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A simple prediction method for the permeability coefficient of water-bearing sand layer after grouting compaction

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A simple prediction method for the permeability coefficient of water-bearing sand layer after grouting compaction

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Abstract. Due to the particularity of the pumping of the compound paste slurry material, the traditional stress analysis method is difficult to apply. Based on the cylindrical hole expansion model of compacted grouting, the theoretical formula of the compacted grouting displacement field of soil is established on the basis of simplified body strain. Based on the displacement field theory, the analytical solution of the soil permeability coefficient after grouting and compaction is established according to the compressed porosity and Konzeny-Carman equation. The field test of compact grouting was carried out, and the water injection test was used to obtain the change of permeability coefficient before and after grouting under different grouting intervals. The obtained results are in good agreement with the theoretical solution and have certain engineering guidance significance.

1. Introduction

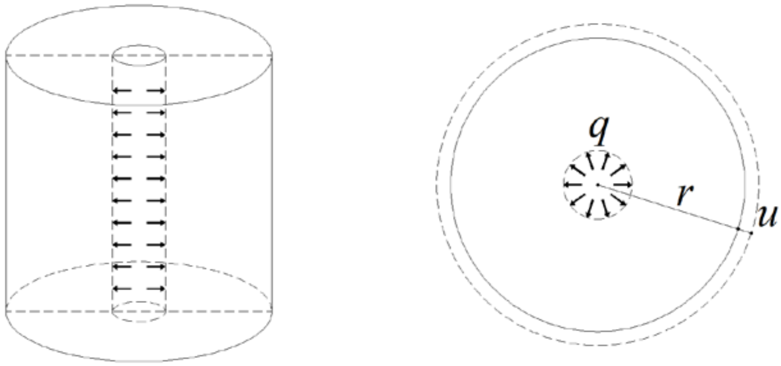
The compound paste slurry is based on the traditional pure cement slurry, and the modifier and bentonite are added to make the slurry fluidity and setting time adjustable. This feature makes it well used in the field of seepage prevention: In the process, the slurry does not precipitate out of water, and the plugging effect is good. The slurry diffusion distance can be effectively controlled. At the same time, the permeability coefficient of slurry stone body reaches the order of 10-7cm / s, and its strength can also better meet the engineering requirements.

Although the compacted grouting method using composite paste materials has a good effect in the treatment of embankment seepage, as an emerging material, a certain theory is needed to determine the matching grouting parameters to guide the actual engineering design. For the purpose of seepage prevention, the permeability coefficient of the soil before and after grouting is the most worthy of attention. The permeability coefficient is related to the amount of grouting, the pressure of grouting, and the nature state of the soil. The compacted grouting method using composite paste materials has a good effect in the treatment of embankment anti-seepage. Due to the special nature of the paste material, it is impossible to inject the cement slurry into the formation through a relatively certain pressure. In actual engineering, it needs to be injected by pulse grouting. The grouting pressure at this time is in the form of pulse wave. Therefore, the commonly used stress analysis does not work well. For this problem, some scholars analyzed from the perspective of injected volume and soil displacement [1, 2]. Based on the strain path method and considering the dissipation of excess pore water pressure, Luo made a theoretical derivation of the squeezing displacement field of a single pile under static pressure [3]. When the distribution of the displacement field is obtained, the change of the permeability coefficient can be derived from the relationship between volume strain and porosity.

2. Analytical solution

2.1. Soil displacement field

In order to calculate the displacement field distribution of compacted grouting, the following assumptions are made: (1) The compacted grouting body is cylindrical; (2) The soil within the influence range of compact grouting is an isotropic homogeneous body; (3) During the grouting process, the soil does not undergo infiltration and hydraulic splitting, and there is no vertical deformation. (4) Soil particles are incompressible.



(a)**.** Columnar expansion model. (b). Plane calculation model.

Figure 1. Schematic diagram of compacted grouting.

As shown in the figure 1, due to grouting compaction, it is assumed that a certain point (r, θ) in the soil body expands. According to the geometric relationship:

$$\frac{2\pi(r+u)}{1+\varepsilon_V}\Delta u = q\Delta t \tag{1}$$

where r is the radius from a certain point in the soil to the center, u is the radial displacement ε_V generated by the grouting compaction at that point is the volume strain generated in the micro-section, and q is the grouting rate.

