

Testing Analysis of Composite Ground with Grouting Piles and Deep Mixing Piles

Shao Li* Liu Songyu Shao Xinfa

(Institute of Geotechnical Engineering, Southeast University, Nanjing 210096, China)

Abstract: This paper discusses a new technique to improve soft ground with grouting piles and deep mixing piles. The bearing capacity of composite ground and the stress ratio between piles and soil is discussed by means of the static test. Based on Mindlin solution and Boussinesq solution, the additional stress and settlement of the composite ground are acquired. Compared the practical value with calculation, a better calculating method is confirmed.

Key words: grouting piles, Mindlin solution, Boussinesq solution, deep mixing piles

The ground engineering is one of the most important parts of a high building. There are many ground treatment methods used to improve soft soil. This paper introduces a new method with which deep mixing piles and grouting piles are used together to improve soft soil. Through the static load test, the stress ratio between pile and soil is discussed and the bearing capacity of the composite ground is determined. This paper focuses on a new method using Mindlin solution and Boussinesq solution of the elastic mechanic to calculate the additional stress and settlement. Compared with the practical observed settlement, we think calculated settlement may be a better method to calculate the settlement of this treatment scheme.

1 Treatment Scheme

The high building consists of four parts, they are seven floors, ten floors, thirteen floors and seventeen floors. Its composite ground is originally designed with deep mixing piles and then grouting piles are set among

deep mixing piles owing to heightening the building. The deep mixing pile's length varies from 14m to 16m. The diameter of the deep mixing pile is 700mm, distance between piles is 1.5m × 1.9m, amount of deep mixing piles is 679. The allowable bearing capacity of composite ground formed by deep mixing piles is 180kPa. The grouting pile's diameter is 400mm. Its length varies from 9m to 11m. The allowable bearing capacity of single grouting pile is 450kN. The allowable bearing capacity of composite ground made of deep mixing pile and grouting piles is 360kPa. Amount of grouting piles is 399. The general conditions of engineering geological are shown in Tab.1.

1.1 The construction method of grouting pile

First bore the designed depth by screw drill bit. At the same time the cement slurry and pulverized fuel ash slurry (PFA) are poured into the bottom of drill pipe. At the center of the pile a steel tube is buried in advanced through which cement slurry is pushed again at pressure 0.3 to 0.5MPa after 2 or 3d. When the

Tab.1 General conditions of engineering geological

Layer of soil	Sorts of soil	W/%	γ /(kN · m ⁻³)	<i>e</i>	<i>s_r</i> /%	<i>I_p</i>	<i>I_L</i>	<i>a</i> ₁₋₂ /MPa ⁻¹	<i>E</i> _{s1-2} /MPa	<i>C</i> /kPa	φ /(°)	<i>f_k</i> /kPa	<i>q_s</i> /kPa	<i>q_{sk}</i> /kPa
①	Filled soil	38.1	18.4	1.007	96.4	11.2	1.29	0.570	3.52			60		
②-1	Silt, silty sand	29.1	18.8	0.841	91.9	5.8	1.05	0.246	8.34	5.3	26.9	130		40
②-2	Silt	34.3	18.5	0.956	96.9	7.6	1.46	0.373	5.35			90		26
③-1	Silt	23.3	19.9	0.663	94.9	7.4	0.76	0.303	6.08	15.9	14.8	200		68
③-2	Silty clay	24.3	20.2	0.665	95.8	12.8	0.40	0.264	6.57	28.3	14.6	250		60
③-3	Silty clay, silt	20.9	20.7	0.585	96.8	9.1	0.50	0.280	5.76	13.0	15.5	230		68
④	Silty and gravel											350		80
⑤-1	Strong weathered rock											300		78
⑤-2	Middle weathered rock											800	1?300	110
⑤-3	Light weathered rock											2?100	3?400	2?800

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* Born in 1969, female, graduate, master.

following conditions are satisfied, cement slurry stopped pushing.

- (a) Cement slurry oozed over underground;
- (b) Pressure exceed 0.5MPa;
- (c) The quantity of pushing slurry exceeds the controlled value.

The first grouting is about 5 – 8d, drill or wash the center of the steel tube until the soil is found. It is shown that the steel tube is not blocked, then push slurry secondly. The ground piles' construction process is shown in Fig.1.

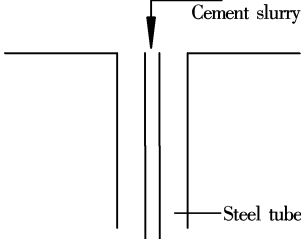


Fig.1 Ground piles' construction process

1.2 The static load test

The static load test is made to determine the bearing capacity of composite ground and the stress ratio between piles and soil. The dimension of the load plate is 2.4m × 2.4m, including two deep mixing piles and two grouting piles. Its p - s curve is shown in Fig.2. We add load to 800kPa and the final settlement is 20.21mm. The allowable bearing capacity corresponding to $s/b = 0.07$ is 722kPa. Meanwhile the pressure cell and stress gauge meter are set up at top of the piles and the face of the soil between the piles. The stress ratio between deep mixing piles and soil is about 2, between grouting piles and soils is about 40. So the deep mixing piles are flexibility piles and grouting piles are rigidity piles.

