Analysis of the Impact of Engineering Construction on the near Built Seawalls Based on PLAXIS

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ABSTRACT: The article analyzes the impact of a constructing sewage treatment plant on the built seawall nearly by PLAXIS finite element software, located on the coast eastern Zhejiang. As the construction carrying on, the settlement and horizontal displacement are gradually increasing on the top and backwater slope of the seawall. The settlement on the top of Seawalls is 35.91 cm, the horizontal displacement is 50.76 cm; the settlement on the back slope is 71.45 cm, the horizontal displacement is 48.54 cm. During the construction process, settlement increase rate at the foot of the backwater slope was significantly larger than that at the top of the seawalls. The horizontal displacement increase rate at the top of the seawalls was slightly larger than that at the foot of the backwater slope. The settlement and horizontal displacement of the seawall exceed the normal allowable deformation, which threatens the safety of the seawall. It is necessary to take reinforcement measures for the seawall to ensure safe operation.

1. Foreword
With the rapid development of our economy and technology, buildings, structures, terminals, ports, highways, airports and other buildings (structures) are increasing. However, there are fewer and fewer natural foundations without treatment that can be directly used in coastal areas. For construction in the seawall area, in order to improve their bearing capacity of the foundation and increase the safety of the building, it is necessary to drain the weak foundation firstly[1]. The foundation in seawall surrounding area generally consists of deep and weak sea soil, with characteristics of large plasticity index, high natural water content and void ratio, small gravity, high compressibility and small permeability[2]. Vacuum preloading is one of the effective methods to reinforce soft soil foundation. It has the characteristics of low reinforcement cost, short reinforcement period and no environmental pollution[3]. Especially in the treatment of large-area foundation, the advantage is more obvious. Therefore it is widely used in foundation reinforcement engineering[4].

2. Project Overview
This paper selects a sewage treatment plant in the southeast coast of Zhejiang as the research object. In order to greatly reduce the pollutant discharge, save the sewage transportation cost, reduce the operating cost, optimize the layout of the sewage system, the sewage treatment plant site is adjacent to the built seawall, further protecting the entire sea environment. The main structures of the sewage treatment plant are pump house, aerated grit chamber, biochemical pool, pump house, mud storage...
pool, integrated equipment room, water inlet and outlet monitoring room, comprehensive building and
door guard. The foundation of the biochemical pool dam and the bottom of the pool are treated by
vacuum preloading, and the pile foundation is used for each building foundation in the auxiliary area.
The engineering layout is shown in Figure 1.

The sewage treatment plant is located in the seawall area. The planned red line is located on the
inner side of the seawall, and the backwater slope of the seawall is placed in the red line of the sewage
treatment plant. The site of sewage plant is complex in geology and topography. At present, it is a fish
pond with a foundation of 30m deep silt. The seawall was built in 1994, grading IV. The building level
is 4th, and the design moisture level is once in 20 years. The cofferdam project on the outer side of the
seawall has not yet been approved. Therefore, the seawall is still a first-line seawall, and it is
responsible for flood control and moisture protection, and protects the normal operation of the people's
life and production.

![Image](https://example.com/image1.png)

**Figure 1** The engineering layout

3. Research object and construction plan

3.1 Integrated equipment room basic situation

The integrated equipment room in the auxiliary area is selected as the research object. The plane size
is 85.84m×25.54m, which is a reinforced concrete frame structure with layer heights of 8.50 and
3.00m respectively. The pile foundation is made of prestressed concrete pipe piles with a diameter of
Φ600, totaled 128. The pile end should go in the silty clay layer 1.0m or more, the average pile length
is 50m. The ground floor is reinforced with concrete slabs to meet the requirements for settlement
during later use. It is calculated that the total weight of the integrated equipment is 5.68*10^4kN, and
the surface load of ground floor is 42.5 kN/m^2. A schematic diagram along the vertical seawall is
shown in Figure 2.
3.2 Construction plan

(1) After the vacuum preloading is completed, the engineering auxiliary area will be backfilled one month later, and backfilled to 2.0m elevation. The backfilling duration is about 20 days.

