Analysis of the influence about different materials on the settlement of the connecting section of seawall and sluice based on PLAXIS

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ABSTRACT: The article analyzes the uneven settlement of the connecting section of the East 1# sluice of the Oufei I reclamation project by PLAXIS finite element software, obtaining results of the development law of settlement and the location of the largest uneven settlement on the connecting section of the sluice under the conditions of the ordinary riprap mode and the empty box mode. The comparative analysis results show that the settlement on the two sluices is relatively close, and the settlement on the seawall is quite different, which is close to 2 times. The uneven settlement of the connecting section of the seawall and sluice is mainly manifested at the junction of the empty box of the sluice and the rubble area of the seawall. The empty box mode can reduce the weight of the seawall in order to reduce the uneven settlement on the connecting section of the seawall and sluice.

1 Foreword
The role of sluices is mainly to control the water level. They are relatively important parts of the composition of water conservancy hubs. They often form water conservancy hubs with dikes, seawall and other structures to play a role in flood control and tide blocking. Seawalls and sluices are important engineering facilities for preventing storm surges and mitigating storm surge water damage. However, as they are built on soft foundations, the seawalls, especially the connecting sections of the sluices, are prone to uneven settlement[1]. When this uneven settlement exceeds a certain limit, due to the low rigidity of the seawall superstructure and the low bearing capacity of the foundation, it is easy to cause cracks or landslides in the superstructure; after the cracks are formed, the erosion caused by the continuous entry of seawater and rainwater will lead to the development of deformation and cracks, and the lateral anti-seepage system is destroyed. If it develops to a certain extent, water leakage (seepage) will occur, endangering the safety of the seawall itself[2].

2 Project Overview
This paper selects the East 1# sluice and the seawall connecting section of the Oufei Phase I reclamation project as the research object, and analyzes the influence of different materials on the uneven settlement of the connecting section of the sluice with PLAXIS finite element software[3]. The sluice is designed according to the first-level building and 100-year standard. The designed full discharge is 501m³/s, 3 holes 8m, the top elevation of the sluice bottom plate is -3.0m, and the top
Elevation of the sluice is 11.0m. The sluice chamber adopts a parapet structure aligned with the top of the seawall. The chamber has a total length of 22m, the middle pier width is 2.0m, and the side pier width is 1.0m. The heads of the upstream and downstream piers are all streamlined. The chamber is a unit with a total width of 30m. There is a box beam pipe room on the chamber, the box beam is C40 reinforced concrete structure, and the top elevation is 11.0m. The layout of the sluice is shown in Figure 1.

![Figure 1](image-url)

Figure 1  The engineering layout

### 3 Parameter selection

Through conventional geotechnical tests, triaxial tests and advanced consolidation tests, the parameter table of the soil hardening model is obtained. The model parameters of each layer under the soil hardening model are determined as shown in Table 1 and Table 2.

**Table 1**  Basic parameters of soil hardening model

| Soil name      | Thickness | Soil weight | Saturated bulk density | Void ratio | Permeability coefficient |
|----------------|-----------|-------------|------------------------|------------|--------------------------|
|                | H (m)     | ρ (kN/m³)   | ρ sat (kN/m³)          | e          | kₐ (m/day)      kᵥ (m/day) |
| 2-3 Silt with silt | 5~6       | 17.4        | 19.6                   | 1.32       | 4.38E-06        6.65E-06     |
| 2-4 silt       | 15~16     | 16.6        | 18.9                   | 1.71       | 1.62E-07        2.35E-07     |
| 3-1 Mucky clay | 5~6       | 18          | 20.5                   | 1.23       | 8.85E-07        6.59E-07     |
| 3-3 Silty clay | >4        | 19          | 20.6                   | 0.85       | 6.52E-05        7.89E-05     |
Table 2  Main parameters of soil hardening model

| Soil name          | Thickness (m) | Cohesion (kPa) | Internal friction angle (°) | $E_{50}$ (kPa) | $E_{ur}$ (kPa) | $E_{oed}$ (kPa) | $m$ |
|--------------------|--------------|---------------|-----------------------------|---------------|---------------|----------------|-----|
| 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   |

4 Model building

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 seawall 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 mode transition is adopted, and the elevation gradually decreases from 11.0 m to 7.8 m. The place behind the wing wall is filled with solidified soil.

