Application of Vacuum Preloading in Foundation Treatment of River

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Abstract. Vacuum preloading method is a commonly used dewatering and drying method for soft foundation soil in China, which has the characteristics of low cost and high treatment efficiency. Vacuum preloading method has been widely used throughout the country as a simple, fast and economical foundation treatment method. It is necessary to treat foundation before river construction revetment and upper landscape structure in order to meet the requirement of slope stability by taking a river course in a reclamation area as an example. In this paper, vacuum preloading method is used to treat soft foundation after comparison and selection of various foundation treatment methods. It is feasible to apply vacuum preloading technology to soft foundation treatment engineering of river course.

1. Introduction
Soft soil and bad foundation are often encountered in engineering construction, including soft clay, organic soil and peat soil, loose sand and silt, artificial fill, etc. It is necessary to reinforce the foundation when the soft soil and bad soil in natural foundation cannot meet the requirements of stability, deformation and seepage of buildings. The purposes of foundation reinforcement include: (1) improving the shear strength of soil to ensure the stability of river slope; (2) improving the bearing capacity of foundation to meet the requirements of service load; (3) reducing the compressibility of soil to meet the requirements of settlement control of structures in later stage.

Reasonable treatment methods should be used in soft foundation according to the thickness of soft soil, engineering characteristics and time limit requirements. At present, the soft foundation treatment methods widely used in China include vacuum preloading method, surcharge preloading method and cement mixing pile method.

In this paper, vacuum preloading method is recommended after comparison of various foundation treatment methods mentioned above.

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:
\begin{equation}
K = \frac{2R[(r_0 - \lambda_0)\theta + \lambda_0b] + \sum(c_i L_i + W_i \cos \alpha_i \tan \phi_i) + T}{\sum W_i \sin \alpha_i} \tag{1}
\end{equation}

In the formula:
- \(L_i\)、\(W_i\)——Length and weight of the soil strip;
- \(C_i\)、\(\phi_i\)——Shearing strength of the soil;
- \(\alpha_i\)——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.

2.2. Calculation conditions

The calculation condition is divided into the construction period and the normal running period. Natural cross plate index is adopted in the soil index of untreated area. Cross plate index of strength increase is adopted in soil layer of drainage plate treatment area. The river channel excavation is carried out after the soft foundation treatment is completed.

2.3. Shear strength index

1. Embankment soil: \(r=16.6\text{KN/ m}^3, r'=6.6\text{KN/ m}^3, C=4.1\text{KPa, } \phi=2.3^\circ\).
2. Embankment stone: \(r=18.6\text{KN/m}^3, r_{sat}=21\text{KN/m}^3, r'=11\text{KN/ m3}, C=0\text{KPa, } \phi=40^\circ\).

3. The engineering example

3.1. Introduction of river channel in reclamation area

The river course to be excavated belongs to the coastal green belt landscape engineering of the reclamation area. The planned road which is at the stage of preloading is in the reclamation area on the west side of the river and the seawall which has been completed and accepted is on the east side.

There is a temporary channel with a bottom elevation of 0.00~1.00 m at the planned excavation site. The river is 30-65 m wide and extends from northwest to southeast according to the landscape construction drawings. The proposed site is originally a beach, then dredged and filled to form a land area. The height of the river bed to be excavated is -1.00m. Landscape vegetation and sketches are on both sides of the river bank. In order to achieve the landscape effect, the two sides of the river have different heaps and elevations.

According to the construction drawings of the landscape part, in the narrow river channel with constant water level, the slope below the shoreline with constant water level is 1:5 to the bottom of the river. The basic pattern is shown in Fig. 1:

![Figure 1. Typical section of river revetment](image1)

According to the construction drawings of the landscape part, in the river with wider river width, hydrophilic trestle and platform at the local constant water level, the slope below the shoreline of the constant water level is 1:8 to the bottom of the river. The basic form is shown in Fig. 2:

![Figure 2. Typical section of river revetment (with hydrophilic stack and platform section)](image2)
3.2. Hydrology and geology
The normal water level of the river is 2.60 m, and the once-waterlogged water level of the river is 3.26 m in 20 years. The main design parameters of foundation soil are shown in Table 1.

| Stratum                | Bearing capacity (Kpa) | Compression modulus (Mpa) | Side friction of pile | Shear strength (C φ) |
|------------------------|------------------------|---------------------------|-----------------------|---------------------|
| Dredger fill           | 45                     | 2.0                       | 4                     | 4                   |
| Silt containing silt   | 45                     | 2.1                       | 4                     | 4                   |
| Silt A                 | 45                     | 1.7                       | 4                     | 4                   |
| Silt B                 | 50                     | 1.8                       | 5                     | 5                   |