(2) The pile foundation begins after the completion of the backfilling in the auxiliary area, and the duration is about 50 days.

(3) As the pile foundation completed, then piles detection, piles picking and the caps will be carried out, then the bottom plate for the lower elevation structure and the wall will be carried out. the whole process lasted about 80 days. During the period, the area will be gradually backfilled to the location of the ground beam for the integrated equipments (Elevation 4.0m or so).

(4) The structure above the ground constructed about 80 days, and the other area gradually backfilled to the 4.8m elevation during the period.

(5) Pavement and greening construction trimmed to a design elevation of 5.0m.

4. Numerical Analysis of the impact of Engineering Construction on Seawall

4.1 Model parameter selection

Due to the difference in soil layer and physical and mechanical parameters between the vacuum preloading treatment zone and the seawall area, the partitioning block is carried out during modeling. Both of the shallow soils have a certain transactionality. The soil layer and model parameters of the vacuum preloading zone are shown in Table 1. The soil layer and model parameters of the seawall body are shown in Table 2.

Table 1 The soil layer and model parameters of the vacuum preloading zone

| Soil name | Soil thickness (h(m)) | Soil weight (γ(kN/m³)) | Cohesion (c(kPa)) | Internal friction angle (φ(°)) | Compression modulus (E1,2(MPa)) | Poisson’s ratio (μ) | Horizontal permeability coefficient (k₀(cm/s)) | Vertical permeability coefficient (k₁(cm/s)) |
|-----------|----------------------|------------------------|------------------|--------------------------|-------------------------------|-----------------|-----------------------------------------------|---------------------------------------------|
| ① clay    | 1.2                  | 17.50                  | 22.3             | 11.5                     | 2.94                          | 0.33            | 5.45E-04                                       | 4.65E-04                                     |
| ② silt    | 22.6                 | 15.80                  | 10.3             | 7                        | 1.70                          | 0.33            | 5.97E-04                                       | 5.68E-04                                     |
| ③-1 MUDDY clay | 4                 | 16.69                  | 15.7             | 7.6                      | 2.31                          | 0.33            | 6.22E-04                                       | 5.39E-04                                     |
| ④-1 clay  | 8                    | 19.15                  | 39.0             | 14.0                     | 8.25                          | 0.32            | 3.99E-07                                       | 3.67E-07                                     |
| ⑤-2 Silty clay | 5                 | 18.40                  | 32.0             | 11.5                     | 6.18                          | 0.32            | 4.75E-07                                       | 4.17E-07                                     |
| ⑥-2 clay  | 20                   | 18.58                  | 26.2             | 13                       | 4.47                          | 0.32            | 4.75E-04                                       | 4.75E-04                                     |

Table 2 The soil layer and model parameters of the seawall body

| Soil name | Soil thickness (h(m)) | Soil weight (γ(kN/m³)) | Cohesion (c(kPa)) | Internal friction angle (φ(°)) | Compression modulus (E1,2(MPa)) | Poisson’s ratio (μ) | Horizontal permeability coefficient (k₀(cm/s)) | Vertical permeability coefficient (k₁(cm/s)) |
|-----------|----------------------|------------------------|------------------|--------------------------|-------------------------------|-----------------|-----------------------------------------------|---------------------------------------------|
| ⑦-2 clay  | 20                   | 18.58                  | 26.2             | 13                       | 4.47                          | 0.32            | 4.75E-04                                       | 4.75E-04                                     |
4.2 Modeling, material definition, and meshing

The PLAXIS analysis model is established according to the size of the seawall, the distance from the integrated equipment to the seawall, the range of the vacuum preloading treatment area and the treatment depth of the drainage board. The model after meshing is shown in Figure 3.