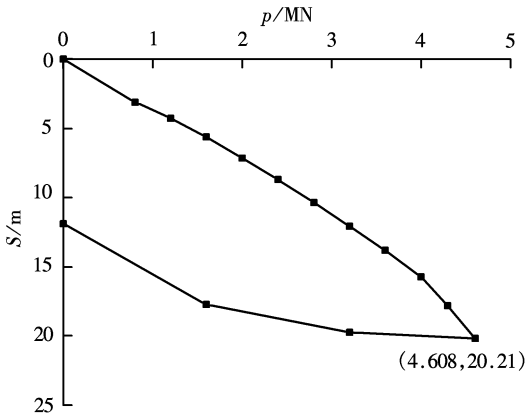


Fig.2 p - s curve

2 Calculation of Settlement

Because composite ground consists of flexibility piles and rigidity piles, the conventional method to calculate settlement is not suitable. In this paper the approach is proposed to calculate settlement, in which additional stress is calculated by means of Mindlin solution^[3] and Boussinesq solution^[4] of elastic mechanics. The settlement of composite ground is made of two parts: one is the settlement of the compound ground, another is the below compound ground. The calculation of the compound ground mainly have several methods, such as composite modulus^[1], revising stress, compress amount of pile^[2] and so on.

2.1 The method of calculation by using Mindlin solution and Boussinesq solution

In this paper piles and soil are respectively considered. The load beared on pile passes onto soil by piles' frictional resistance. The stress of soil caused by frictional resistance and tip resistance of pile adopts Mindlin solution to calculate, whereas the stress caused by uniformly distributed load adopts Boussinesq solution. The sum of two values is the additional stress of the composite foundation.

$$\sigma_z = \sigma_1 + \sigma_2 + \sigma_3 \quad (1)$$

where σ_1 is additional stress caused by deep mixing piles; σ_2 is additional stress caused by grouting piles; σ_3 is additional stress of soil.

The stress of soil σ_3 adopts Boussinesq solution. The formulae are given as follows.

$$\sigma_s = \iint_{l \times b} \frac{3prz^2}{2\pi R^5} dx dy \quad (2)$$

where

$$r = \sqrt{(x - x_0)^2 + (y - y_0)^2}$$

$$R = \sqrt{(x - x_0)^2 + (y - y_0)^2 + z^2}$$

The calculation of σ_1 and σ_2 adopts Mindlin solution. The formulae are given as follows.

$$\sigma_1 = \sigma_d + \sigma_c \quad (3)$$

$$\sigma_2 = \sigma_d + \sigma_c \quad (4)$$

where

$$\begin{aligned} \sigma_d = & \sum_{i=1}^n \sum_{j=1}^m \frac{p_d}{8\pi(1-\mu)} \left[-\frac{(1-2\mu)(z-H)}{R_1^3} \right. \\ & + \frac{(1-2\mu)(z-H)}{R_2^3} - \frac{3(z-H)^3}{R_1^5} \\ & - \frac{3(3-4\mu)z(z+H)^2 - 3H(z+H)(5z-H)}{R_2^5} \\ & \left. - \frac{30zH(z+H)^3}{R_2^7} \right] \end{aligned} \quad (5)$$

where σ_d is additional stress caused by tip resistance; p_d is tip resistance; H is the length of the pile and

$$\begin{aligned}
 R_1 &= \sqrt{(x_{ij} - x_0)^2 + (y_{ij} - y_0)^2 + (z_0 + H)^2} \\
 R_2 &= \sqrt{(x_{ij} - x_0)^2 + (y_{ij} - y_0)^2 + (z_0 - H)^2} \\
 \sigma_c &= \sum_{i=1}^n \sum_{j=1}^m \left\{ \int_0^H \frac{p_\xi}{8\pi(1-\mu)} \left[-\frac{(1-2\mu)(z-\xi)}{R_1^3} \right. \right. \\
 &\quad + \frac{(1-2\mu)(z-\xi)}{R_2^3} - \frac{3(z-\xi)^3}{R_1^5} \\
 &\quad - \frac{3(3-4\mu)z(z+\xi)^2 - 3\xi(z+\xi)(5z-\xi)}{R_2^5} \\
 &\quad \left. \left. - \frac{30z\xi(z+\xi)^3}{R_2^7} \right] d\xi \right\} \quad (6)
 \end{aligned}$$

where σ_c is additional stress below the bottom of pile caused by frictional resistance; p_ξ is the value of the distribution pressure of frictional resistance; μ is Poisson's ratio of soil, and

$$\begin{aligned}
 R_1 &= \sqrt{(x_{ij} - x_0)^2 + (y_{ij} - y_0)^2 + (z_0 + \xi)^2} \\
 R_2 &= \sqrt{(x_{ij} - x_0)^2 + (y_{ij} - y_0)^2 + (z_0 - \xi)^2}
 \end{aligned}$$

where x_{ij}, y_{ij} are the coordinate of deep mixing pile or grouting pile on the horizon; x_0, y_0, z_0 are the coordinate of the requested point of stress; H is the depth of the compound foundation.

