

# Research Article

# **Experimental Study on Diffusion Law of Post-Grouting Slurry in Sandy Soil**

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In order to study the diffusion law of grouting slurry in sand areas, the grouting of cement slurry in sand was analyzed by the indoor grouting test under different water-cement ratios, grouting pressures, grouting amounts, and soil qualities, and the law of the post-grouting slurry is obtained. The results show that the grouting method is affected by the grouting pressure, water-cement ratio grouts in sands with different permeability coefficients, which are mainly manifested as osmotic diffusion, are basically the same; under the same water-cement ratio, when the grouting pressure is relatively small, the diffusion of modes of slurry is mainly osmotic in sand. The diffusion radius of cement slurry in sand has a good power function relationship with grouting pressure, water-cement ratio, permeability coefficient, and grouting amount. And, the empirical function model of slurry diffusion radius is proposed by regression analysis. The research results provide a certain theoretical and experimental reference for post-grouting in sandy areas.

## 1. Introduction

Geotechnical engineering reinforcement plays an important role in its stability and safety, especially for fractured rock mass and soft soil layer [1-7]. While drilling and punching piles for mud-retaining walls in sand areas, there are problems such as muddy ground, stress relaxation, sediment, and disturbance of bearing end resistance so that the pile-end resistance and pile side friction resistance are significantly reduced [8-12]. In order to eliminate the hidden dangers such as pile-bottom sediment and pile mud film, the foundation treatment grouting technology was quoted into the foundation pile and the grouting construction technology of the bored pile was formed. The grouting technology was also widely used in geotechnical engineering [13-18]. The technology adopts pressure grouting measures by adopting pile end (hole bottom) and pile side (hole wall) and uses the slurry to compact, split, infiltrate, fill, and solidify the pile-end bearing layer and sediment and the pile surrounding mud. The knot and

other functions are used to increase the strength of the soil around the pile, thereby increasing the ultimate bearing capacity of the pile. At the same time, the grouting parameters are determined based on engineering experience. Many scholars have studied the diffusion mechanism of slurry by theoretical analysis, model test, and on-site monitoring [19–23]. Kusakabe et al. [24] carried out an indoor test of the post-grouting of the prefabricated piles with the bearing layer being sandy soil. It is considered that the failure form of the precast piles after grouting at the pile end is the puncture failure of the column and the splitting of the grouting body. Mullins et al. [25] furthered the study of the bearing mechanism of grouting after pile foundation in nonclay. Kleinlugtenbelt et al. [26] and other scholars [27-31] conducted a grouting model test of loose sand and soil layers. Gothäll and Stille [32, 33] led a study of expansion effect of cracks during grouting and also analyzed the interaction between cracks. Mohamed [28] studied the mechanism and regularity of slurry diffusion and filling under different experimental conditions. Nikbakhtan et al.

[34] studied the anisotropy of the slurry diffusion law under hydrodynamic conditions and promoted the development of grouting theory. Zhang et al. [35] studied the diffusion law of cement slurry in clay. Qian et al. [36] discussed the possibility of multiple grouting, revealing the relationship between the diffusion and filling of the slurry in the pores, the number of grouting, and the permeability coefficient and porosity of the rock mass. Besides, the grouting technology was also widely used to strengthening fractured rock mass, improving soil properties, etc. [2, 3, 37, 38]. However, there are few studies on the diffusion properties and mechanism of the slurry in the sand area. Reasonable grouting parameters are used to avoid the waste of engineering investment and the conditions for ensuring the quality of the project. Therefore, good grasp of diffusion mechanism of the slurry in the sand area is the premise to determine the parameters of the grouting process.

In order to solve the problems and deficiencies in the above research, this paper will analyze the mechanism of post-grouting slurry diffusion in the sand soil area and study the diffusion law of slurry under different factors through the laboratory test so as to provide theoretical and experimental reference.

