The three-dimensional numerical analysis of the impact of newly Seawall with inner epeirogenic through blowpipe to adjacent pile foundation of bridge

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Abstract. The internal force and deformation of the adjacent bridge pile foundation is influenced by newly Seawall with inner epeirogenic through blowpipe, which may endanger the normal operation of the bridge. Using Plaxis3D software in this paper, the subsoil is used by the Hardening Soil model, and analysis the mechanism of the influence of bridge pile foundation by the newly Seawall with the inner epeirogenic through blowpipe when the distance between Seawall and bridge is changed from 200m to 250m, 300m, 350m and so on, which provides reasonable safety distance between the Seawall and bridge. The analysis results show that the vertical displacement and internal force of bridge pile foundation is less affected by the newly Seawall with the inner epeirogenic through blowpipe, which will not affect the bearing capacity of the bridge pile foundation. However, the horizontal displacement of pile foundation of the bridge is greater influenced by newly Seawall with the inner epeirogenic through blowpipe, which will affect the normal operation of the bridge. As long as reasonable rate is controlled by epeirogenic through blowpipe, the max horizontal displacement of pile foundation can meet the design requirements when the distance is 300m between Seawall and bridge.

1. Introduction
With the development of coastal cities, soil resources have become a bottleneck restricting urban development, and there are often overlapping and adjacent phenomena in engineering construction. Excessive tensile stress and displacement of pile foundation of adjacent structures lead to ground filling, stacking and other construction.

YangMin [1] pointed out that the large horizontal displacement of the pile foundation caused by long-term stacking or even overload was the main reason for the collapse of the factory building. What is more, he proposed Standard of control for the displacement of pile foundation. LiXuefeng [2] summarized the research status of the influence of lateral displacement on abutment pile foundation. The displacement of pile foundation is closely related to the degree of soil consolidation, and is significant impacted by loading rate of subgrade. YaoWenjuan [3] used three-dimensional ABAQUS software to analyze and study the additional settlement and additional internal force caused by side...
load in soft foundation, which affected the safe use of wharf. By replacing and strengthening the soft soil, which is reducing the settlement of the soil. Meanwhile, the influence on the internal force and deformation of the pile foundation can be obviously reduced. NieRusong[4] used three-dimensional finite element program to analyze the influence mechanism of the filling soil behind the abutment of low bearing platform on the internal force and deformation of pile foundation, and pointed that the horizontal displacement of pile and the maximum bending moment of pile body increase linearly with the increase of filling soil. In order to determine the nearest influence distance between the embankment and the buildings with pile foundation, the loading test was carried out on the embankment beside the buildings in this paper [5]. The results show that when the distance between pile foundation and the toe of embankment is more than 4 times of soft soil thickness, the influence of embankment filling on the pile foundation can be ignored.

In this paper, the finite element method is used to analyze the influence of different distance of Seawall filling and inside land filling on the internal force and deformation of bridge pile foundation, so as to provide a basis for determining the safe distance of between Seawall and Bridge.

2. Project profile
The bridge approach the Seawall, which upper structure is 50m span with prestressed concrete continuous beam, the lower structure using bored pile foundation. Pile caps for the round, diameter of 8.5m, the elevation of + 2.5m, and thickness of 2.5m. There are four bored piles under the pile cap, which diameter is 1.5m, length is 95m, and the bottom elevation of pile is - 95m. The layout about piles and pile caps as shown in figure 1.

The bridge and the Seawall of west side close. The distance between center line of the bridge and the Seawall axis is 300m.

Now the Seawall project will be built on the east side of the bridge, which is shown in figure 2. In the process of Seawall construction, large horizontal displacement of the soil occurs within a certain range. When the bridge is close to the seawall, large horizontal displacement may occur to the pile foundation of the bridge, which affecting the safe use of the bridge.

In this paper, plaxis3D software is used, and the Soil Hardening Model is adopted. When the distance between the bridge and Seawall is 200m, 250m, 300m and 350m respectively, the influence of the seawall construction and the filling in the surrounding area on the internal force and deformation of the pile foundation of the bridge is analyzed, which providing a basis for determining the reasonable distance between Seawall and Bridge.

