A Study on the Diffusion Radius of Sand Layer Grouting Based on Fractal Theory

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Abstract. This article focuses on the problem of excessive diffusion range of grouting body encountered in engineering projects, and analyzes in detail the possible influencing factors. Based on fractal theory, the filling coefficient and diffusion mechanism of grouting body in sandy soil layer are analyzed from a microscopic perspective, as well as their influencing factors and causes. Based on the diffusion mechanism, targeted solutions have been proposed, effectively saving costs.

Keywords: Grouting, Fractal Theory, range, mechanism of diffusion.

1 Introduction

Grouting is the preparation of a certain material into a slurry, which is drilled through pressure equipment and injected into the gaps of particles in the formation, the interface of the soil layer or the cracks of the rock layer for diffusion, solidification, and solidification, in order to achieve the goal of strengthening the formation or preventing leakage. With the deepening of the "the Belt and Road" construction and the rapid development of China's economy, large-scale high-rise buildings, water conservancy and hydropower, deep mine, urban subway and other projects have been started. The sand layer of the aquifer is a poor layer that is often exposed during construction of such projects. The structure of the water-bearing sand layer is loose, with poor self-stability. Construction disturbance is prone to disasters such as collapse, water burst, sand blasting, and surface collapse, often causing serious casualties and economic losses. Grouting technology involves disciplines such as chemistry, fluid mechanics, engineering geology, hydrogeology, and geotechnical mechanics, and is closely related to hydraulic electronic technology. It is mainly used to reduce the permeability of rocks and soil, increase their strength, or reduce the deformation of the foundation. In recent years, it has also been used to repair concrete cracks. Practice has shown that grouting can significantly improve the mechanical strength and impermeability of sand layers, and grouting technology has become an effective way to reinforce and treat aquifers. In grouting engineering, it is common to encounter sandy soil layers, gravel soil, and other formations with high porosity and good permeability that are rich in water. In these

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strata, the grouting slurry mainly penetrates and diffuses, and the groundwater flow rate has a significant impact on the slurry diffusion. Portland cement is the most widely used and widely used grouting material, but cement slurry is atypical granular slurry. At present, domestic and foreign experts and scholars have conducted in-depth the theoretical analysis and systematic experimental research on porous media infiltration grouting. Eriksson et al. [1] proposed the percolation effect of the injected medium on the slurry during the slurry diffusion process based on a mesh model of slurry diffusion; Chupin et al. [2] studied the one-dimensional grouting diffusion of cement-based grouting material 926 geotechnical mechanics in sandy soil in 2017 through indoor experiments and finite element numerical simulation, demonstrating that the infiltration effect of sandy soil has a significant impact on the diffusion of cement-based slurry; Bouchelaghem et al. [3] conducted infiltration grouting simulation on deformable saturated porous media, using a model that takes into account the deformation of the solid particle skeleton, the migration of the slurry, and the dilution and filtration of the slurry during the migration process; Saada et al. [4] conducted penetration grouting tests using cement suspension and proposed a theoretical model that considers the infiltration effect of sandy granular media; Fang Kai et al. [6] proposed a cement slurry diffusion model under spherical pore diffusion conditions based on summarizing the standards for grout injectability. Chen Xingxin et al. [5] revealed the coupling mechanism between suspended particle size and hydrodynamic forces on the migration characteristics of suspended particles in saturated porous media through indoor soil column experiments. Kim et al. [7] considered the time-varying viscosity of the slurry and the changes in porosity of the porous medium, and concluded that the filtration amount of the slurry depends on the cement particle size, concentration, and porous medium particle size. Herzig et al. [8] studied the filtration deposition mechanism of slurry particles in porous media based on mass conservation equations, similarity criteria, and dynamic equations, and obtained the filtration coefficient under certain conditions. Existing research has mostly promoted the development of infiltration grouting theory from the perspective of the filtration mechanism of slurry particles in porous media, while research on the migration and diffusion changes of water slurry under infiltration effect is even rarer. Therefore, this article conducted a constant pressure infiltration grouting experiment in sandy soil media, systematically revealing the sealing mechanism and migration rules of water slurry under infiltration effect The research conclusion not only promotes the development of infiltration grouting theory, but also has high engineering application value. Due to the complex properties of slurry and injected rock and soil media, there is currently no very complete mathematical model for dynamic water grouting, and theoretical research still lags behind engineering practice. Grouting design mainly relies on engineering experience. Due to the complexity of slurry diffusion laws, the naturalness of sand layer structures, and the diversity of construction techniques, existing research still cannot fully meet the needs of engineer in construction. Therefore, this paper conducts a study on the diffusion radius of sand grouting based on fractal theory.