## 2. Experimental Design of Post-Grouting Slurry Diffusion Law

The sand grouting chamber test with three different permeability coefficients was designed in the experiment. The physical properties of the sand and cement used are shown in Tables 1 and 2. The permeability coefficients of the three different sands are 0.11 cm/s, 0.13 cm/s, and 0.93 cm/s. The designed grouting pressure is 0.2 MPa, 0.3 MPa, 0.4 MPa, and 0.5 MPa, and the water-cement ratio is 0.4, 0.5, 0.6, 0.8, and 1.0. Each group of sand permeation coefficient was tested in 25 groups to study the effects of grouting technical parameters on slurry diffusion in sand such as different permeability coefficient, slurry water-cement ratio, grouting pressure, and grouting amount. The indoor simulated pressure grouting test device is shown in Figures 1 and 2. The device comprises an air compressor, a pressure regulating valve, a pressure vessel, a measuring instrument, a test frame, and a test die. The air compressor is suitable for a pressure less than 0.8 MPa and a displacement of 120 L/min; the test mold was made of seamless steel tubes with an inner diameter of 150 mm and wall thickness of 10 mm, and the mold height was 300 mm. During the test, the air compressor outputs high-pressure gas and the pressure regulating valve controls the pressure of high-pressure gas at a certain value. Then, the high-pressure gas was input into the pressure vessel. Under the action of grouting pressure, the slurry flows through the grouting pipe and is injected into the test mold.

## 3. Analysis of Test Results of Post-Grouting Slurry Diffusion Law

3.1. Characteristics of Grouted Concretion in Sand. Figures 3–5 show the morphology of grouted concretion of different

sand samples, with the grouting pressure of P = 0.2 MPa and water-cement ratio (W/C) of 0.5, 0.6, 0.8, and 1.0.

It can be seen from Figures 3–5 that the slurry is mainly infiltrated and diffused in the sand by spherical or elliptical spherical diffusion; the samples with the permeability coefficient  $k_1 = 0.11$  cm/s and  $k_2 = 0.13$  cm/s are in the same note. Under the same grouting condition, the morphology of nodules is basically similar. When the grouting pressure is relatively small, the cement slurry is mainly osmotic diffused. Through osmotic diffusion, cement slurry fills the pores between sand particles and solidifies sand particles, which improves the strength and bearing capacity of sand soil.

The analysis shows that when the slurry is relatively thick, that is, the water-cement ratio is relatively small, the cement slurry coexists in the soil by permeation diffusion and compaction diffusion. The cement slurry first penetrates and diffuses into the far sand and fills the sand pores. As a good filter material, under the action of high and stable grouting pressure, the free water in the cement slurry is forced to filter through the sand body so that the concentration of the cement slurry in the sand pores increases and a circle of high strength and density cement sand stone body is formed near the mouth of the grouting pipe. Subsequently, since the grouting pressure does not increase any longer and is less than the creping pressure, the following slurry cement particles cannot pass through the soil so as to squeeze the surrounding soil to form a spherical bubble phenomenon in the center of the sample. When the water cement-ratio is relatively large, the cement slurry mainly diffuses in an infiltration manner, and at the same time, the pressure filtration effect is accompanied by the entire grouting process.

3.2. Influence of Water-Cement Ratio on Slurry Diffusion. When the permeability coefficients are  $k_1 = 0.11$  cm/s,  $k_2 = 0.13$  cm/s, and  $k_3 = 0.93$  cm/s, the grouting pressures are P = 0.2 MPa, 0.3 MPa, 0.4 MPa, and 0.5 MPa, respectively. The relationship between the slurry diffusion diameter and the slurry water-cement ratio is shown in Figures 6–9.

It can be seen from Figures 6–9 that when the grouting pressure is constant, the diffusion diameter of the cement slurry in the sand increases with the increase of the watercement ratio of the slurry. For the sand sample with the permeability coefficient  $k_1 = 0.11 \text{ cm/s}$  and  $k_2 = 0.13 \text{ cm/s}$ , when the grouting pressure is P = 0.2 MPa, the relationship between the slurry diffusion diameter and the watercement ratio and the morphology of the grouted concretion are similar. When the grouting pressure is greater than 0.2 MPa and the slurry water-cement ratio is 0.5:1 to 1:1.0, the diffusion diameter increase range of the slurry is slowed down. When the grouting pressure is 0.4 MPa and 0.5 MPa and the water-cement ratio is 0.8, the slurry diffusion diameter reaches the maximum value of the inner diameter of the test mold and the diffusion diameter reaches 150 mm. In addition, when the permeability coefficient of the sand sample is  $k_1 = 0.11$  cm/s, the water-cement ratio of the slurry is 0.4, the grouting pressure is 0.2 MPa, and the diffusion diameter is 65 cm. When the grouting pressure of the sand

Soil sample	Natural density $\rho$ (g/cm <sup>3</sup> )	Natural moisture content <i>w</i> (%)	Proportion $G_1$	Pore ratio <i>e</i>	Porosity <i>n</i> (%)	Permeability coefficient <i>k</i> (cm/s)
S1	1.95	21.98	2.69	0.68	40.31	0.11
S2	1.93	22.81	2.64	0.68	40.63	0.13
S3	1.96	20.72	2.79	0.72	41.95	0.93

TABLE 1: Physical properties of sand.