|    | h(m) | γ(kN/m³) | c(kPa) | φ(°) | E₁₂(MPa) | μ  | kᵥ(cm/s) | kᵧ(cm/s) |
|----|------|----------|--------|------|-----------|----|----------|----------|
| Dry masonry | / | 19.40 | 1 | 36 | 100 | 0.35 | 1 | 1 |
| ①-0 Prime fill | 4.5 | 18.91 | 34.8 | 13.9 | 6.66 | 0.32 | 2.43E-06 | 3.91E-06 |
| ① Muddy silty clay | 5.8 | 17.30 | 16.7 | 9.3 | 2.80 | 0.30 | 3.16E-06 | 6.10E-07 |
| ②-1 Muddy clay | 5 | 16.73 | 14.0 | 6.7 | 2.27 | 0.33 | 5.61E-07 | 5.13E-07 |
| ②-2 silt | 13 | 15.64 | 7.5 | 4.7 | 1.76 | 0.33 | 7.22E-08 | 6.95E-08 |
| ③-1 Muddy clay | 7 | 16.87 | 15.6 | 7.5 | 2.24 | 0.32 | 1.72E-07 | 4.11E-07 |
| ④-1 Silty clay | 5 | 19.15 | 39.0 | 14.0 | 8.25 | 0.32 | 3.99E-07 | 3.67E-07 |
| ④-2 Silty clay | 5 | 18.40 | 32.0 | 11.5 | 6.18 | 0.32 | 4.75E-07 | 4.17E-07 |
| ⑤-2 Clay | 20 | 18.58 | 26.2 | 13 | 4.47 | 0.32 | 4.75E-04 | 4.75E-04 |

4.3 Construction simulation

Since the seawall construction is completed for a long time, it is necessary to carry out long-term consolidation after initial stress generation to simulate the stress and strain process of the actual seawall body. This simulation process is as follows: 1. Vacuum pressure was gradually increased from 0 kPa to 80 kPa, lasting 120 days; 2. The area was backfilled to 2.0 m elevation after 30 days; 3. The prestressed concrete pipe pile was set up for 50 days; 4. Pouring reinforced concrete floor, the tank is gradually backfilled to 4.0m elevation during the period, lasting 80 days; 5. The above-ground construction of the integrated equipment room is carried out, and backfilled to the 4.8m elevation for 80 days. 6. Finally, the road surface and greening construction was carried out and backfill area trimmed to a design elevation of 5.0m.

4.4 Simulation result analysis

According to the simulation results, the maximum settlement of the foundation is 132.80cm and the maximum horizontal displacement is 63.76cm when the vacuum preloading process is completed. The maximum settlement of the foundation is 191.00cm and the maximum horizontal displacement is
-103.90 cm when the construction is completed. The cloud diagram at the end of vacuum preloading and at the completion of construction is shown in Figure 4 and Figure 5.

![Figure 4: Cloud diagram at the end of vacuum preloading](image1)

![Figure 5: Cloud diagram at the completion of construction](image2)

The maximum settlement and horizontal displacement on the inner side of the top, the back slope of the backwater and the entire construction site are counted separately at each stage, as shown in Table 3.

| Construction stage                  | Location         | Settlement (cm) | Horizontal displacement (cm) | Remarks |
|-------------------------------------|------------------|-----------------|------------------------------|---------|
| At the end of vacuum preloading     | Maximum          | 132.80          | 63.76                        |         |
|                                     | Seawall top      | 15.89           | -12.64                       |         |
|                                     | Slope foot       | 14.49           | -11.06                       |         |
| Backfill to 2.0m elevation          | Maximum          | 135.00          | -61.04                       |         |
|                                     | Seawall top      | 11.63           | 9.88                         |         |
|                                     | Slope foot       | 13.07           | 10.92                        |         |
| Prestressed pipe pile is completed  | Maximum          | 139.00          | -59.66                       |         |
|                                     | Seawall top      | 12.78           | 9.01                         |         |
|                                     | Slope foot       | 14.34           | 10.00                        |         |
| Reinforced concrete floor slab      | Maximum          | 139.30          | -69.70                       |         |
According to Table 3, the settlement and horizontal displacement on the top and the backwater slope of the seawall at each stage can be drawn, as shown in Figure 6 and Figure 7.

