Paper ID: CS725 The 4th International Conference on Applied Mathematics, Modeling and Computer Simulation (AMMCS 2024)

Analysis of Soft Soil Foundation Treatment Using High Vacuum Densification Method via Finite Element Simulation

Guanghui JIANG[a,b], Yajing CHANG[a,b], Junli CHENG[a,b], Hao SHAN[c,*], Shuo YANG[c], Baoning HONG[d]

[a] CSCEC Road and Bridge group CO., LTD., Shijiazhuang, Hebei, China

[b] Hebei Province Highway Engineering Green Construction Technology Innovation Center, Shijiazhuang, Hebei, China

[c] School of Civil Engineering , Xuzhou University of Technology, Xuzhou, Jiangsu, China

[d] College of Civil and Transportation Engineering, Hohai University, Nanjing, Jiangsu, China

*Corresponding author's email: shanhao@ xzit.edu.cn

Introduction

The high vacuum densification method represents an innovative approach in foundation treatment, particularly for soft soil conditions prevalent in coastal regions. This method integrates high vacuum drainage with dynamic compaction, employing multiple low compaction energies to consolidate the soft soil foundations. While previous studies have explored the strengthening mechanisms and construction techniques of this method through theoretical analysis, field and laboratory tests, and numerical calculations, there is a gap in the literature regarding the finite element dynamic analysis of its efficacy on soft soil foundations.

In this study, we focus on a coastal roadbed project as a case study to establish a finite element analysis model using PLAXIS software. The aim is to investigate the treatment effects of the high vacuum densification method on soft soil foundations. The project's profile includes a highway subgrade in a coastal area with a thick layer of weak soil, which, if used directly, would lead to excessive post-construction settlement. Therefore, foundation treatment measures are essential to enhance the bearing capacity and reduce settlement.

Research objectives

- To evaluate the effectiveness of the high vacuum densification method in treating soft soil foundations in coastal areas using finite element analysis software PLAXIS.
- To provide insights into the method's application in coastal regions, informing engineering practice and future research.

Methods

Simplification of dynamic compaction load

In dynamic compaction construction, the elastic constant (S) can be expressed as a function of the hammer's radius (r), elastic modulus (E), and Poisson ratio (υ).

$$S = \frac{2rE}{1-\upsilon^2}$$

There is the following relationship between the hammer bottom contact stress (P) and the compaction amount (U):

$$\pi r^2 P = SU$$

$$m\ddot{U} = -\pi r^2 P$$

$$m\ddot{U} + SU = 0$$

where m is the rammer mass.

Since $U=0$ and $\dot{U}=u=\sqrt{2gh}$, when t=0, where u is the speed when the rammer reaches the surface and h is the fall distance, according to this initial condition, we can get:

$$U = \sqrt{\frac{2mgh}{S}} \sin\sqrt{\frac{S}{m}}\,t$$

$$P = \frac{\sqrt{2mghS}}{\pi r^2} \sin\sqrt{\frac{S}{m}}\,t$$

When t=0, it satisfies $P=0$, $U=0$, $\ddot{U}=0$;

According to the same loading and unloading time, the hammered soil contact stress time t_N can be obtained as:

$$t_N = \pi\sqrt{\frac{m}{S}}$$

The roadbed treatment parameters of dynamic compaction treatment in this project are rammer radius 1.25m, rammer mass 12t, rammer drop distance 10.0m, impact power 1200kJ, tamping number 3, tamping distance 5.0m, tamping elastic modulus 2.76MPa and Poisson ratio 0.2. Then in this project , the hammered soil contact stress time $t_N = 1.3s$, The contact stress can be expressed as $P = 847\sin 24.5t$ (kPa).

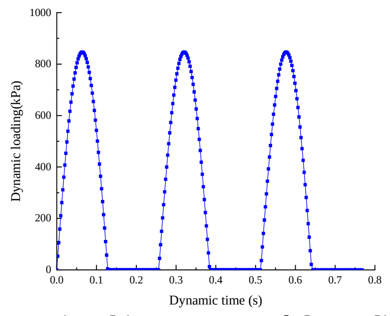

Figure 1. Time history curve of the cyclic load

Numerical simulation

Simplification of geometric models

The two-dimensional finite element model was developed using the PLAXIS finite element software to enhance the precision of the calculation. The actual thickness of each soil layer was rounded for improved accuracy, resulting in a calculated depth of 23.0m. Specifically, the soil layers from top to bottom are as follows: 1.0m of mixed fill, 10.0m of silty clay, 5.0m of silty clay, 5.0m of clay, and 2.0m of sandy silty clay. Additionally, in this roadbed project, the roadbed width is 30m, and both sides of the processing width are expanded by 2.0m, leading to a calculated width of 34.0m.