TABLE 2: Physical properties of ceme
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Loss on ignition (%)	Fineness (%)	Initial setting (time/min)	Final setting (time/min)	Stability	Flexural strength (MPa)	Compressive strength (MPa)
≤2.5	1.2	120	240	Qualified	≥7.5	≥48.0



FIGURE 1: Schematic diagram of the test device.



FIGURE 2: Test device real map.

sample is 0.3 MPa, the diffusion diameter is 79 mm, the grouting pressure is 0.4 MPa, and the slurry diffusion diameter is 87 mm. When the grouting pressure is 0.5 MPa, the slurry diffusion diameter is 112 mm. It can be seen from the above analysis that when the slurry is thicker, the diffusion range of the slurry is smaller. Therefore, it is recommended that the slurry water-cement ratio should not be less than 0.5 when grouting the sand soil.

3.3. Influence of Grouting Pressure on Slurry Diffusion. When the sand samples with the permeability coefficients  $k_1 = 0.11 \text{ cm/s}, k_2 = 0.13 \text{ cm/s}, \text{ and } k_3 = 0.93 \text{ cm/s} \text{ are under}$ the condition that the water-cement ratio is 0.4, 0.5, 0.6, 0.8, and 1.0, the slurry diffusion diameter and the injection relationship between slurry pressure is shown in Figures 10-12. The morphology of the concretion with a permeability coefficient of  $k_2 = 0.13$  cm/s in the slurry watercement ratio of 0.5 is shown in Figure 13. When the watercement ratio is in the range of 0.4~0.6, the slurry diffusion is greatly affected by the grouting pressure and the diffusion diameter increases with the increase of the grouting pressure; when the permeability coefficient is  $k_1 = 0.11$  cm/s, and the slurry water-cement ratio is in the range of 0.4 and 0.5, the slurry diffusion diameter of the sand increases linearly with the grouting pressure.

For sands with a permeability coefficient of  $k_2 = 0.13$  cm/s and  $k_3 = 0.93$  cm/s, when the water-cement ratio of the slurry is in the range of 0.4 and 0.5 and the grouting pressure is increased from 0.2 MPa to 0.3 MPa, the diffusion range of the slurry increased rapidly. When the water-cement ratio is 0.4, and the slurry diffusion diameter is about 110 mm, the water-cement ratio is 0.5 and the slurry diffusion diameter is about 130 mm. When the grouting pressure continues to increase to 0.5 MPa, the slurry diffusion diameter increases by about 10 mm.



FIGURE 3: Shape of concretion of sample after different water-cement ratios of soil sample. (a) W/C = 0.5. (b) W/C = 0.6. (c) W/C = 0.8. (d) W/C = 1.0.



FIGURE 4: Shape of concretion of sample after grouting with different water-cement ratios of soil sample S2. (a) W/C = 0.5. (b) W/C = 0.6. (c) W/C = 0.8. (d) W/C = 1.0.



FIGURE 5: Shape of concretion after sample grouting with different water-cement ratios of soil sample S3. (a) W/C = 0.5. (b) W/C = 0.6. (c) W/C = 0.8. (d) W/C = 1.0.

When the grouting pressure is 0.3 MPa and 0.4 MPa, and the slurry water-cement ratio is 0.5, the cement slurry has a dense cement slurry at the grouting nozzle. The test phenomenon shows that when slurry water-cement ratio is relatively small, the diffusion mode of slurry gradually changes from osmotic grouting to compaction grouting with the increase of grouting pressure. The concentration of slurry near the nozzle of the grouting tube is much larger than the concentration of slurry outside the concretion. And, there is osmotic effect, that is, the smaller the slurry watercement ratio is, the more obvious the seepage effect of the sand medium shows.

When the slurry water-cement ratio is 0.8 and 1.0, the slurry penetrates and diffuses to the entire test mold diameter at a low grouting pressure of 0.2 MPa. From the test results and the morphology of each concretion, when the slurry water-cement ratio is relatively small, that is, the slurry is relatively thick, the diffusion mode of the slurry is related to the size of the grouting pressure; when the slurry water-cement ratio is relatively large, that is, the slurry is relatively thin, the diffusion diameter of slurry increases with the increase of grouting pressure.