Therefore, the total displacement at a point in time t is the integral of equation (1) over time

$$u = \int_0^t \frac{(1+\varepsilon_V)q}{2\pi(r+u)}dt \tag{2}$$

Among them, since ε_V varies with the grouting amount q and radius r, in order to simplify the calculation, the average body strain within the compaction range is used instead:

$$\overline{\varepsilon_V} = \frac{\Delta V}{V} = -\frac{Q}{\pi(L/2)^2} \tag{3}$$

where: Q is the total grouting volume per linear meter. L is the distance between two adjacent compacted grouting piles. Under the action of the two, there is basically no radial displacement from the first pile $L/2$

Simultaneously (2) and (3), the displacement at a certain point (r, θ) in the soil can be obtained:

$$u = \left(R^2 - \frac{2R^4}{L^2} + r^2\right)^{1/2} - r \tag{4}$$

where: R is the radius of compacted grouting pile, $R=(Q/\pi)^{1/2}$.

Analysis formula (4) can be obtained: The displacement caused by compacted grouting in the soil is related to the radius, the distance between the grouting piles and the amount of grouting. As the amount of grouting increases, the larger the volume of soil compacted and compressed, the greater the displacement of the soil; when the amount of grouting is fixed, the distance between two adjacent grouting points is greater, the same point in the soil the smaller the radial displacement. Therefore,

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increasing the amount of grouting or intensifying the grouting interval can effectively increase the influence radius of grouting, which is also consistent with the actual situation on site.

2.2. Permeability coefficient

During the compaction grouting of water-bearing sand layer, the expansion of the slurry bubble squeezes the soil body, and the pore water in the affected area is squeezed out, thus exerting a certain compaction effect on the loose sand layer and achieving the effect of anti-seepage reinforcement. The relationship between strain and displacement during this compaction process can be expressed as:

$$\varepsilon_V = \varepsilon_r + \varepsilon_\theta \tag{5}$$

$$\varepsilon_r = \frac{\delta u}{\delta r} \qquad \varepsilon_\theta = \frac{u}{r} \tag{6}$$

Assuming that the soil particles are incompressible, the changed porosity is:

$$n_1 = 1 - \frac{V_s}{V^{'}} = 1 - (1 - n_0)(1 + \varepsilon_V) \tag{7}$$

For porous media, the relationship between permeability and porosity can be determined according to the Konzeny-Carman equation:

$$k = \frac{n^3}{C(1-n)^2 S^2} \tag{8}$$

In the formula (8), C and S are constant coefficient and unit solid surface area, respectively, and n is the porosity of the porous medium.

The ratio of permeability coefficient before and after grouting η is:

$$\eta = \frac{k}{k_0} = \frac{n_1^3}{n_0^3}\frac{(1-n_0)^2}{(1-n_1)^2} \tag{9}$$

Simultaneous formula(4)(6)(7)(9), the change of permeability coefficient at each point after compacted grouting can be obtained, and in actual engineering, the grouting can be predicted according to the designed grouting volume, combined with the original permeability coefficient and porosity of the field Whether the permeability coefficient after compaction meets the requirements of anti-seepage.

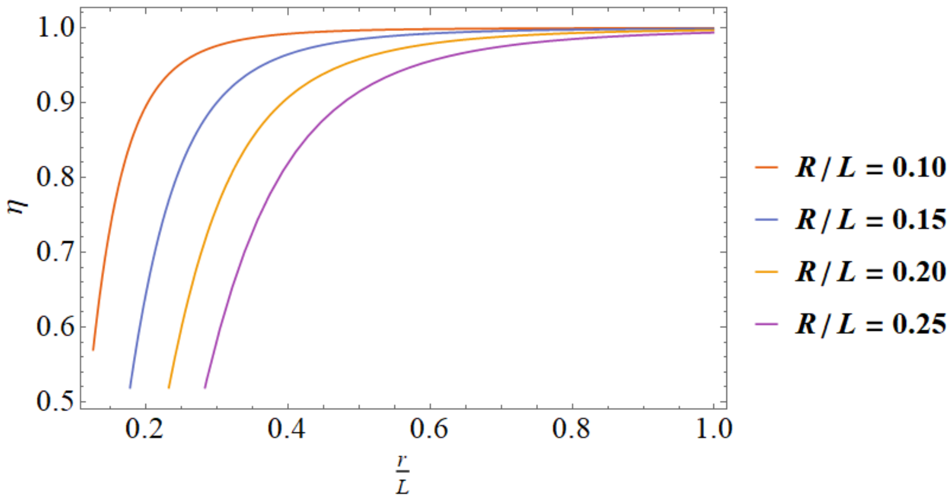

Figure 2. Variation of the change ratio η with r at n_0 =0.3.