3.3. Comparison of foundation treatment schemes
In view of the soft foundation treatment project in reclamation area, the vacuum preloading method, surcharge preloading method and cement mixing pile method are compared in Table 2.

| Method                  | Vacuum preloading | Surcharge preloading | Cement mixing pile |
|-------------------------|-------------------|----------------------|--------------------|
| Degree of difficulty in construction | The construction is convenient and requires high quality control. | Because of the poor soil quality, the next stage loading can be carried out only after the strength of the soil increases to a certain extent. | Construction is convenient. |
| Settlement deformation | The soil has a large settlement, until the required settlement rate is reached. | Soil is prone to instability due to large settlement during construction. | There is no obvious settlement during the construction process. The soil still has a large settlement when the upper structure is constructed. |
| Construction period     | 5 months          | 12 months            | 5 months(with 10 mixers) |
| Environmental impact    | Less              | Serious              | Less               |
| The influence on the greenbelt | The soil can be directly used as greening soil after salt drainage. | The construction of greenbelt will be affected by the unloaded stonework. | There will be local collapse during construction because local soil parameters have not been improved. |

According to the engineering experience of domestic constructed projects, vacuum preloading method is suitable for this project, with short construction period and low investment.

3.4. Design purpose
Two typical sections of the river are selected to calculate the bank slope stability during the construction period under the condition of direct excavation of the river. The calculation results are shown in Table 3.

| Section | K (West side) | R(m) | K (East side) | R(m) |
|---------|---------------|------|---------------|------|
| A       | 0.94          | 41.08| 0.93          | 51.74|
| B       | 0.96          | 28.95| 0.94          | 67.03|
If the river is excavated directly, the East and west of the river will be excavated during the construction period. The safety factor of side slope stability cannot meet the requirements of the code. The excavation and filling on both sides of the landscape green belt reduce the stability of the bank slope because the riverbank line is close to the foot of the inner slope of the seawall and the height of the fill is high. The local stability coefficient of steep slope is especially low. In addition, the most dangerous slip arc may pass through a riprap embankment or a closed earth. This is not conducive to the structural integrity and seepage stability of the seawall body.

4. Design of vacuum preloading scheme

4.1. Design conditions
The river channel excavation is carried out after the soft foundation treatment is completed.

4.2. Design scheme
Site leveling should be implemented before vacuum preloading construction. There are two seals, one non-woven geotextile, 0.50m thick medium-coarse sand cushion and one 30 kN/m braided geotextile from top to bottom. A single row of clay enclosure piles is built around the vacuum preloading area in order to ensure tightness. C-type plastic drainage plate is used vertically (square layout, spacing 0.90m). The bottom elevation of plastic drainage plate is -9.00~17.50m.
The typical section is shown in Figure 3.

![Figure 3. Typical section of vacuum preloading](image)

4.3. Stability calculation
Taking section 1 and section 2 as examples, the range of vacuum preloading is determined, and the stability of bank slope after soft foundation treatment is calculated according to the strength growth index calculated. The calculation results are shown in Table 4:

| Section | Working condition | K (West) | R(m) | K (East) | R(m) | Processing area |
|---------|------------------|----------|------|----------|------|----------------|
| A       | Construction period | 1.14 | 34.34 | 1.23 | 55.01 | The width is 47 m. Bottom elevation is-10.0~-14.0m |
|         | Operating period | 1.23 | 27.83 | 1.35 | 54.36 | |
| B       | Construction period | 1.13 | 35.99 | 1.15 | 49.36 | The width is 59 m. Bottom elevation is-9.0~-17.5m |
|         | Operating period | 1.26 | 40.50 | 1.28 | 49.75 | |

The depth of drainage plate should exceed 3.00 m below the dangerous sliding surface for the project controlled by stability when the soft soil is deep. After calculation, the bottom elevation of the vacuum preloading drainage plate is -9.00 to -17.50 m.
5. Conclusions

(1) If the river is excavated directly according to the design of river revetment in the construction drawings of the landscape green belt, it will have adverse effects on the stability of river slope, the overall stability of the backwater side of the sea embankment, the structural integrity of the sea embankment and the seepage stability of the sea embankment, so the foundation treatment must be carried out before the construction of the river revetment and the upper landscape structure.

(2) According to the engineering experience of our country's built projects, vacuum preloading method is suitable for this project through comparison and selection, with shorter construction period and lower investment.

(3) Unlike most vacuum preloading projects, this project aims at the soft foundation treatment of landscape river course in reclamation area. The two sides of the river bank are landscape. In order to achieve the landscape effect, the two sides of the bank have different heaps and elevations, so the vacuum preloading treatment depth required in different river sections is different.

(4) After vacuum preloading treatment, the stability safety of river slope and the overall stability safety of seawall backwater slope meet the requirements of the code.

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