3.4. Influence of Grouting Amount on Slurry Diffusion. Figures 14-22 are diagrams showing the correspondence relationship between the grouting amount of each test piece and the slurry diffusion diameter. Under the same grouting pressure and with the same soil sample, the diffusion diameter of the slurry generally increases with the increase of the water-cement ratio of the slurry. When the water-cement ratio increases to 0.8, the slurry diffusion diameter reaches 150 mm; the corresponding grouting volume generally increases with the increase of watercement ratio. When the water-cement ratio is 1.0, the grouting diffusion diameter reaches the required grouting amount of 150 mm, but the grouting volume of slurry with a diffusion diameter up to 150 mm is smaller than that of water-cement ratio of 0.8. When the water-cement ratio is 0.8, the same soil sample with the same grouting pressure,



FIGURE 6: Characteristics of slurry diffusion (P = 0.2 MPa).



FIGURE 7: Characteristics of slurry diffusion (P = 0.3 MPa).

the slurry diffuses to the entire test mold diameter, and the required grouting amount is the largest. When the two kinds of sand bodies have permeability coefficient k1 = 0.11 cm/s and k2 = 0.13 cm/s, under the same grouting pressure and with the same water-cement ratio, the grouting amount is basically close.

## 4. Post-Grouting Slurry Diffusion Radius Function Model

#### 4.1. Factors Affecting Slurry Diffusion

4.1.1. Influence of Soil Properties on Post-Grouting. In the bored pile, the injectability, permeability, and compactness of the soil layer at the pile end and the pile side are the main



FIGURE 8: Characteristics of slurry diffusion (P = 0.4 MPa).



FIGURE 9: Characteristics of slurry diffusion (P = 0.5 MPa).

factors affecting the grouting effect at the pile end and the pile side. The diffusion of slurry in the soil layer is an important factor affecting the grouting effect, and the important factor affecting the diffusion of the slurry is the injectability of the soil. The injectability of the soil is affected by the structural characteristics of the soil, the particle size of the slurry, and the rheological properties of the slurry. Among the factors, soil particle gradation and slurry particle size are the two main factors affecting injectability.

According to the existing engineering experience, the cement slurry water-cement ratio used for post-grouting of bored piles is generally 0.4–0.9, most of which are suspended-type slurry. When the effective diameter of pores between soil particles is smaller than the diameter of cement particles, the slurry cannot be injected into the soil. When



FIGURE 10: Characteristics of slurry diffusion ( $k_1 = 0.11 \text{ cm/s}$ ).



FIGURE 11: Characteristics of slurry diffusion ( $k_2 = 0.13 \text{ cm/s}$ ).

the effective diameter between the soil particles is larger than the cement particles, but if the effective diameter of the soil is not large enough, the slurry flows slowly in the pores of the soil and the diffusion range of the slurry will be small and it may not be injected into the soil so that the pregrouting effect is not achieved. Therefore, the slurry can flow smoothly into the soil only in a sufficiently large soil pore.

If the post-grouting soil is coarse-grained soil, the soil layer has high porosity. The slurry carries out infiltration and consolidation and compaction on the pile-end and pile side soil layers. The strength and deformation modulus of the soil around the pile end are increased to generate the enlarged head of the grouted stone body so that the area and ultimate bearing capacity of the pile end are increased, and the area



FIGURE 12: Characteristics of slurry diffusion ( $k_3 = 0.93 \text{ cm/s}$ ).



FIGURE 13: Concretion morphology.



FIGURE 14: Characteristics of slurry diffusion (P = 0.2 MPa,  $k_1 = 0.11$  cm/s).

around the pile is enlarged to widen the pile diameter, thereby improving the pile side friction.

If the post-grouting soil layer is fine-grained soil, the soil layer has poor soil injectivity. The slurry is compacted and



FIGURE 15: Characteristics of slurry diffusion (P = 0.3 MPa,  $k_1 = 0.11$  cm/s).



FIGURE 16: Characteristics of slurry diffusion (P = 0.4 MPa,  $k_1 = 0.11$  cm/s).



FIGURE 17: Characteristics of slurry diffusion (P = 0.2 MPa,  $k_2 = 0.13$  cm/s).



FIGURE 18: Characteristics of slurry diffusion (P = 0.3 MPa,  $k_2 = 0.13$  cm/s).



FIGURE 19: Characteristics of slurry diffusion (P = 0.34 MPa,  $k_2 = 0.13$  cm/s).



