Surcharge preloading consolidation analysis of coastal road considering permeability of dredged soil

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Abstract. Due to the high plasticity index and low permeability of reclaimed ground composed of dredged soil, the reinforcement period is very long, which makes the merits of vacuum preloading, short reinforcement time, disappear. Surcharge preloading method becomes the most suitable and economic way. The equivalent permeability method is used to simulate the installation of the plastic vertical drain and the influence of different permeabilities, namely the interval space is calculated numerically.

1. Introduction

As the expansion of the infrastructure construction, the contradiction between the land resource and the road development becomes more and more intense. One of the effective ways is increasing the area of reclaimed land. However, the difficulty of development of reclaimed land lies in the soft dredged soils, which is pumped over by the slurry pump from the seabed. During the reclamation, the structure of the soft soil is destroyed and the soil particles gradually deposits as fine particles. Therefore, the typical characteristics of reclaimed soil are large plasticity index, high water content, high compressibility and low permeability. Because of poor physical and mechanical property, the reclaimed ground should be reinforced before acting as foundations [1].

For the reinforcement methods of soft ground, usually there are replacement, surcharge preloading, vacuum preloading, composite foundation etc., in which the drainage method is of economic and effective to apply in the large area. Compared with the surcharge preloading method, the merit of the vacuum preloading method is the short period of reinforcement, even though the cost of vacuum preloading is higher. Considering the high plasticity index and low permeability of the reclaimed soil, the reinforcement time of both the vacuum preloading and the surcharge preloading usually lasts at least six months, even two years [2-5]. In light of this, there would be no advantage for using vacuum preloading. In practical engineering, after the reclamation of the ground there will be a long-time placement before it is used as ground foundation and at this case it is very suitable to use the surcharge preloading method to deal with the dredged soil.

2. Calculation conditions

2.1. Plastic vertical drains

In order to accelerate the drainage of reclaimed ground, the plastic vertical drains are installed at certain space. One of the difficulties in the calculation of drainage consolidation is the simulation of...
the vertical drains. The common method is the equivalent transferring method from the axial-symmetric sand well to the plane-strain sand wall based on the equal degree of consolidation at various stages. Viewing from the macro level, the installation of plastic vertical drain improves the permeability of the reclaim ground. Chai et al. [6] proposed a simple method to calculate the drainage problem where the installation of vertical drains can be regarded as the improvement of the vertical permeability of the ground and the transferring equation is shown in Eq. 1.

\[
 k_{ve} = \left(1 + \frac{2.5l^2 k_h}{\mu D^2 \mu k_v} \right)
\]

where \(l\) means the length of plastic vertical drain, \(D\) means equivalent diameters of drain space, \(k_h\) and \(k_v\) are horizontal and vertical permeability coefficients respectively, \(k_{ve}\) is the equivalent coefficient of permeability of the improved reclaimed ground. As can be seen, the smaller the space of the plastic vertical drains, the larger the equivalent coefficient of permeability is. In this calculation, the influence of different equivalent permeability, namely different space, on the reclaimed ground is investigated.

2.2. Calculation parameters
Plaxis3D is used in this calculation and the constitutive model is Mohr- coulomb. The parameters are listed in Table 1. In order to evaluate the influence of equivalent permeability, five values are adopted varying from \(1.2 \times 10^{-7}\) cm/s to \(1.2 \times 10^{-5}\) cm/s.

| Drainage type | Undrained A |
|---------------|-------------|
| Unsaturated bulk density (kN/m\(^3\)) | 16.8 |
| Effective Young’s modulus (kPa) | 1800 |
| Poisson’s ratio | 0.3 |
| Effective cohesive strength (kPa) | 4.0 |
| Effective internal frictional angle (°) | 5.0 |
| Equivalent permeability (cm/s) | \(1.2 \times 10^{-7}\) \(4.8 \times 10^{-7}\) \(1.2 \times 10^{-6}\) \(6.0 \times 10^{-6}\) \(1.2 \times 10^{-5}\) |

2.3. Calculation Stages
The construction process is shown in Fig. 1. As can be seen, the construction of the road is divided into two layers to avoid the instability of embankment. Between the construction of two layers, there is 10-day interval for the consolidation of the ground.
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(c) Filling of 2nd layer

![Construction stages](image)

**Figure 1.** Construction stages.

3. Calculation results

The settlement of the reclaimed ground under the surcharge preloading is shown in Fig. 2. The permeability of improved ground is used as a benchmark and other four permeabilities is demonstrated. Because the road embankment is constructed in two stages, the settlement can be also clearly divided into two stages. Once the surcharge load is applied on the reclaimed ground, there would be a sudden increase of settlement due to the undrained behavior of the reclaimed soil. After then, the consolidation process becomes predominate with assist of the plastic vertical drain. The settlement gradually increase but the rate of the settlement become smaller and smaller. When the permeability coefficient is very small, the consolidation settlements at two stages are also very small. With the increase of permeability coefficient, the final settlement becomes larger and the time reaching the maximum settlement becomes shorter, which means the consolidation stage gets faster and faster. After 80 days, the settlement of improved ground is 0.84m while the final settlement is 1.03m. Namely, if there is no improvement of the permeability of the reclaimed ground the residual settlement would be 0.19m. When the permeability coefficient is enlarged 100 times, the time to reach the final settlement is only 42 days, which is much accelerated. Usually, it is deemed that the permeability of the soft ground can be enlarged 100 times after the installation of the plastic vertical drains.

![Settlement](image)

**Figure 2.** Settlement at the center of bottom surface of embankment.

The distribution of settlement in both the reclaimed ground and the road embankment is shown in Fig. 3. As mentioned above, when the layer is applied suddenly, there is a significant increase in the settlement. Along with the consolidation process, the settlement then gradually spreads towards the deep layer of the ground. After the filling of the second layer, the settlement mainly concentrates at the range of first layer and the maximum settlement occurs in the middle of the road embankment.
4. Conclusions
The surcharge preloading method is numerically investigated considering the influence of equivalent permeability coefficient, which provides a way the deal with such problems. The conclusions are as follows:

1) After the embankment load, the consolidation process becomes predominate and the settlement gradually increase, but the rate of the settlement become smaller and smaller.

2) When the permeability increases, the drainage process is significantly accelerated and the risk of instability is reduced.

As the development of the coastal area, land reclamation has been one of the most important ways to solve the land shortage. The reclaimed soil is of high plasticity index, low permeability and complex physical mechanism, which make it always the research highlights in geotechnical engineering. Until now, the drainage consolidation methods such as vacuum preloading, surcharge preloading, electroosmosis preloading or the combination of two or three methods are still the most effective reinforcement methods. Recently, some novel methods involving chemistry methods are also proposed. For example, the water reducing agent is used to expel the pore water in the reclaimed soil as much as possible. However, the cost of such new method is much higher and the applicability range is also very limited. Therefore, the emphasis should be put on the composition of mineral components and microscopic structure of the reclaimed soil to get deep comprehension.

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