Analysis of Heterogeneous Settlement of Connecting Sections of Embankment on Deep Soft Ground Based on PLAXIS

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ABSTRACT: The article analyzes the uneven settlement of the dam gate connection section of a reclamation project along the coast of eastern Zhejiang by PLAXIS finite element software, and compares and analyzes the in-situ monitoring results to understand the settlement development law of the dam gate connection section during operation and the location of the largest uneven settlement. Through analysis, after the sluice and the seawall are connected, the sluice settlement in the first year of the operation period is 5.51 mm, the settlement at the seawall is 105.30 mm, and the settlement difference is 99.79 mm; the cumulative settlement of the sluice is 9.01 mm, and the cumulative settlement at the seawall is 214.00 mm and the settlement difference is 204.99 mm. The uneven settlement of the connecting section of the dyke is mainly manifested at the junction of the empty box of the sluice and the riprap area of the seawall. When the uneven settlement is large, it will cause road cracks.

1. Foreword
The role of sluices in water conservancy projects is mainly to control the water level, which is a relatively important part of the composition of water conservancy hubs [1]. Embankments and sluices along the embankment are important engineering facilities to prevent storm surges and mitigate storm surges [2]. Because the southeast coast of Zhejiang is mainly a soft soil foundation, the seawall, especially the sluice connection section, is prone to uneven settlement. When the uneven settlement exceeds a certain limit, cracks or landslides are likely to occur in the superstructure due to the low stiffness of the superstructure of the seawall and the low bearing capacity of the foundation; after the cracks are formed, erosion caused by the continuous intrusion of seawater and rainwater causes the embankment deformation and cracks to be further developed. Moreover, the lateral anti-seepage system is damaged, and if it develops to a certain extent, water leakage will occur, endangering the safety of the seawall and its disaster reduction benefits [3].

2. Project Overview
This article selects the sluice and the seawall in a reclamation project along the southeast coast of Zhejiang as the research object. The uneven settlement of the connection between the seawall and sluice was analyzed by PLAXIS finite element software and compared with the results of in-situ monitoring [4]. The sluice is designed according to the Grade 1 building and the standard once in 100 years. The designed drainage flow is 501 m$^3$/s, 3 holes and 8 m, the top elevation of the gate floor is -3.0 m, and the elevation of the gate is 11.0 m. The sluice was tested for water acceptance in April 2018 and completed in June 2019. It has been one and a half years since the water was passed. The
layout of the sluice is shown in Figure 1.

![Sluice Layout Diagram](image)

**Figure 1** The engineering layout

### 3. Parameter selection and model building

#### 3.1 Selection of soil model parameters

Through routine indoor geotechnical tests, triaxial tests and advanced consolidation tests, the parameters of the soil hardening model are obtained. The model parameters of each soil layer are shown in Table 1 and Table 2.

| Soil name            | Thickness | Soil weight | Saturated bulk density | Void ratio | Permeability coefficient |
|----------------------|-----------|-------------|------------------------|------------|--------------------------|
|                      | H (m)     | γ (kN/m³)   | γsat (kN/m³)           | c          | kₜ (m/day)               |
| 2-3 Silt with silt   | 5~6       | 17.4        | 19.6                   | 1.32       | 4.38E-06                 |
| 2-4 silt             | 15~16     | 16.6        | 18.9                   | 1.71       | 1.62E-07                 |
| 3-1 Mucky clay       | 5~6       | 18          | 20.5                   | 1.23       | 8.85E-07                 |
| 3-3 Silty clay       | >4        | 19          | 20.6                   | 0.85       | 6.52E-05                 |

| Soil name            | Thickness | Cohesion  | Internal friction angle | Eₕ₀ | Eₘₜ | Eₖₑₜd | m |
|----------------------|-----------|-----------|-------------------------|-----|-----|-------|---|
|                      | H (m)     | c (kPa)   | φ (°)                   | kPa | kPa | kPa   |   |
| 2-3 Silt with silt   | 5~6       | 17.4      | 19.6                    | 4100 | 23000 | 2300  | 0.8|
| 2-4 silt             | 15~16     | 16.6      | 18.9                    | 3500 | 17000 | 1700  | 1  |
| 3-1 Mucky clay       | 5~6       | 18        | 20.5                    | 3900 | 21000 | 2200  | 0.85|
| 3-3 Silty clay       | >4        | 19        | 20.6                    | 4000 | 24000 | 3500  | 1  |
3.2 Model establishment and construction loading process

The PLAXIS model is established according to the structure of the sluice. The sluice has 3 holes with a width of 8 m. The elevation of the sluice top is 11.0 m, and the elevation of the seawall top is 7.8 m. The foundation of the connecting section of the dyke is treated with plastic drainage board, and the installation depth is 25 m. The total length of the sluice and seawall connection section is 63 m, and the empty box model transition is adopted, and the elevation gradually decreases from 11.0 m to 7.8 m.