2 Project Overview

The building of this project mainly consists of 7 high-rise buildings (building numbers 8-13), 1commercial building (building numbers 20), an auxiliary podium, and a pure basement. The site is equipped with an overall basement, with an excavation depth of approximately 3.4-4.8m below the ground level. The proposed building structure type is shear wall structure and frame structure, and the proposed foundation type is pile raft foundation The foundation of this project adopts drilled cast-in-place piles, and the static load test results of engineering piles indicate that the vertical ultimate bearing capacity of some single piles does not meet the design requirements, so it is necessary to reinforce the foundation

3 Site issues and cause analysis

Through daily construction record statistics and calculations, the daily grouting volume of this project greatly exceeds the expectations of the project department, in order to prevent high costs and the impact of the injected slurry on the surrounding strata and even buildings. It is necessary to identify and solve the reasons for the excessive grouting volume. Generally speaking, the main reasons for excessive grouting volume are local formation leakage and human construction factors. Conventional grouting volume abnormalities are most likely caused by local formation collapse during the drilling process, increasing the amount of grouting. However, excessive filling coefficient caused by human factors often occurs in individual holes, and there is rarely a large area of abnormal grouting volume. So it can be judged that the overall grouting volume is relatively large due to geological reasons. Due to the unclear diffusion mechanism of slurry in sandy soil, in order to solve this problem, fractal theory is used to study the diffusion mechanism of pipe slurry in sandy soil.

4 Research on the diffusion of grouting body in sandy soil

4.1 Research on Sand Permeability Based on Fractal Dimension

Due to the compliance of on-site construction personnel and initial grouting pressure with specifications, and without considering the influence of human factors, the diffusion of grouting in sandy soil largely depends on its pores and permeability. Therefore, by studying the relationship between the pore structure and permeability of sandy soil, the influencing factors of the diffusion radius of grouting are identified. The initial setting time of cement slurry is relatively long, and the time it takes to reach the finals table diffusion state during the dynamic water infiltration grouting process is less than the initial setting time. Moreover, the viscosity of cement slurry remains basically unchanged before the initial setting, and can be regarded as a Newtonian fluid. The flow of cement slurry and water in these formations conforms to the applicable conditions of Darcy's law, and the two-phase seepage theory based on Darcy's law can be applied to describe the infiltration and diffusion process of cement slurry under dynamic water conditions. The final stable diffusion state of the slurry can be described through steady-state calculation results. [9]

The diffusion of cement slurry in the formation refers to the flow of viscous fluids formed by cement particles and water in porous media. According to the concept and application fields of porous media, research on porous media has the following characteristics:

1) Complex structure with strong randomness. According to the definition, it can also be found that the structure of porous media is extremely complex and not necessarily. The law of pore size is often very small, and traditional methods and conventional instruments are almost unable to directly analyze porous media Research. [10]

