Research on Permeability Characteristics of Waterproof Curtain Slurry for Foundation pit in Saturated Sand

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Abstract. For the construction of a waterproof curtain in saturated and highly permeable sand, conventional slurry often fails to form a filter cake and instead penetrates through the sand, leading to a loss of impermeability at the working face and posing a risk of instability. This study, based on a self-designed 3D variable cross-section slurry permeation column test system, aims to investigate the mechanism of filter cake formation during slurry permeation. The results reveal distinct permeation patterns in the sand as the viscosity coefficient of the slurry increases, including the permeation zone type, filter cake - permeation zone type, and filter cake type. Low-viscosity slurry samples fail to develop a filter cake, resulting in the majority of slurry pressure acting on the sand layer, which is detrimental to both seepage prevention and face support. Conversely, high-viscosity slurry samples form a dense filter cake. The increase in slurry viscosity promotes stronger interactions between slurry particles and sand particles, leading to the formation of a denser filter cake with accelerated development. The increase in slurry viscosity promotes stronger interactions between slurry particles and sand particles, leading to the formation of a denser filter cake with accelerated development.

Keywords: slurry permeation; permeation patterns; formation mechanism of filter cake

1 INTRODUCTION

During the excavation process of a foundation pit, it is common practice to construct a waterproof curtain as a measure to control groundwater, preventing its ingress into the pit and ensuring smooth construction progress. The main principle involves drilling holes around the pit during excavation and injecting waterproofing materials into these

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holes to form a sealed curtain, effectively impeding groundwater infiltration. Typically, materials such as cement slurry, polymers, bentonite, or other waterproofing agents are utilized for constructing this curtain, thereby mitigating the impact of groundwater on the foundation pit [1,2].

In low-permeability formations such as clay or silty clay, characterized by small pore sizes, slurry tends to form a filter cake within the grouting area, thereby preventing water infiltration from the surrounding areas. However, high-permeability formations such as fine sand or gravelly sand, slurry readily penetrates the formation and seeps out directly, resulting in a significant loss of slurry and a sharp decrease in impermeability [3]. Addressing how to formulate slurry based on the properties and particle size distribution of the formation is crucial to achieving the formation of a high-quality filter cake within the grouting area. Various self-designed slurry infiltration devices are utilized for conducting slurry filtering tests, evaluating the effect of slurry on forming filter cakes based on parameters such as filtration loss [4], pore water pressure [5-6], or characteristics of filter cake [6]. The impact of slurry composition and ratio on the filtration law of slurry is investigated.

The current permeation column devices, predominantly hollow cylinders with uniform cross-sections positioned vertically on the ground, exhibit differences from the actual 3D variable cross-section permeation behavior of slurry in engineering scenarios. This study utilized a self-designed 3D variable cross-section slurry permeation column test system to conduct permeation tests on bentonite slurry with varying rheological properties in high-permeability sand layers. The investigation focused on the filter cake characteristics during the 3D slurry permeation process, aiming to elucidate the permeation characteristics of saturated sand layer slurry and the formation laws of filter cake, providing reference for the design and construction of cutoff walls in saturated sand layers.

2 MATERIALS AND METHODS

2.1 Variable Cross-section Slurry Permeation Column Test System

A self-designed variable cross-section slurry permeation column test system was developed, as illustrated in Fig. 1. This system primarily comprises a variable cross-section permeation column, a pressure system, a slurry storage tank, a real-time filtration loss monitoring system, and a data acquisition system. The permeation column, comprising upper and lower cylinders (10 cm and 15 cm diameter, 30 cm height), features grouting inlets and air valves for ventilation. The pressure system, with an air compressor and stabilizer, regulates air pressure for slurry injection, ensuring stability. A slurry storage tank, connected to the compressor via a grouting pipe, stores slurry. Integrated with the monitoring system, the data acquisition system enables real-time recording of key parameters for accurate data collection.

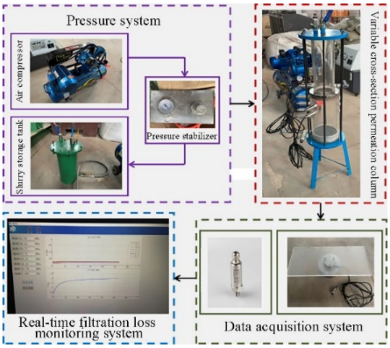

Fig. 1. Schematic diagram of the variable cross-section slurry permeation column test system. (Captured by the author)

Sand was compacted in layers to fill the lower cylinder. After saturating the sand layer and confirming air tightness, slurry was injected into the upper cylinder for pressurized permeation. Data analysis included observing filter cake characteristics and analyzing parameter variations.