FIGURE 20: Characteristics of slurry diffusion (P = 0.2 MPa,  $k_3 = 0.93$  cm/s).



FIGURE 21: Characteristics of slurry diffusion (P = 0.3 MPa,  $k_3 = 0.93$  cm/s).



FIGURE 22: Characteristics of slurry diffusion (P = 0.4 MPa,  $k_3 = 0.93$  cm/s).

filled with the pile-end and the pile side soil layers. The soil formed by the composite grouting of the grouted stone body is formed at the pile end, the load can be transmitted through the reticular stone body, and even the load can act on the reticular stone body so that the ultimate bearing capacity of the single pile is greatly increased. The mechanical properties of the soil on the pile side are improved, and the frictional resistance on the side of the pile is increased.

Whether post-grouting is at the pile end or on the pile side, the bearing capacity of the foundation pile increases by the coarse-grained soil layer rather than the fine-grained soil layer. Therefore, the post-grouting of the bored pile in the coarse-grained soil layer with good permeability and strong injection can fully improve the bearing capacity of the foundation pile.

4.1.2. Influence of Grouting Amount and Grouting Pressure on Post-Grouting. When the conditions, such as the characteristics of the post-grouting formation, grouting equipment, pile size, grouting process, and grouting pressure, are the same, the larger the grouting amount is, the larger the diffusion radius of the slurry in the soil layer is, and the loadbearing capacity has increased.

The magnitude of the grouting pressure is closely related to the diffusion area of the slurry in the soil layer. When the grouting pressure is high, the fine cracks in the rock and soil are cracked after being subjected to high pressure; therefore, the injectivity of soil is improved. When there is a weak part in the soil, the high-pressure slurry flows to a weak part. When the grouting pressure reaches the starting pressure, the slurry is split and grouted in the soil layer, and a network of stone formation is formed in the soil layer to improve the soil in density, strength, etc. At the same time, the high grouting pressure can filter out the excess water in the slurry so that the strength of the rock mass of the pile side and the pile side slurry increases. Under the same conditions, when the grouting pressure is large but does not exceed the starting pressure, the diffusion radius of the slurry in the soil layer is large and the permeability is strong; when the grouting pressure is small, the diffusion radius of the slurry is small and the penetration is small and poor. However, when the grouting pressure is greater than the severity and strength of the overburden layer, it will cause damage to the foundation and its superstructure. Therefore, the post-grouting pressure is not as large as possible, and the grouting pressure should be reasonably determined based on the basic principle of nondestroying the stratum structure or only a small amount of local damage.

4.2. Function Model of Slurry Diffusion Radius. From the above test results and the analysis of factors affecting postgrouting, it is known that the diffusion radius of the slurry is related to soil quality, grouting pressure, grouting amount, water-cement ratio. and other factors. The existing research results show that [26–28], the slurry diffusion radius has a power function relationship with the factors, such as the grouting pressure P, the grouting amount Q, the water-cement ratio W, and the permeability coefficient k. The diffusion radius of the cement slurry in sand is calculated according to the following mathematical model:

$$y = a x_1^b x_2^c x_3^d x_4^e.$$
(1)

According to the indoor test results of the sand-medium diffusion mode, the diffusion radius and grouting amount of the grouted tube bodies in the sand medium are shown in Table 3.

The regression analysis was carried out on the test results in Table 3. The diffusion radius function of the cement slurry in the sand was

$$R = 1.9065k^{0.0461}W^{0.2333}P^{0.1168}Q^{0.2491},$$
 (2)

where R is the diffusion radius (cm) of cement slurry, K is the permeability coefficient of sandy soil (cm/s), W is the cement slurry water-cement ratio, P is the grouting pressure (MPa), and Q is the grouting volume (ml).

It can be seen from equation (2) that the most important factor affecting cement grout diffusion in sand is the grouting quantity, and at the same time, it is affected by the grout parameters: grout water-cement ratio and grouting

