness. The main methods to analyse the permeability of fractured media are hydraulic method and geological method. The hydraulic method mainly aims at the cracks that are hidden in the underground and do not have the geological investigation condition (Achal and Kawasaki, 2016; Kumar and Singh, 2015; Zhang, 2015; Cucumo et al., 2016; Eusebi et al., 2017; Lou et al., 2016; Chen et al., 2016). The geometric parameters affecting the permeability of fractured medium are calculated by the water pressure test. Geological analysis is the method to obtain permeability parameters by measuring and making a statistic of occurrence, spacing, fracture width, roughness, density and so on of fractures with the conditions of geological survey. In the actual engineering application, it is more common to use two methods together. First of all, the geological method is used to detect some easily detected parameters, and then the parameters that are difficult to be detected are calculated by hydraulic method.
The permeability coefficient of fractured media is a physical quantity that expresses the permeability of fractured medium, which is expressed by m/s (Shelton, et al., 2015). The greater the value, the stronger the permeability, and the smaller the value, the weaker the permeability. The mathematical methods used to express permeability coefficient can be divided into the following situations.
(1) Permeability coefficient of a single fracture

Laminar flow: $K_f = \frac{v\delta^2}{12\mu} = \frac{Ag\delta^2}{12\gamma_w}$

Turbulence: $K_f = 4A\sqrt{g\delta}\,\lg(\frac{\omega}{a/d})$

In the above two formulas, δ refers to the crack opening degree;
γ_w indicates the severe liquid;

μ suggests the slurry dynamic viscosity;
A represents degree of fracture continuity;
ω is relative roughness coefficient of fracture;
a shows the absolute roughness of fracture surface;
g means gravity acceleration;
d indicates the hydraulic diameter.
(2) Continuous fracture permeability coefficient

Laminar flow: $K = \frac{\delta}{b} K_f + K_m$

Turbulence: $K' = \frac{\delta}{b} K'_f + K'_m$

In the above formulas, K is single fracture laminar flow permeability coefficient;
K_f refers to the single turbulence permeability coefficient;
K_m indicates rock permeability coefficient;
b suggests the fracture spacing.

3.2 Method for judging seepage parameter of fractured medium

According to fracture genesis and rock type, rock mass permeability coefficient and unit fracture thickness fracture rate m are determined (m=δT, T represents the rock fracture density, which indicates the number of cracks in 1m thick fractured rock stratum) (Blaheta et al., 2015), as shown in table 1. Then the fracture width is determined according to the fracture rate, permeability coefficient and fracture density.

Table 1: The relationship among genesis of fissures, coefficient of permeability and porosity

Rock	Genetic characteristics of fracture zone	Permeability coefficient	Porosity
Argillaceous rock, sandstone, crystalline shale, granite, silty rock, porphyry and other crystalline rocks	Rock forming fracture zone and metamorphic fracture	1.16×10^{-9}-1.16×10^{-6}	0.001-0.003
Argillaceous rocks, crystalline shale, siltstone, sandstone, granite, porphyry, and other crystalline rocks	The external fracture zone, including the man-made role	1.16×10^{-7}-5.8×10^{-5}	0.003-0.01
Porphyry, sandstone, quartzite, granite, hard limestone and other crystalline rocks and sedimentary rocks	Tectonic fault zone and paleo weathering crust	1.16×10^{-6}-1.16×10^{-3}	0.01-0.03
Limestone, chalk, dolomite, gypsum, anhydrite, and other salt bearing rocks and salts	The complex tectonic fracture zone and paleo weathering (dissolution, leaching) caused by Custer	1.16×10^{-4}-5.8×10^{-3}	0.01-0.03
Dolomite, chalk, gypsum, limestone, anhydrite and other salt bearing rocks and salts	Close to surface and pond	5.8×10^{-3}-5.8×10^{-2}	0.03-0.07

4. Injectivity analysis of grouting material

For grouting materials, there are two factors affecting the permeability grouting effect of fractured media, size effect and rheological effect. The size effect mainly affects the granular slurry (suspension) permeability, and the rheological effect mainly influences the permeability of slurry solution.