![Figure 1 the layout about piles and pile caps](image1)

![Figure 2 the layout between Seawall and the bridge](image2)
3. Calculating parameter

According to report of geotechnical investigation, which provides the compression modulus $E_{1:2}$ pointed the ratio of stress and strain by consolidation pressure from 100kPa to 200kPa. However, the numerical simulation of different constitutive model required different calculating parameter. In this paper, by using geotechnical laboratory functions from Plaxis3D soft and the current research results to determine the parameter of Soil Hardening Model, which using modulus such as $E_{0.5}^{\text{ref}}$, $E_{\text{oed}}^{\text{ref}}$ and $E_{ur}^{\text{ref}}$.

Wang Wei dong researched the soft soil parameters of Soil Hardening Model in Shanghai area, The results shows that the soil of $E_{0.5}^{\text{ref}}$ value for $E_{\text{oed}}^{\text{ref}}$ 0.9 ~ 1.3 times, $E_{\text{oed}}^{\text{ref}}$ value for $E_{1:2}$ 0.9 ~ 1.0 times. At the same time, the soft soil from TianJin shows that $E_{0.5}^{\text{ref}}$ value for $E_{\text{oed}}^{\text{ref}}$ 0.5 ~ 1.8times, and $E_{\text{oed}}^{\text{ref}}$ value for $E_{1:2}$ 0.8 ~ 2.1 times.

Wang Wei dong and Chen Bo lang through the comparative analysis between numeric calculation and engineering measured data, pointed out that when $E_{0.5}^{\text{ref}}=E_{\text{oed}}^{\text{ref}}$, $E_{ur}^{\text{ref}}=4 E_{0.5}^{\text{ref}}$, $E_{\text{oed}}^{\text{ref}}=E_{1:2}^{\text{ref}}$ or $E_{0.5}^{\text{ref}}=E_{\text{oed}}^{\text{ref}}$, $E_{ur}^{\text{ref}}=5 E_{0.5}^{\text{ref}}$ and $E_{\text{oed}}^{\text{ref}}=E_{1:2}^{\text{ref}}$. The numerical results are close to the engineering measured data.

In addition, it is suggested in the Plaxis3D Material Manual that $E_{0.5}^{\text{ref}}=E_{\text{oed}}^{\text{ref}}$, $E_{ur}^{\text{ref}}=3 E_{0.5}^{\text{ref}}$. In this paper, the functions of geotechnical laboratory in Plaxis3D are utilized, and $E_{1:2}$ and $E_{\text{oed}}^{\text{ref}}$ satisfy the equation such as $E_{1:2}=1.25E_{\text{oed}}^{\text{ref}}$.

According to the above discussion, the parameters of the Soil Hardening Model in this paper as follow: $E_{\text{oed}}^{\text{ref}} = 0.8E_{1:2}$, $E_{0.5}^{\text{ref}} = E_{\text{oed}}^{\text{ref}}$, $E_{ur}^{\text{ref}} = 3E_{0.5}^{\text{ref}}$. Meanwhile, the power exponent m, take 1.0 for soft clay, 0.5 for sand and 0.8 for other clay. The parameters of the Soil Hardening Model are shown in table 1.

The calculation parameters of pile and cap are respectively shown in table 2 and table 3.

| Soil layer number | Name of soil   | Natural gravity (kN/m³) | Saturated gravity (kN/m³) | osmotic coefficient (10⁻⁶/cm/s) | Cohesion (kPa) | Internal friction angle (°) | stiffness parameters of Soil Hardening Model | Kref/a | Kref/c |
|------------------|---------------|------------------------|------------------------|-------------------------------|----------------|----------------------------|------------------------------------------|--------|--------|
| 1                | Rip rap       | 19.4                   | 21.4                   | 1                             | 1              |                           |                                           |        |        |
| 2                | dredger fill  | 17                     | 18                     | 0                             | 0              |                           |                                           |        |        |
| 3                | muddy silt clay | 17.4                 | 17.5                 | 0.000419                      | 0.001139       | 13                       | 28.3                      | 1.8 | 5.4 | 1 | 0.526 |
| 4                | Silty clay    | 18.9                   | 19                    | 0.088214                      | 0.042854       | 18                       | 30.4                      | 4.2 | 12.6 | 0.8 | 0.494 |
| 6                | clay          | 19.2                   | 19.5                 | 0.097565                      | 0.036461       | 15                       | 24.8                      | 3.7 | 11.1 | 0.8 | 0.581 |
| 7                | silt clay     | 19.2                   | 19.3                 | 0.000971                      | 0.000795       | 15                       | 20.1                      | 6.2 | 18.6 | 0.8 | 0.514 |
| 8                | medium sand   | 19.2                   | 20                    | 0.021341                      | 0.021341       | 20                       | 36.5                      | 7.3 | 21.9 | 0.5 | 0.405 |