2) It involves multiple research fields. From the perspective of application scope, heat and mass transfer, fluid mechanics, seepage theory, and expansion Scattering theory and other disciplines will appear in the study of porous media theory, and in many cases, multiple phenomena work together, It has many interdisciplinary characteristics, which increase the difficulty of research. 3) Even though research on porous media involves a wide range, However, theoretical research on porous media varies in different fields. The permeability of porous media is usually obtained by empirical or semi empirical formulas, resulting in significant errors and affecting Most disordered porous media are not suitable. At present, people are gradually deepening their research on the structure of porous media, especially the pore structure The study of the structure found that the pore structure of most porous media (such as activated carbon, gravel) has Statistical uniformity, pore size and quantity distribution exhibit power-law function characteristics, so fractal geometry is used to outline porous media The characteristics of porous structure are more applicable, and fractal geometry provides practical prediction and theoretical research for the permeability of such porous media Provided different research methods and ideas. Due to the use of fractal theory to calculate the permeability of porous media, which involves the cross-sectional area of porous media flow, and the irregularity of the porous media structure, it is difficult to calculate the cross-sectional area of fluid flow in porous media. Therefore, we believe that when cement slurry flows in pipelines, the bending of the porous pipeline will reduce its flow velocity. Therefore, the bending of the porous pipeline is an important factor affecting permeability, So the fractal dimension of pore tortuosity is used to describe the degree of curvature of porous pipelines. When the pores are not bent, it is considered that the fluid permeability pipeline is a straight line, which is a one-dimensional state. As the degree of curvature of the pores increases, the fractal dimension of the pores also increases. Finally, the curvature of the pores will fill the entire space, and the fluid channel will change from a one-dimensional line to a two-dimensional plane state

The relationship between pore fractal dimension and pore permeability is

$$K = \frac{\mu L0Q}{\Delta pA0} = \frac{\pi}{128}\frac{A}{A0}\frac{D}{3+DT-D}L_0 - D_T\lambda_{max}^{3+DT-D} \quad (1)[5]$$

We can draw the following conclusion from the above equation:

The permeability of sand is directly proportional to its fractal dimension, directly proportional to its maximum pore size, and inversely proportional to its pore bending fractal dimension.

Next, we will analyze the microstructure of the sandy soil. Based on the definition of the box dimension and the boxes counting process, the contour image into 500x500 pixels The grid with images is 1, and without images is 0. Firstly, using 8x8 cells as the basic unit thirty-one The box counting method calculates the total amount of images by continuously reducing the grid size and recording the presence of The sum of the image parts and the length of the box, resulting in a series of information about the length of the box and the presence of the image The points related to the total number of boxes are simulated to obtain an approximate straight line with a slope of Calculate the fractal dimension D of the pore structure that we need to obtain. [11]

4.2 Research on the diffusion range of grouting body in sandy soil

Firstly, by simplifying the seepage channel into a tortuous pore, we can assume that the flow mode of the grouting body in the formation is single-phase horizontal flow, and the seepage direction remains vertical, resulting in radial leakage. We do not consider the volume and temperature changes of the grouting body during the movement process. At this time, we can simplify the flow of the grouting body into a Bingham model under the influence of the initial grouting pressure[12]

His general form is:

$$\left(1-\frac{4}{3}\lambda H+\frac{1}{3}\lambda^4 H^4\right)\nabla^2 p-\frac{4}{3}(\lambda+\lambda^4 H^3)\nabla H\cdot\nabla p=\frac{\varphi u c_1}{K}\frac{qp}{dt} \tag{2}$$

Where ϕ is the porosity of porous media; K is the permeability of porous media; $u$is the dynamic viscosity of the Bingham fluid

At this point, based on the equation, we can see that the diffusion radius of the slurry is inversely proportional to its dynamic viscosity and directly proportional to its permeability. According to our conclusion in the previous section, it can be seen that its permeability is inversely proportional to its pore tortuosity fractal dimension. As the grouting body is configured according to a unified standard, its influencing factor is its pore tortuosity fractal dimension.

Through the verification of excavation results, it can be seen that the theoretical grouting diffusion radius is basically consistent with the actual grouting diffusion radius (see Figure 1 for comparison between the actual and theoretical values of grouting diffusion radius)