4.1 Size effect

The fracture grouting basically does not change the structure of rock mass medium, so the particle size of grouting material must be smaller than the fracture size of rock mass medium. That is to say, satisfying the size effect of grouting material on fracture is the premise of seepage grouting. Assuming that the particle size of grouting material is d and the crack size of bottom is D, then the premise of grout penetration to fracture is R=D/d>1, where R is the clearance ratio (Katunská and Katunský, 2015).
However, due to the influence of slurry concentration, in normal circumstances, the slurry particles often go into the fractures in the form of multi particles holding together, resulting in blocking grouting channels and affecting grouting effect. Therefore, the effect of particle clogging must be taken into account when determining the size

effect. When the clearance R>3, the structure formed by the group of particles is unstable and can be easily defeated by the grouting pressure, and the grouting channel cannot be blocked. Therefore, R=D/d>3 is usually used as the basis for designing grouting materials.

Table 2: The relationships among density of fractures, wide of cracks and coefficient of permeability

Porosity	Fracture density (1/m)							
	1-3		3-10		10-30		30-100	
	δ(m)	K(m/s)	δ(m)	K(m/s)	δ(m)	K(m/s)	δ(m)	K(m/s)
0.001-0.003	1.0×10^{-3}	1.16×10^{-6}	3.0×10^{-4}	1.16×10^{-7}	1.0×10^{-4}	5.8×10^{-8}	3.0×10^{-5}	1.16×10^{-9}
0.003-0.010	3.3×10^{-3}	5.8×10^{-5}	1.0×10^{-3}	1.16×10^{-5}	3.3×10^{-4}	5.8×10^{-7}	1.0×10^{-4}	1.16×10^{-7}
0.010-0.030	1.0×10^{-2}	1.16×10^{-3}	3.0×10^{-3}	1.16×10^{-4}	1.0×10^{-3}	1.16×10^{-5}	3.0×10^{-4}	1.16×10^{-6}
0.030-0.100	3.3×10^{-2}	5.8×10^{-2}	1.0×10^{-2}	5.8×10^{-3}	3.3×10^{-3}	5.8×10^{-4}	1.0×10^{-3}	1.16×10^{-4}

4.2 Rheological effect

The rheological property of slurry is the index of fluidity of grout under external force. The better the fluidity of the slurry, the less the pressure loss in the flow process, and the further the slurry can spread in the fracture, which is beneficial to the grouting. On the contrary, the slurry is difficult to spread and is unfavourable to grouting. The flow law of slurry in crack is similar to that of water in fissure. The difference is that the viscosity of water is low, while the viscosity of slurry is relatively large, so it is difficult to flow in fracture. The rheological properties of slurry flow in cracks depend on the structural properties of the slurry. Figure 1 shows a few of the most basic fluid rheological curves.