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.

![Figure 2](image2)

**Figure 2** Simplified sluice analysis model

![Figure 3](image3)

**Figure 3** PLAXIS analysis model of Sluice

The loading process during construction is shown in Table 3.

Table 3  Loading elevations of seawall sections at various levels  Unit: m

| Section               | Original coated surface | Original coated surface | 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            |
5 Analysis of simulation results
The simulation results of East 1# sluice are shown in Table 4, the settlement comparison curves of seawall and sluice are shown in Figure 4 and 5, and the comparison curves of sluice and seawall under the two conditions of seawall material are shown in Figure 6 and 7. According to PLAXIS finite element analysis of the settlement on the connecting section of the sluice under the ordinary riprap and empty box seawall modes, the uneven settlements of the ordinary riprap embankment model for 1, 2, 5, and 10 years are 209.03mm and 347.47mm, 663.30mm, 848.21mm respectively; the uneven settlement of the empty box embankment model for 1 year, 2 years, 5 years, and 10 years are: 99.79mm, 204.99mm, 398.69mm, 559.47mm respectively. Comparing the settlements of sluices and seawalls under the two seawall material conditions, it is found that the settlements of the sluices of the two are relatively close, and the settlement of the seawall is larger, which is close to 2 times. The empty box seawall model can greatly reduce the dead weight of the seawall, so that the seawall settlement during the operation period is reduced by nearly half.

Table 4  Simulation results during sluice operation

|                  | Ordinary riprap seawal modes | Empty box seawal modes | Remark          |
|------------------|-----------------------------|------------------------|-----------------|
|                  | Sluice settlement (mm)      | Seawall settlement (mm) | Uneven settlement (mm) | Sluice settlement (mm) | Seawall settlement (mm) | Uneven settlement (mm) |
| Completed        | 0.00                        | 0.00                   | 0.00             | 0.00                    | 0.00                    | 0.00                        |
| 1st year         | 6.32                        | 215.35                 | 209.03           | 5.51                    | 105.30                  | 99.79                        |
| 2nd year         | 10.56                       | 358.03                 | 347.47           | 9.01                    | 214.00                  | 204.99                       |
| 5th year         | 19.94                       | 663.30                 | 643.36           | 17.96                   | 416.65                  | 398.69                       |
| 10th year        | 35.24                       | 883.45                 | 848.21           | 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).

Figure 4  The seawall and sluice settlement curves (ordinary riprap seawal modes)

Figure 5  The seawall and sluice settlement curves (empty box seawal modes)
6 Conclusion

(1) According to PLAXIS finite element analysis of the settlement on the connecting section of the sluice under the ordinary riprap and empty box seawall modes, the uneven settlements of the ordinary riprap embankment model for 1, 2, 5, and 10 years are 209.03mm and 347.47mm, 663.30mm, 848.21mm respectively; the uneven settlement of the empty box embankment mode for 1 year, 2 years, 5 years, and 10 years are: 99.79mm, 204.99mm, 398.69mm, 559.47mm respectively. Comparing the settlements of sluices and seawalls under the two seawall material conditions, it is found that the settlements of the sluices of the two are relatively close, and the settlement of the seawall is larger, which is close to 2 times.

(2) The uneven settlement of the connecting section of the east 1# sluice is mainly manifested at the junction of the empty box of the sluice and the riprap area of the seawall. The results of simulating the uneven settlement of the connecting section of the sluice with two different materials can be known that the empty box seawall model can greatly reduce the dead weight of the seawall, so that the seawall settlement during the operation period is reduced by nearly half.

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