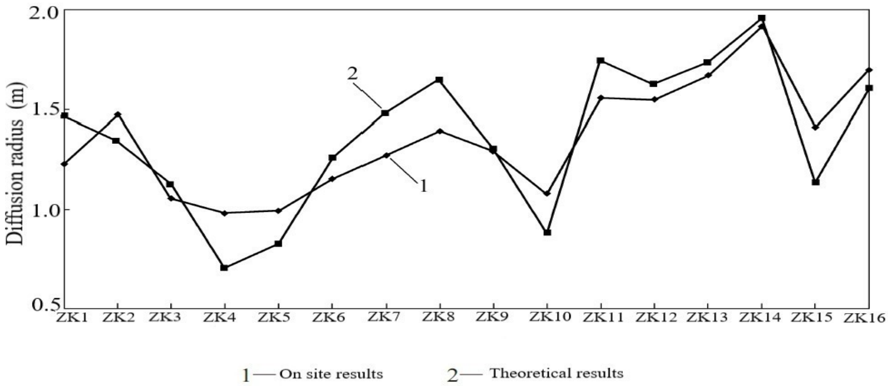

Fig. 1. between the actual and theoretical values of grouting diffusion radius.

5 Control measures for excessive diffusion range of slurry

Based on previous theoretical derivation and experimental verification, it can be seen that the main reason for the excessive diffusion radius of the grouting body in this case is the large fractal dimension of its own pore tortuosity. Therefore, we need to change other influencing factors of the grouting body to solve the problem of the formation in a targeted manner. [13] Therefore, the following suggestions for handling measures are made:

1. Due to the fact that the permeability range of the grouting body in sandy soil is related to its initial grouting pressure, increasing the initial pressure will increase the permeability range of the grouting body, but at the same time, it is necessary to ensure the grouting effect of the grouting body. Therefore, conducting grouting permeability tests in advance and selecting appropriate initial grouting pressure are the core methods to solve this problem. [14]

2.Due to the fact that the permeability range of grouting material in sandy soil is related to the dynamic viscosity of the slurry, the diffusion range will correspondingly decrease when it dynamic viscosity is high. Therefore, increasing the density of bentonite slurry can increase it viscosity or using organic polymer bentonite composite slurry. It can also increase the dynamic viscosity of the slurry and reduce the diffusion range of the grouting material. After using the above methods, the subsequent slurry consumption and diffusion radius of this project were effectively reduced (see Figure 2 for the comparison of diffusion radius after excavation and before excavation).

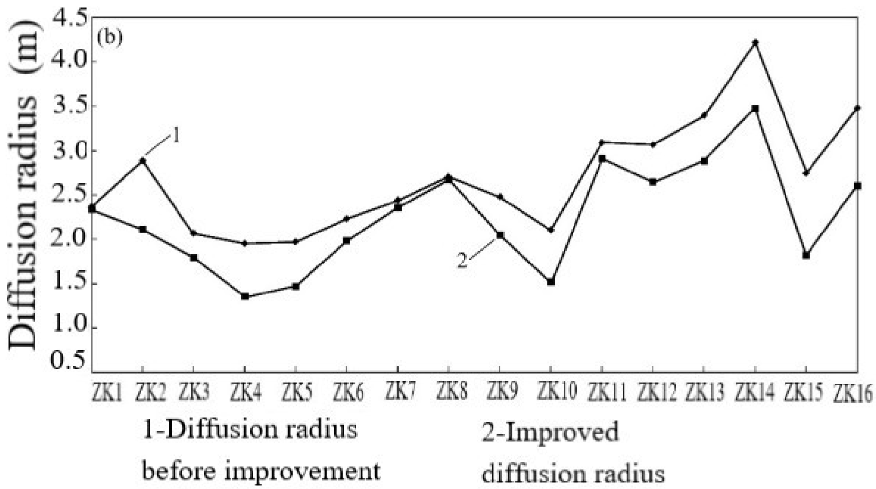

Fig. 2. the comparison of diffusion radius after excavation and before excavation

6 Subsequent grouting effect testing

Throughout the entire construction process, settlement observation is maintained at all times, and regular observation is carried out from the beginning of the project to the end of foundation reinforcement, and then until the completion of the project. After reinforcement, the horizon deformation of the surrounding retaining structure and piles of the foundation pit is significantly reduced, and the soil layer under the piles is compacted, reducing the unbalanced horizontal force generated by the excavation of the foundation pit on the piles. From the measured pile settlement around the foundation pit, it can be seen that grouting reinforcement effectively controls the settlement of the pile foundation and surrounding ground, ensures the normal passage of vehicles and pedestrians around the deep foundation pit, and also reduces the risks brought by the deep foundation pit project. Both evaluations have achieved the effect of grouting reinforcement. All have met the design requirements for the foundation treatment of the project, successfully saving funds and shortening the construction period for this project.