2.2 Slurry Materials

The experimental bentonite slurry contains sodium-based bentonite, Sodium carboxymethyl cellulose (CMC), and water. Three slurry sets (NS-1, NS-2, and NS-3) were prepared with a constant 12% bentonite content. The CMC content varied at 0%, 0.1%, and 0.3%.

3 TEST RESULTS AND ANALYSIS

3.1 3D Permeation Characteristics of Pure Bentonite Slurry

Fig. 2 illustrates the permeation form and deposition type of NS-1 slurry in the saturated sand layer after the permeation test. Under pressure, the slurry rapidly and continuously permeated into the saturated sand layer, accompanied by the generation of a large amount of turbid filtrate. When the permeation time reached 40 s, all the slurry in the slurry tank was completely lost, and the slurry permeated through the entire sand layer, marking the conclusion of the permeation test. During the permeation process of the NS-1 slurry, the solid particles in the slurry did not completely settle to block the pores of the sand layer, allowing the slurry to continuously permeate into the sand layer. Therefore, no filter cake formed on the surface of the sand layer, indicating a permeation pattern characterized by a fully permeable zone without a filter cake.

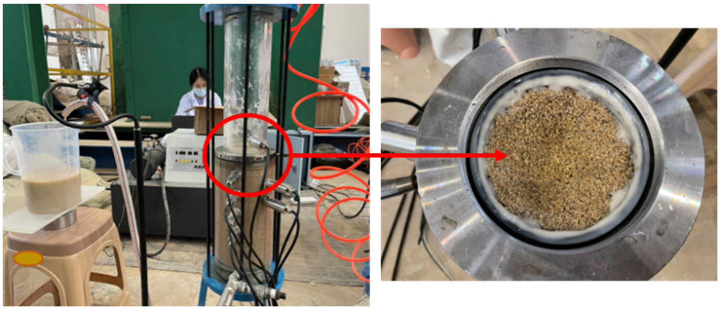

Fig. 2. Permeation form and deposition type of NS-1 slurry. (Captured by the author)

3.2 3D Permeation Characteristics of Slurry with 0.1% CMC Content

The permeation form and deposition type of NS-2 slurry in the saturated sand layer are shown in Fig. 3. Under pressure, the slurry level gradually decreases in the slurry tank. After 110 seconds of permeation, the slurry level stabilizes, maintaining a distance of 10 cm from the surface of the sand layer. The penetration distance of the slurry in the saturated sand layer is approximately 15 cm. This indicates that the slurry particles partially block the pores of the shallow sand layer to some extent, impeding further permeation of the slurry into the sand layer. Instead, the slurry accumulates on the surface of the sand layer, leading to the gradual formation of the filter cake. This permeation pattern can be considered a combination of filter cake and permeation zone.

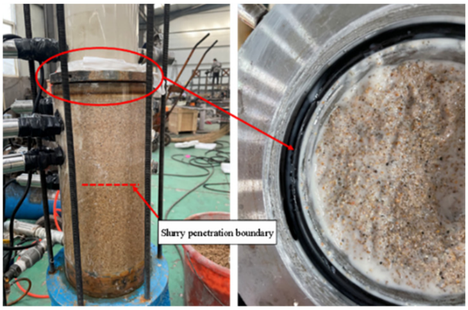

Fig. 3. Permeation form and deposition type of NS-2 slurry. (Captured by the author)

3.3 3D Permeation Characteristics of Slurry with 0.3% CMC Content

The permeation form and deposition type of NS-3 slurry in the saturated sand layer are shown in Fig. 4. Under pressure, the slurry struggles to permeate into the saturated sand layer, with a penetration distance of only 3.5 cm after 110 seconds of permeation. At this point, a large amount of slurry accumulates on the surface of the sand layer, forming a dense and thick filter cake. This effectively reduces the porosity and permeability coefficient of the sand layer surface and prevents subsequent slurry infiltration. Previous studies have defined slurry permeation types with a final permeation zone length to sand layer height ratio of less than 20% as filter cake types. According to this definition, the permeation distance ratio of NS-3 slurry is 12.28%, indicating a filter cake type permeation in the saturated sand layer.