Figure 6 Settlement comparison diagram on the top and backwater slope of the seawall at each stage

Figure 7 Horizontal displacement comparison diagram on the top and backwater slope of the seawall at each stage
According to Figure 6, after the vacuum preloading is completed, the settlement at the top of the seawall and the backwater slope is reduced during the backfilling of the area between the integrated equipment and the seawall to the 2.0m elevation. At the end of the pressure, 15.89cm and 14.49cm are reduced to 11.63cm and 13.07cm, and the decrease at the top of the seawall is larger. With the increase of the subsequent filling elevation and the construction of the integrated equipment, the settlement gradually increases from 11.63cm and 13.07cm at 2.0m elevation to 35.91cm and 71.45cm at the completion of construction; in this process, the rate of settlement increase at the foot of the backwater slope is significantly larger than that at the top of the seawalls, especially after the reinforced concrete slab is completed in the integrated equipment room (ie, backfilled to 3.0m elevation), the settlement at the foot of the backwater slope increases sharply.

According to Fig. 7, as the elevation of the backfilling soil between the integrated equipment and the seawall increases, the horizontal displacement on the top of the seawall and the backwater slope gradually turns to the outer sea side. -12.64cm, -11.06cm at the end of the vacuum preloading increased to 9.88cm and 10.92cm when backfilled to 2.0m elevation. With the subsequent construction, the horizontal displacement gradually increased from 9.88cm and 10.92cm at the 2.0m elevation to 50.76cm and 48.54cm at the completion of the construction. The two are close to each other. The rate of increase in horizontal displacement at the top of seawall is slightly larger than that at the foot of the backwater slope.

5. Conclusion

(1) Through the numerical simulation analysis of the construction of the integrated equipment of the sewage treatment plant by PLAXIS finite element, the maximum settlement of the foundation is 132.80cm and the maximum horizontal displacement is 63.76cm when the vacuum preloading treatment is completed; the maximum settlement of the foundation is 191.00cm when the construction is completed. The maximum horizontal displacement is -103.90cm. The maximum value appears in the vacuum preloading area of the biochemical pool.

(2) The settlement on generated the top of the seawall is 35.91cm, the horizontal displacement is 50.76cm; the settlement of the backwater slope is 71.45cm; the horizontal displacement is 48.54cm. During the construction process, the settlement and horizontal displacement of the seawall and the backwater side gradually increased, and the settlement increase rate at the foot of the backwater slope was significantly larger than that at the top of the seawall. The horizontal displacement increase rate at the top of the seawall was slightly larger than that at the foot of the backwater slope.

(3) The settlement and horizontal displacement obtained from the analysis exceed the normal allowable deformation of the seawall, which threatens the safety of the seawall. It is necessary to take reinforcement measures for the seawall to ensure the safe operation of the seawall.

(4) Since the pile foundation of the integrated equipment adopts prestressed pipe piles, the squeezing effect will occur during the pile laying process. The static pore water pressure of the soil will increase with the piles being laid, and dissipation takes a long time. Therefore, the construction loading rate should be controlled during the filling, and small mechanical should be adopted to reduce the disturbance to the seawall and foundation.

Acknowledgments
This work was financially supported by Zhejiang Institute of Hydraulic & Estuary Dean Fund Project (ZIHE2016011); Zhejiang Province Science and Technology Agency Key Research and Development Project (2017C03008); Zhejiang Province Science and Technology Plan Project (2017C33138); Zhejiang Province Water Resources Department Science and Technology Planning (RC1733); Zhejiang Province Water Resources Department Science and Technology Planning (RB1614).

References
[1] Gong, X., Yan, Y. (2002) Discussion on Mechanism of Soft Soil Foundation Strengthened by Vacuum Preloading. J. Journal of Harbin University of Architecture, 35(2): 7-10.
[2] Huang, S., Gao, D., Sun, G. (2005) Soft soil foundation and underground engineering. China Building Industry Press, Beijing.
[3] Lou, Y. (2001) Vacuum drainage preloading method for reinforcing soft soil technology. People's Communications Publishing House, Beijing.
[4] Zhu, J., Shu, X. (2007) Strengthening Soft Foundation of Dredger Filling by Vacuum Preloading. J. China Water Transport, 7: 52-53.