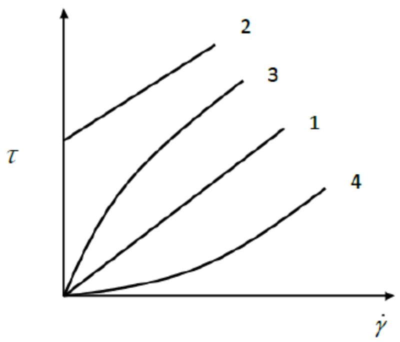

Figure 1: The rheological curve of various fluids

In Figure 1, 1 refers to the Newton fluid; 2 indicates the Bingham fluid; 3 suggests the shear thinning fluid; and 4 represents the shear thickening fluid.
The Newton fluid is a single-phase homogeneous system, water and most chemical grout belong to Newton fluid, and cement slurry with water cement ratio W/C greater than 1 also belongs to Newton fluid. Non Newton fluid is generally multiphase fluid, such as suspension. And cement slurry with mud and water cement ratio of W/C less than 1 is generally also referred to as non Newtonian fluid. The viscosity of a Newton fluid is a constant, while the viscosity of non Newton's fluid is not constant and it varies with time. We can see from Figure 1 that, the rheological curve of Newton fluid and Bingham fluid is a relatively simple line, which is also two kinds of fluids that are commonly used by grouting. For the curve represented by 3, when the shear rate increases, the apparent viscosity decreases, known as shear thinning fluid or pseudoplastic fluid, and it is manifested by shear thinning during the flow. For the fluid represented by curve 4, with the increase of shear rate, the apparent viscosity increases (the curve is convex). It is called shear thickening fluid or swelling fluid, and it is shown as shear thickening during the flow. For the slurry applied in the grouting engineering, people usually regard slurry as Newton fluid and Bingham fluid to study.
The Newton fluid is a typical viscous fluid, and its rheological curve is a straight line through the origin, as the curve 1 shown in Figure 1. Its constitutive equation is $\tau=\mu\dot{\gamma}$
τ refers to the shearing stress; $\dot{\gamma}$ indicates the shear rate or velocity gradient; μ suggests dynamic viscosity.

The Bingham fluid is the typical plastic fluid, and its rheological curve is a straight line not through the origin, as the curve 2 shown in Figure. Its constitutive equation is: $\tau_0=\mu\dot{\gamma}$

4.3 Slurry viscosity

Slurry viscosity is the main parameter affecting the rheological properties of slurry. Since the viscosity of ordinary pulps varies little with time, the viscosity of slurries is often considered a constant in engineering applications. However, the viscosity of the slurry changes with time. Zhao Ziliang tested the viscosity of the pure cement slurry at different times in different water cement ratios:

Table 3: The changes of slurry viscosity with time going on

Water cement ratio	0min	10min	20min	30min	40min
0.7:1	23.0	23.0	25.2	27.2	29.4
1:1	18.5	19.2	20.9	23.0	24.8
1.5:1	16.6	17.3	18.8	20.0	21.5
2:1	16.0	16.4	17.1	18.1	19.5

Notice: Each time the viscosity is tested three times to take the average, and the unit is s.

According to the data in the column of 0min, the viscosity of slurry varies with the change of water cement ratio, and the bigger the water cement ratio is, the thinner the slurry is and the smaller the viscosity is. From the data of the water cement ratio 0.7:1, the viscosity of the slurry increases with the increase of time. From the overall data, the change rate of slurry viscosity decreases with the increase of water cement ratio.

5. Conclusions

Basic research on the flow pattern under the condition of moving water is carried out and the major achievements are:

(1) The permeability of fractured media and the injectivity of grouting materials are further expounded and analysed.

(2) The variation law of slurry velocity in grouting process is systematically analysed. At the grouting hole, the upstream side slurry flow rate is less than the downstream side flow rate. The grouting pressure is certain, with the extension of time, grouting hole slurry velocity decreases, and the corresponding slurry front decreases gradiently.

(3) The greater the grouting pressure, the more conducive to the spread of slurry, especially helpful for the diffusion of slurry to the upstream direction

(4) The aperture size plays an important role in the grouting difficulty. Because under hydrostatic condition, the pressure is inversely proportional to the square of the fracture opening degree, under the hydrodynamic condition, it is just to add additional conditions based on this law. However, the natural fracture aperture is usually a fixed value that it is difficult to change. But some cracks in the surrounding rock are soft rock engineering, and they will be affected by the grouting pressure and further expanded. In this condition, we can improve the grouting pressure to expand the fractures to improve the grouting efficiency.

Reference

Achal V. and Kawasaki S., 2016. Biogrout: A Novel Binding Material for Soil Improvement and Concrete Repair. Frontiers in microbiology, 7.