Because the left and right sides of the sluice are symmetrical, in order to improve the calculation efficiency of the model, a simplified model is used in this modeling to analyze the deformation of the connecting section of the sluice on the right side of the sluice. The simplified analysis model of the sluice is shown in Figure 2, and the PLAXIS model is shown in Figure 3. The loading process during construction is shown in Table 3.

Table 3  Loading elevations of seawall sections at various levels

| Section      | Original coated surface | Crushed stone level | First level | Second level | Third level | Fourth level | Fifth level | Sixth level | Seventh level | Eighth level | Dike pavement |
|--------------|-------------------------|---------------------|-------------|--------------|-------------|--------------|-------------|-------------|---------------|--------------|---------------|
| Seawall      | -4                      | -3                  | -2          | -1           | 0           | 1.5          | 3           | 4.5         | 6             | 7.5          | 7.8           |

According to PLAXIS finite element analysis, the sluice and the seawall enter the operation period. The sluice settlement in the first year of the operation period is 5.51 mm, the settlement at the seawall...
is 105.30 mm, and the settlement difference is 99.79 mm. The cumulative settlement of the sluice during the two years of operation is 9.01 mm. The cumulative settlement at the seawall is 214.00 mm and the settlement difference is 204.99 mm; the cumulative settlement of the sluice at the 5th year operating period is 17.96 mm, the cumulative settlement at the seawall is 416.65 mm and the settlement difference is 398.69 mm; the cumulative settlement of the sluice at the 10th year is 30.23 mm, the accumulated settlement at the seawall is 589.70 mm, and the settlement difference is 559.47 mm.

The simulation results of the sluice are shown in Table 4, and the comparison curve of the settlement between the seawall and the sluice is shown in Figure 4.

|                  | Sluice settlement (mm) | Seawall settlement (mm) | Uneven settlement (mm) | Remark |
|------------------|------------------------|-------------------------|------------------------|--------|
| Completed        | 0.00                   | 0.00                    | 0.00                   |        |
| 1st year         | 5.51                   | 105.30                  | 99.79                  |        |
| 2nd year         | 9.01                   | 214.00                  | 204.99                 |        |
| 5th year         | 17.96                  | 416.65                  | 398.69                 |        |
| 10th year        | 30.23                  | 589.70                  | 559.47                 |        |

Note: The settlement of the seawall in the table is the maximum settlement of the seawall at the successive stages of the sluice (the same below).

According to PLAXIS simulation results, the sluice and seawall subsidence fitting curve is shown in Figure 5. The relationship between the sluice and sluice connection section settlement and time is:

\[ y = -5.0867x^2 + 109.34x + 3.7608 \]  \[ R^2 = 0.9991 \],  \[ 0 < x < 10 \]

5. Comparative analysis of numerical simulation and in-situ monitoring
According to the in-situ monitoring results, it is known that since the completion and acceptance of the sluice at the end of June 2019, the settlement at the top of the seawall was 48.0 mm, the PLAXIS simulation result was 45.6 mm, and the difference is 4.9%. The 4 settlement monitoring points of the sluice gate chamber have averaged 10.75 mm in the 2 years since the completion of the sluice construction, and the PLAXIS simulation result was 9.01 mm. The difference between the two was 1.74 mm, and the difference was 16.2%.

6. Conclusion
(1) According to PLAXIS finite element analysis, the sluice and the seawall enter the operation period. The sluice settlement in the first year of the operation period is 5.51 mm, the settlement at the seawall is 105.30 mm, and the settlement difference is 99.79 mm. The cumulative settlement of the sluice in the operation period is 9.01 mm. The cumulative settlement at the seawall is 214.00 mm and the settlement difference is 204.99 mm; the cumulative settlement of the sluice at the 5th year operating period is 17.96 mm, the cumulative settlement at the seawall is 416.65 mm and the settlement difference is 398.69 mm.
(2) Since the completion and acceptance of the sluice at the end of June 2019, the settlement at the top of the seawall was 48.0 mm, the PLAXIS simulation result was 45.6 mm, and the difference is 4.9%. The 4 settlement monitoring points of the sluice gate chamber have averaged 10.75 mm in the 2 years since the completion of the sluice construction, and the PLAXIS simulation result was 9.01 mm. The difference between the two was 1.74 mm, and the difference was 16.2%.

(3) The uneven settlement of the sluice dyke connection section is mainly manifested at the junction of the sluice empty box and the seawall throwing area, where the uneven settlement will cause cracks in the road surface.

(4) Through the research in this article, the analysis results of PLAXIS software are similar to the results of on-site monitoring in situ. It can provide a reference for research on measures to reduce uneven settlement of seawall and sluice connection.

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