As shown in figure 2, under the same grouting amount, the impermeability of the soil around the grouting point is significantly improved, and the permeability coefficient of the soil outside the radius of twice the grouting consolidation body is not obvious. At the same interval, as the amount of grouting increases, the permeability coefficient of the soil with the same radius is smaller; as the amount of grouting increases, the slope of the curve slows down, meaning that when a certain permeability coefficient is reached, a larger injection The amount of slurry obtained can have a larger influence range, which is consistent with the actual on-site grouting experience.

3. Field Test

The cover layer in the site of a dike anti-seepage project is Quaternary silty clay with a layer thickness of about 10m, and below it is a water-bearing sand layer with a layer thickness of about 5m. The underlying bedrock is strong-medium weathered limestone. On the basis of compaction grouting technology, composite paste material is used for grouting reinforcement of water-bearing sand layer. After calculating the influence radius and anti-seepage effect of the compacted grouting theory at the test site using the compacted grouting impermeability theory, a compact grouting field test was carried out, and the soil between the piles under different grouting intervals was measured by water injection experiment The change of the permeability coefficient of the test verifies the rationality of the anti-seepage theory of compacted grouting.

Table 1. Mix proportion design of grouting material.

Cement (kg)	Water (kg)	Bentonite (kg)	Modifier (kg)
150	150	150	1.5

The compound paste material was used in the field test, and its ingredients are shown in table 1. The test reached the designated depth of the formation through geological drilling, and the grouting material was continuously and uniformly and effectively controlled from the bottom to the top with the help of pulsating instantaneous high-pressure grouting, so as to achieve compacted soil and improve the impermeability purpose. The permeability coefficient before and after grouting is measured by water injection experiment. By arranging inspection holes in the middle of two adjacent grouting holes for water injection experiment, the change of permeability coefficient is obtained. The results of the water injection test before irrigation and the water injection test hole after irrigation are shown in table 2.

(a). Compound paste slurry. (b). Adjacent grouting points.

Figure 3. Field compaction grouting test.

It can be drawn from the analysis of the table 2 that during the compaction grouting process, the impermeability of the soil has been improved. Under the condition of similar porosity, the slurry injection volume at the interval L = 1m is obviously smaller than that at L = 1.5m. After grouting, the permeability coefficient of the sand layer is reduced to the order of 10^{-5}, which basically meets the requirements of anti-seepage. By comparing the changes of permeability coefficient before and after grouting, it can be seen that the simple calculation method of permeability coefficient proposed in this paper can better meet the field experimental data. The error between the actual value and the analytical value is basically within 15%, and the analytical value is greater than the actual value, making the design prediction of actual grouting biased to safety. To a certain extent, the rationality of this simple calculation method is verified.

Table 2. Test results of compact grouting.

Number	L(m)	n_0(%)	Q (m^3/m)	k(cm/s) Original state	After grouting	Analytical value	Tolerance (%)
1	1.0	13.7	0.453	1.11×10^{-4}	4.86×10^{-5}	5.63×10^{-5}	15.4
2	1.0	14.3	0.515	1.28×10^{-4}	5.24×10^{-5}	6.08×10^{-5}	16.0
3	1.0	14.6	0.502	1.43×10^{-4}	5.62×10^{-5}	6.25×10^{-5}	11.2
4	1.5	12.6	0.716	1.10×10^{-4}	5.97×10^{-5}	6.82×10^{-5}	14.2
5	1.5	12.9	0.736	1.09×10^{-4}	6.15×10^{-5}	6.72×10^{-5}	11.1
6	1.5	13.5	0.804	1.13×10^{-4}	6.09×10^{-5}	6.74×10^{-5}	10.7

4. Conclusion

This work is based on the shrinkage hole expansion model, and an alternative calculation method for the displacement field and permeability coefficient of the cracked sand layer after compaction grouting is pushed. The calculation results are in better agreement with the field test. The influence range of compacted grouting on the permeability coefficient is about double-layer pile diameter. In actual engineering design, it is recommended to control the ratio of the estimated stone size to the grouting interval to not exceed 0.25. For the formation that penetrated at the original initial rate, it is appropriately expanded Design the anti-seepage requirement of the uniform grouting volume or intensified grouting interval.

5. Acknowledgments

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