Simplification of plastic drain board

The plastic drainage plates are spaced 1.1m apart and arranged in a staggered pattern, extending to a depth through the soft soil layer, resulting in a length of 11.0m for each drainage plate. Following the installation of the plastic drainage board, a 0.8m sand cushion is placed on the roadbed. This study utilizes the PLAXIS finite element software to simulate the plastic drainage board's drainage system.

Simplification of vacuum tube

Two vacuum tubes were buried during soft foundation treatment utilizing the high vacuum densification method in this project, with one tube buried at a depth of 7.0m and another tube at a depth of 4.0m. The primary function of the vacuum tubes was to facilitate subgrade drainage. The PLAXIS finite element software was configured to maintain a zero hole pressure at the waterline, effectively achieving forced drainage. Consequently, two drainage lines are established at depths of 4.0m and 7.0m to simulate the functionality of the vacuum tubes.

Results

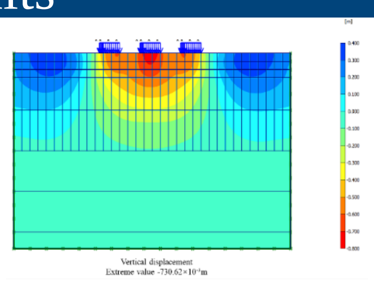

Figure 2. Vertical displacement cloud

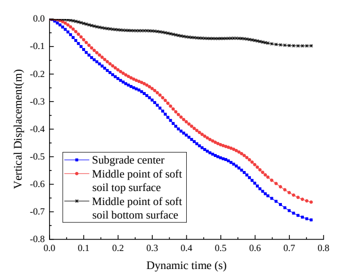

Figure 3. Vertical Displacement Time-history Curve

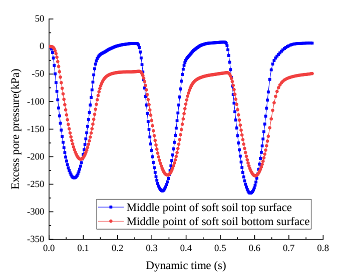

Figure 4. Excess pore water pressure time curve

(1) After compaction, the roadbed center shows the maximum vertical displacement, which diminishes towards the sides, and the method's impact is confined to the soft soil layer.

(2) Vertical displacement in the roadbed increases from top to bottom during compaction, with significant changes during loading and minimal rebound after unloading.

(3) Excess pore water pressure in the soft soil rises during compaction and stabilizes quickly upon unloading, with the top layer experiencing more change and complete dissipation compared to the bottom layer.

Conclusions

- The method effectively consolidates soft soil, enhancing bearing capacity and reducing post-construction settlement.
- Treatment leads to a gradual decrease in soil layer displacement, with the compaction area causing significant longitudinal displacement. The method's influence is limited to the soft soil layer's bottom..
- During dynamic compaction, excess pore water pressure rapidly rises then stabilizes, dissipating quickly during unloading to reach a stable level.

References

[1] Yuefu Zhou, Han Wenlong, Su Dong, et al. Study of the Nonuniform Consolidation Characteristics of Soft Soils Using a Novel Model [J]. Buildings, 2023, 13(12): 3104

[2] Youzhi Shi, Jianfeng Chai, Shuzhi Lin, et al. Application of high vacuum densification method to soft soil foundation treatment engineering at pingtan comprehensive experimental area [J]. Journal of Engineering Geology, 2017

[3] Ruifang Wang, Jia Zhu. Application of High Vacuum Preloading Method in Soft Soil Improvement of a Harbor Project [J]. Soil Engineering and Foundation, 2022, 36 (3): 313-316+326

[4] Lankaran Z. E. , Daud N. N. N. , Rostami V. , et al. Consolidated Drained Triaxial Test on Treated Coastal Soil and Finite Element Analysis Using PLAXIS 2D [J]. Advances in Materials Science and Engineering, 2022

[5] Chong Zhou, Chenjun Yang, Hui Qi, et al. Evaluation on improvement zone of foundation after dynamic compaction [J]. Applied Sciences, 2021, 11: 2156