Selection of treatment methods for soft foundation of river in a reclamation area

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Abstract. Several drainage channels are usually planned in the reclamation area in order to ensure the basic water surface ratio. It is necessary to conduct deep foundation treatment before the excavation of the river due to the high water content of hydraulic fill in reclamation area. Cement mixing pile method has been widely used in the treatment of river soft foundation as a method with mature construction technology, moderate overall cost and obvious treatment effect. Taking a river in a reclamation area as an example, it is recommended to adopt the cement mixing pile method to treat the soft foundation of the river after comparing the vacuum preloading method and cement mixing pile method.

1. Introduction
The concept of "basic water surface ratio" is proposed as a control index of water area protection in order to strengthen the protection of water area. Lakes and rivers are usually planned in the reclamation area in order to ensure the basic water surface ratio.

There is almost no bearing capacity due to the high moisture content of the reclamation area. Vacuum preloading method which reaches the current coating surface is generally used as shallow layer treatment. The characteristic value of bearing capacity of topsoil in the enclosure can meet the requirements of light machinery entering the site after reclamation. However, it is still muddy soil with low strength within the depth of 30m below the hard crust layer. The deep treatment of the soft foundation soil must be carried out to ensure the overall stability of the revetment if the bank revetment is excavated in the reclamation area.

2. Theoretical analysis methods
2.1. Stability analysis method
Sweden slice method is advocated in the stability analysis. The penetrability in seepage zone is simplified as an alternative unit weight based on Code for design of sea dike project. The formula is as follows:

\[ K = \frac{2R[(\tau - \lambda)\theta + \lambda b] + \sum (c_i L_i + W_i \cos \alpha_i \tan \phi_i) + T}{\sum W_i \sin \alpha_i} \]  

In the formula:
\( \ell, w \) — Length and weight of the soil strip;  
\( c_i, \varphi_i \) — Shearing strength of the soil;  
\( \alpha \) — The intersection of normal and vertical lines;  
\( T \) — Design strength of geotextiles;  
\( R \) — Radius of the sliding arc;  
\( \tau_0 \) — Intercept of the intensity curve;  
\( \lambda \) — Slope of the intensity curve. 

\[
C = C_1 m + C_s (1 - m) \quad (2)
\]

\[
\varphi = \left( \frac{\tan \varphi_1}{1 + \frac{K_2}{K_1}} + \frac{\tan \varphi_2}{1 + \frac{K_1}{K_2}} \right) \quad (3)
\]

In the formula:  
\( C \) — Cohesion of composite foundation;  
\( C_1 \) — Cohesion of piles;  
\( C_s \) — Cohesion of soil between piles;  
\( m \) — Replacement rate;  
\( \varphi \) — Internal friction angle of composite foundation;  
\( \varphi_1 \) — Internal friction angle of mixing pile body;  
\( \varphi_2 \) — Internal friction angle of soil between piles;  
\( K_1 \) — Rigidity of mixing pile;  
\( K_2 \) — Stiffness of soft soil around pile;  

2.2. Calculation conditions  
The calculation condition is divided into the construction period and the normal running period. Strength indexes for the quick direct test is adopted in the soil index of untreated area. Composite foundation index is adopted in treatment area\(^1\).

3. The engineering example  
3.1. Introduction of river channel in reclamation area  
A reclamation area is located outside the current seawall. The width of the planned river channel is about 20-60m, and the bottom elevation is about -1.0-0. A hydrophilic platform is set at 3.0m to reduce the cost of foundation treatment of river revetment due to the great difference between the planned ground elevation and the planned river bottom elevation. The flood level (P=5\%) of the river course is 3.26-3.28m, and the normal water level is 2.62m.

| Stratum             | Shear strength | \( \varphi \) |
|---------------------|----------------|--------------|
| Dredger fill        | 7.6            | 11.3         |
| Silt 1              | 7.8            | 10.6         |
| Silt 2              | 8.3            | 9.4          |
| Silt 3              | 19.6           | 8.7          |
| Composite foundation| 27.6           | 17.6         |