7 Conclusion

This article provides a detailed analysis of the possible influencing factors of the large diffusion range of slurry encountered in engineering. Based on fractal theory, from a microscopic perspective, the box dimension of sand was determined, and the relationship between dimension and permeability coefficient, as well as the relationship between permeability coefficient and grouting diffusion radius, was derived. The filling coefficient and diffusion mechanism of grouting in sand layers were analyzed, as well as their influencing factors and reasons. Based on the diffusion mechanism, targeted solutions have been proposed, playing an important role in ensuring the economic benefits of the project during the later grouting construction.

References

1. ERIKSSON M, STILLE H, ANDERSSON J. Numerical calculations for prediction of grout Spreader with account for filtration and varying aperture[J]. Tunnelling and Underground Space Technology, 2000, 15(4): 353-364.
2. CHUPIN O, SAIYOURI N, HICHER P Y. The effects of filtration on the injection of cement-based grouts in sand columns[J]. Transport in Porous Media, 2008, 72(2): 227-240.
3. BOUCHELAGHEM F, VULLIET L, LEROY D, et al. Real-scale miscible grout injection experimental performance of advection-dispersion-filtration model[J]. International Journal for Numerical and Analytical Methods in Geomechanics, 2001, 25: 1149-1173.
4. SAADA Z, CANOU J, DORMIEUX L, et al. Modeling of cement suspension flow in granular porous media[J]. International Journal for Numerical and Analytical Methods in Geomechanics, 2005, 9: 691-711.
5. CHEN Xing-xin, BAI Bing, YU Tao, et al. Couple deffects of particle size and flow rate on characteristics of particle transportation and deposition in porous media[J]. Chinese Journal of Rock Mechanics and Engineering, 2013, 32(Supp.1): 2840-2845.
6. ANG Kai, XIA Tang-dai, BAO Liu-qing, et al. Cement grout dispersion considering filtration in gravel[J]. Chinese Journal of Rock Mechanics and Engineering, YueweiBian, Xiaolong Zhang, Jia Yuan, et al Research on the Micro Mechanism of Sand Grouting Based on CFD-DEM Method [J] Modern Tunnel Technology, 2020,57 (z1): 528-534.
7. KIM J S, LEE I M, JANG J H. Grouting of cement-based grout with consideration of viscosity and filtration phenomenon[J]. International Journal for Numerical and Analytical Methods in Geomechanics, 2009, 33(16): 1771-1797.
8. MITCHELL J K. Soil improvement-State of the art[C] Proceedings of the 10th International Conference on Soil Mechanics and Foundation Engineering. [S. l.]: A. A. Balkema, 1981, (4): 509-565
9. Zhixiong Lin, Bin Zheng Experimental Study on the Effective Diffusion Range Model of Sand Soil Grouting [J] Journal of Heze University, 2019, 41 (2): 44-47.
10. Pengfei Qin Research on the mechanism of sand splitting grouting based on the coupling effect of "slurry soil" [J] Laboratory Research and Exploration, 2022,41 (12): 14-18.
11. Cancer Research UK. (1975) Cancer statistics reports for UK. http://www.cancerreseark.org/aboutcancer/statistics.
12. Rongjun Ding Study on permeability of gravelly soil based on fractal theory [D] Kunming: Kunming University of Science and Technology, 2018.
13. Sun Hongwei Research on the diffusion law of slurry in railway grouting engineering [J] Railway Construction, 2022, 62 (6): 138-142
14. Pengfe Qin, Yan, Zhong Hongwei, et al Research on the Mechanism of Sand Grouting Reinforcement Based on Infiltration Effect [J] Metal Mines, 2022 (4): 208-213.