According to the additional stress of compound ground and below compound ground the compress deformation of compound ground and below compound ground can be solved with layer-wise summation method. The formulae are given as follows.

$$s_1 = \sum_{i=1}^n \Delta s_i = \sum_{i=1}^n \frac{\sigma_z}{E_{\text{psi}}} h_i \quad (7)$$

$$s_2 = \sum_{i=1}^n \Delta s_i = \sum_{i=1}^n \frac{\sigma_z}{E_{\text{si}}} h_i \quad (8)$$

$$s = s_1 + s_2 \quad (9)$$

where s_1 is the settlement of the compound ground; s_2 is the settlement below the compound ground; s is the total settlement; E_{psi} is the modular of the composite ground; E_{si} is the modular of the soil; E_{psi} is shown as the modular of the composite ground and has great effect on the value of composite ground settlement. In this approach, the value of the E_{psi} is twenty times as big as that of E_{si} .

2.2 The distribute of the tip resistance and frictional resistance

When we calculate the additional stress caused by the tip resistance and frictional resistance, the distribution of the frictional resistance is necessary. According to the result of research^[2], the ideality

rigidity pile's distribution is equality along the pile and the tip resistance of flexibility pile is very small at working state. We suppose the distribution of the frictional resistance approximately are shown in Fig.3. The distribution of the grouting piles' resistance is the

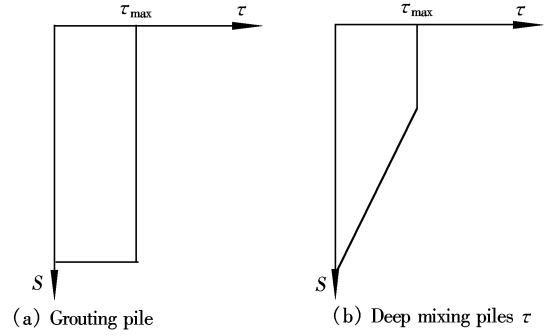


Fig.3 Distribution of the frictional resistance

same as that of the ideality rigidity pile. The distribution of the deep mixing piles' resistance is equality along the pile below the top of the pile about $H/3$ and then reduces linearly to zero at the tip of the pile. Finally, we can draw the conclusion of the settlement. The results of the settlement are shown in Tab.2.

Tab.2 The value of settlement cm

Compound ground	Below compound ground	Sum
2.34	2.95	5.29

3 Practical Settlement

The observation points are shown in Fig.4.

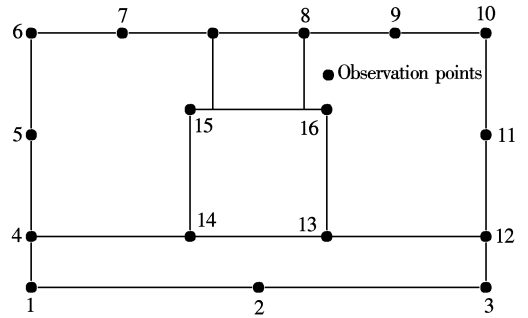


Fig.4 Distribution of observation points

The value of the last observation is 31.12?mm averagely. Because the settlement is not finished, we calculate the final settlement according to three-point method.

$$s_\infty = \frac{s_3(s_2 - s_1) - s_2(s_3 - s_2)}{(s_2 - s_1) - (s_3 - s_2)} \quad (10)$$

where s_∞ is final settlement; s_1 is the settlement of 204?d; s_2 is the settlement of 338?d; s_3 is the settlement of 486?d.

The final settlement is 45?mm. It has finished 70% of overall settlement at the last observation. The value of calculation approaches the value of observation.

4 Conclutions

- 1) Grouting pile is a new technique to improve soft ground. Combined with the deep mixing, we can obtain the better effect.
- 2) The advantage of using grouting pile is that the settlement of building is smaller.
- 3) Combing Mindlin solution and Boussinesq solution to calculate the additional stress and the settlement, the value of calculation is close to the value

of observation. So this calculation method is adapted to the sort of treatment method.

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后灌浆桩法和深层搅拌法加固软土地基的试验研究

邵 俐 刘松玉 邵信发

(东南大学岩土工程研究所, 南京 210096)

摘 要 讨论了一种地基处理新方法:采用后灌浆法和深层搅拌法联合处理软土地基.通过静载荷试验得到了复合地基承载力,同时通过埋设压力盒和应力计得到了桩土应力比.本文采用了 Mindlin 解和 Boussinesq 解联合求解复合地基中及复合地基下卧层土中应力,从而求得复合地基沉降,通过实测数据与计算沉降量的对比, Mindlin 解和 Boussinesq 解联合求解法与实测能较好吻合.

关键词 后灌浆桩, Mindlin 解, Boussinesq 解, 深层搅拌桩

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