Blaheta R., Kohut R., Kolcun A., Souček K., Staš L. Vavro L., 2015. Digital image based numerical micromechanics of geocomposites with application to chemical grouting. International Journal of Rock Mechanics and Mining Sciences, 77, 77-88.

Chen J.D., Wang Z.Q., Tian F.G., 2016, A new hydraulic variable valve timing and lift system for spark ignition engine, Chemical Engineering Transactions, 51, 1249-1254, DOI: 10.3303/CET1651209

Cucumo M., Ferraro V., Kaliakatsos D., Mele M., Galloro A., Schimio R., Le Pera G., 2016, Thermohydraulic analysis of a shell-and-tube “helical baffles” heat exchanger, International Journal of Heat and Technology, 34(S2), S255-S262, DOI: 10.18280/ijht.34Sp0210

Du J., Shen X.G., Feng G.J., Zhu W.W., Xu C.F., 2016, Hydration mechanism of fly ash cement and grouting simulation experiment, Chemical Engineering Transactions, 51, 565-570, DOI: 10.3303/CET1651095

Eusebi A.L., Spinelli M., Cingolani D., Dal Pan M., Fatone F., Battistoni P., 2017, Tertiary filtration with rotating discs for effluent from urban or industrial wastewater treatment plants: hydraulic study and granulometric distribution influence, Chemical Engineering Transactions, 57, 253-258, DOI: 10.3303/CET1757043

Faramarzi L., Rasti A. Abtahi S.M., 2016. An experimental study of the effect of cement and chemical grouting on the improvement of the mechanical and hydraulic properties of alluvial formations. Construction and Building Materials, 126, pp.32-43.

Fonollosa J., Solórzano A., Jiménez-Soto J.M., Oller-Moreno S. Marco S., 2016. Smart Chemical System for Reliable Fire Detection. Procedia Engineering, 168, 444-447.

Katunská J. Katunský D., 2015. Application of Chemical Grouting as an Option of Removing Soil Moisture-a Case Study in the Reconstruction of the Church. Selected Scientific Papers-Journal of Civil Engineering, 10(2), 93-102.

Kumar B., Singh S.N., 2015, Analytical studies on the hydraulic performance of chevron type plate heat exchanger, International Journal of Heat and Technology, Vol. 33, No. 1, pp.17-24. DOI: 10.18280/ijht.330103

Lou Y., Shen J.Q., Yuan S.Y., 2016, Design and application of hydraulic engineering destroy risk avoidance path system based on arcgis engine, Chemical Engineering Transactions, 51, 1003-1008, DOI: 10.3303/CET1651168

Milanović P., 2015. Catalog of engineering works in karst and their effects. In Karst Aquifers—Characterization and Engineering (pp. 361-399). Springer International Publishing.

Shelton J.W., Sadowsky E., Rigby D., Fleetwood P., Peigler J., Hepler W., Hemphill J., Brown J. Anctil M., 2015. When Engineers, Contractors, and Manufacturers Collaborate–Improvements in Chemical Grouting Practices from the Sullivan's Island Construction Management at Risk Project. Proceedings of the Water Environment Federation, 2015(15), 5236-5247.

Wu J.S., Fu M., Tong X., Qin Y.P., 2017, Heat stress evaluation at the working face in hot coal mines using an improved thermophysiological model, International Journal of Heat and Technology, 35(1),67-74, DOI: 10.18280/ijht.350109

Yan Y., Li J., Yue J.H., Zhao L., 2016, Study on pca-lda for fast identifying the type of coal mine water with lif technology, Chemical Engineering Transactions, 51, 1135-1140, DOI: 10.3303/CET1651190

Zhang X.Q., 2015, Hydraulic characteristics of rotational flow shaft spillway, International Journal of Heat and Technology, 33(1), 167-174, DOI: 10.18280/ijht.330123