Data	Permeability coefficient k	Porosity n	Grouting amount	Water-cement	Grouting pressure P	Diffusion radius R
number	(cm/s)	(%)	Q (ml)	ratio W/C	(MPa)	(mm)
1	0.11	40.31	384.61	0.5	0.2	37.25
2	0.11	40.31	474.02	0.6	0.2	60.96
3	0.11	40.31	587.52	0.8	0.2	67.46
4	0.11	40.31	582.91	1	0.2	75.00
5	0.11	40.31	472.54	0.5	0.3	49.50
6	0.11	40.31	537.60	0.6	0.3	65.63
7	0.11	40.31	875.55	0.8	0.3	75.00
8	0.11	40.31	649.34	1	0.3	75.00
9	0.11	40.31	450.53	0.5	0.4	54.50
10	0.11	40.31	659.43	0.6	0.4	57.44
11	0.11	40.31	637.51	0.8	0.4	75.00
12	0.11	40.31	576.25	1	0.4	75.00
13	0.13	40.63	263.73	0.5	0.2	42.83
14	0.13	40.63	566.55	0.6	0.2	66.65
15	0.13	40.63	725.4	0.8	0.2	75.00
16	0.13	40.63	662.37	1	0.2	75.00
17	0.13	40.63	615.43	0.5	0.3	61.84
18	0.13	40.63	566.45	0.6	0.3	66.71
19	0.13	40.63	625.00	0.8	0.3	70.33
20	0.13	40.63	569.51	1	0.3	75.00
21	0.13	40.63	428.65	0.5	0.4	64.35
22	0.13	40.63	763.12	0.6	0.4	69.58
23	0.13	40.63	650.23	0.8	0.4	71.05
24	0.13	40.63	609.36	1	0.4	75.00
25	0.93	41.95	208.82	0.5	0.2	48.75
26	0.93	41.95	566.54	0.6	0.2	57.54
27	0.93	41.95	637.57	0.8	0.2	75.00
28	0.93	41.95	478.52	1	0.2	75.00
29	0.93	41.95	355.74	0.5	0.3	65.59
30	0.93	41.95	360.84	0.6	0.3	67.58
31	0.93	41.95	450.57	0.8	0.3	72.59
32	0.93	41.95	428.61	1	0.3	75.00
33	0.93	41.95	253.65	0.5	0.4	64.45
34	0.93	41.95	310.53	0.6	0.4	69.58
35	0.93	41.95	401.26	0.8	0.4	75.00
36	0.93	41.95	358.77	1	0.4	75.00

TABLE 3: Statistics of grouted concretion test data.

TABLE 4: Comparison between the calculated value and the measured value.

No.	Permeability coefficient k (cm/s)	Grouting quantity Q (ml)	Water-cement ratio <i>W/C</i>	Grouting pressure P (MPa)	Diffusion radius R (mm)		
					Calculated value	Measured value	Error (%)
1	0.67	1518	0.5	1.3	621	715	13.18
2	0.67	1856	0.6	1.2	785	857	8.45
3	0.67	2368	0.8	1.5	1099	979	12.24
4	0.67	2688	1.0	1.2	1280	1387	7.70
5	0.67	2849	0.8	1.6	1332	1234	7.94

pressure. The structural characteristics of sand such as permeability coefficient and porosity have relatively little influence on the slurry diffusion.

4.3. Validation. The geology where a bridge is located is sandy soil, with a sand particle content of 84.05%, silt particle content of 15.95%, porosity of n = 41.15%, and permeability coefficient of k = 0.67 cm/s. Cement slurry is

used for grouting. The slurry diffusion radius calculated by formula (2) and the field test value are shown in Table 4. From Table 4, the comprehensive consideration of permeability coefficient, grouting quantity, water-cement ratio, and grouting pressure is taken. The slurry diffusion radius calculated by formula (2) is compared with the measured value. The maximum error is 13.18%, the minimum error is 7.94%, and calculated values and measured values are in good agreement.

- (1) The post-grouting of sand is mainly based on permeable grouting, but the grouting mode is affected by grouting pressure, water-cement ratio, grouting amount, and soil quality. Under the same grouting pressure, the diffusion mode of slurry with different water-cement ratios in sand with different permeability coefficients is basically the same, which is mainly manifested as permeation and diffusion.
- (2) Under the same water-cement ratio and the relatively small grouting pressure, the slurry is mainly infiltrated and diffused in the sand. With the increase of grouting pressure, when a certain pressure value is reached, the slurry penetration and compaction diffusion exist simultaneously.
- (3) The diffusion radius of cement slurry in sand has a good power function relationship with grouting pressure, water-cement ratio, permeability coefficient, and grouting amount. And, the empirical function model of slurry diffusion radius is proposed by regression analysis. It provides a certain guiding basis for the practical application of the project.

#### **Data Availability**

The data used to support the findings of this study are available from the corresponding author upon request.

#### **Conflicts of Interest**

The authors declare that they have no conflicts of interest.

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