A reasonable treatment method should be adopted for the deep foundation treatment according to the thickness of soft soil, the characteristics of the project and the requirements of the construction period. At present, cement mixing pile and vacuum preloading are the most commonly used to treat the river soft foundation.
3.2. Deep vacuum preloading
The full section vacuum preloading shall be carried out in the excavated river area after the site levelling. The vacuum preloading section is combined with two layers of sealing film, one layer of 200g/m² non-woven geotextile and one layer of 50kN/m woven geotextile from top to bottom. C-type plastic drainage plate is used vertically (square layout, spacing 0.80m). The depth and width of vacuum preloading treatment should be determined according to the stability of river anti sliding[2~3]. The actual vacuum preloading can only ensure that the surface layer has a certain treatment effect of 10m because the drainage plate is bent due to the daubing effect and the foundation settlement deformation, the strength growth value of theoretical calculation is far less than 10m. Take a project in Wenzhou as an example, the construction period of deep vacuum preloading project is 175 days. The conclusion according to the comparison of shear strength of two cross plates is as follows:
1. The strength of shallow foundation soil has increased significantly, especially near the surface, the strength has nearly doubled.
2. Under 10 meters, the strength of foundation soil has increased, but it is not significant.

3.3. Cement mixing pile method
Soft soil harden into high quality foundation with integrity, water stability and certain strength by cement soil mixing pile method using cement as curing agent. One-way mixing construction technology is adopted in the cement mixing pile of this project because the construction of two-way cement mixing pile equipment is interfered by drainage board.
Cement mixing pile is set at the lower part of the hydrophilic platform of river revetment to treat the foundation, with the diameter of 60cm and the spacing of 1.2m. The treatment depth and width of cement mixing pile should be determined according to the stability against sliding of river[4~6].

3.4. Comparison and selection of foundation treatment methods
The deep treatment schemes of vacuum preloading and cement mixing pile are compared and selected. The quantities and costs per linear meter of each scheme are shown in the table as follows:

| C (kpa) | H (m) |
|---------|-------|
| Before reinforcement | After reinforcement |

Figure 1 Strength of cross plate before and after site center reinforcement
Table 2. Comparison and selection of deep treatment schemes

| Project                        | Vacuum preloading                                                                 | Cement mixing pile method                                      |
|--------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------|
| Construction difficulty        | The construction is convenient and requires high quality control.                | The construction is convenient.                                |
| Treatment effect               | The effect of deep treatment below 10 m is not obvious.                           | The effect of foundation treatment is reliable.                 |
| Construction period            | 5 months                                                                         | 6 months (10 mixers).                                          |
| Settlement                     | The settlement of soil mass is large during vacuum preloading.                   | There is no obvious settlement in the process of construction.  |
| Inspection content             | Borehole sampling geotechnical test, cross plate test and load plate test.        | Light penetration, coring and static load test                  |
| Unit cost                      | ¥12512/m, the unit investment is expensive especially in the case of wide river channel | ¥8695/m, the unit investment is lesser than vacuum preloading.  |

It is difficult to carry out vacuum preloading due to the overgrowth of weeds on both sides of the road. Most of the surrounding roads have been constructed, and the conditions for simultaneous implementation of vacuum preloading with the road are not available. In conclusion, the cement mixing pile method is recommended for the deep foundation treatment of river channel in this reclamation area considering the construction difficulty, cost, treatment effect, duration and other factors.

4. Conclusion

(1) The foundation treatment must be carried out before the excavation of the planned river channel since the silt soil with very high water content is within 30m below the surface of the reclamation area.

(2) The effect of vacuum preloading under 10 m depth is not obvious. The cost of vacuum preloading is higher than that of mixing pile in the treatment of soft foundation with wide river width.

(3) The cement mixing pile method not only reduces the settlement after construction, but also effectively improves the shear strength of foundation soil by using the interaction between pile and soil.

(4) The cement mixing pile method is suitable for the project according to the engineering experience.

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