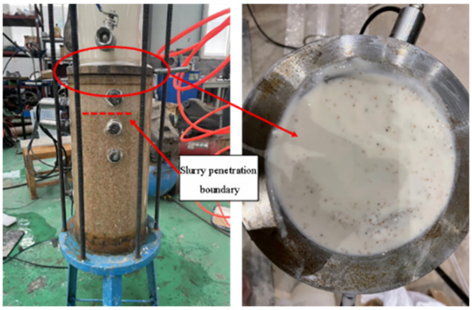

Fig. 4. Permeation form and deposition type of NS-3 slurry. (Captured by the author)

4 ANALYSIS OF FILTER CAKE FORMATION MECHANISM

Based on the results of the permeation tests, the addition of CMC transforms the discontinuous flocculent structure in the bentonite slurry into a continuous semi-solid gel structure, effectively enhancing the viscosity of the slurry. The higher the viscosity of the slurry, the greater the energy loss required for its flow through the high-permeability sand layer. Consequently, stronger interactions occur between slurry particles and sand particles, leading to improved filling of the sand layer pores to some extent. This effectively prevents further penetration of subsequent slurry, resulting in permeation types such as filter cake or filter cake - permeation zone.

Moreover, the increase in CMC content in the slurry significantly enhances the particle size of the slurry. With the increase in slurry viscosity, larger slurry particle sizes hinder the deep penetration of the slurry, causing most slurry particles to quickly accumulate and block at the surface of the sand layer. This effectively reduces the permeability coefficient and porosity of the shallow sand layer, enhancing the effective conversion efficiency of slurry pressure.

5 CONCLUSIONS

Based on the self-designed 3D variable cross-section slurry permeation column test system, the variations of key parameters during the 3D space slurry permeation process were studied, and the rules of slurry permeation and the mechanism of filter cake formation in saturated sand layers were analyzed. The main conclusions are as follows:

(1) With the increase of CMC content, three main types of permeation were observed in the highly permeable sand layers: penetration zone, filter cake - penetration zone, and filter cake formation.

(2) During the permeation of NS-1 slurry in the saturated sand layer, some slurry particles penetrated through the entire sand column. Under this condition, no filter cake was formed, and most of the slurry pressure still acted on the sand layer in the form of permeation force, which was unfavorable for the effective support of the soil mass.

(3) In the permeation process of NS-2 and NS-3 slurries, the slurry gradually accumulated on the sand layer surface to form a filter cake, and preventing the further penetration of subsequent slurry. Compared to NS-2 slurry, the penetration distance of NS-3 slurry in the sand layer significantly decreased, and the thickness of the formed filter cake was larger, resulting in higher efficiency of slurry pressure conversion.

(4) The increase in slurry viscosity not only enhanced the interaction between slurry particles and sand particles but also to some extent enlarged the particle size of slurry particles. Enhancing slurry viscosity is not only an important approach to achieve rapid filter cake formation in saturated sand layers in anti-seepage engineering, but also a crucial means to improve support efficiency.

References

1. Aisen, C. (2009) discussion on several issues of seepage stability of deep foundation pit in multilayered formation. *Chinese Journal of Rock Mechanics and Engineering* **28(10)**:2018-2023.
2. Lam, C., Jefferis, S.A., Suckling, T.P., Troughton, V.M. (2015) Effects of polymer and bentonite support fluids on the performance of bored piles. Soils and Foundations, 55: 1487-1500.
3. Han, X.R., Zhu, W., Liu, Q.W. (2008) Influence of slurry property on filter-cake quality on working face of slurry shield. Rock and Soil Mechanics, 29: 288-292.
4. Min, F.L., Xu, J.B., Du, J.R (2015) Experimental Study on the Slurry Preparation and Filter Cake Formation for a Large-Diameter Slurry Shield in Gravel and Sand Stratum. Modern Tunnelling Technology, 52: 141-146.
5. Fritz, P. (2007) Additives for slurry shields in highly permeable ground. *Rock Mechanics and Rock Engineering* **40(1)**:81-95.
6. Min, F., Wei, D., Jiang, T., Zhang, C. (2014) Experimental study of law of slurry infiltration in strata. Rock and Soil Mechanics, 35: 2801-2806.