| name            | elasticity modulus | diameter/m | pilelength/m | Interface reduction factor | The elevation of the pile/m |
|-----------------|--------------------|------------|--------------|--------------------------|---------------------------|
| pile            | 30Gpa              | 1.5        | 95           | 0.85                      | 0                         |

| name            | elasticity modulus | Poisson's ratio | diameter/m | thickness /m | The elevation of the cap /m |
|-----------------|--------------------|-----------------|------------|--------------|---------------------------|
| cap             | 30Gpa              | 0.2             | 8.5        | 2.5          | 2.5                       |
4. Finite element model and calculation conditions

The axis of the bridge from 300m distance to build seawalls axis as an example, the finite element model is shown in figure 3. The total length of 900m for horizontal direction (X) regional, while for vertical direction, the surface elevation according to the preliminary design height of 0.5m, the bottom area elevation is -120 m, the filling materials of seawall and the dredger fill by using the Linear Elastic Model, while foundation soil using Soil Hardening Model.

Piles and caps are all using the Linear Elastic Model, the bottom elevation of pile take -95m, pile length take 95m, the high of pile caps take 2.5m, and caps diameter take 8.5m. The weight of bridge piers, pile foundations and the upper bridge loads are not considered in the calculation. In this paper, the calculation results of internal force and deformation of piles indicate the additional internal force and deformation by construction of Seawall and land reclamation, The vertical displacement of pile foundation is positive for upward, negative for downward.

The X-axis of positive horizontal displacement is towards the right.

The axial tension of pile body is positive and the pressure is negative.

At the same time, in order to analysis and comparison, this paper selected a pile near the seawall as a typical pile to analyze its internal force and deformation.

![Figure3 three-dimensional finite element model](image1)

![Figure4 grid division diagrams of seawall and dredger fill](image2)

![Figure5 grid division diagrams of cap](image3)

The model adopts tetrahedral element, and the grid division diagrams of soil and cap are shown in figure 4 and figure 5.

In the model, the upper boundary is free, while the lower boundary is fixed, both upper and lower boundaries can be drained. The front, rear, left and right boundaries are normal constraints, while the other directions are free, and drainage are prohibited.

The calculated construction stage of numerical simulation is shown in table 4.

| Serial number | construction stage                          | duration/month | total duration/month |
|---------------|--------------------------------------------|----------------|---------------------|
| 1             | The seawall is built at a height of 4m      | 3              | 123                 |
| 2             | The seawall is built at a height of 8m      | 3              | 126                 |
| 3             | Seawall complete                            | 12             | 138                 |
| 4             | The elevation of dredgerfill is 6m          | 24             | 162                 |
| 5             | Hydraulic reclamation Over 5 years          | 60             | 222                 |
5. Analysis of computing result

When the distance between the bridge and Seawall is 300m, the lateral displacement of typical pile is shown in the figure 6.

![Completion of Seawall](image)

**Figure 6a completion of Seawall**

![Completion of Hydraulic Reclamation](image)

**Figure 6b completion of hydraulic reclamation**

![5 Years After Hydraulic Reclamation](image)

**Figure 6c 5 years after hydraulic reclamation**

As can be seen from the figure 6:

1. The horizontal displacement of bridge pile foundation is caused by newly built Seawall with inner epeirogenic through blowpipe. The typical pile of top horizontal displacement is 6.4mm after completion of Seawall, while pile of tip horizontal displacement is 1.8mm; The typical pile of top horizontal displacement is 9.5mm after completion of hydraulic reclamation, while pile of tip horizontal displacement is 2.8mm; The typical pile of top horizontal displacement is 3.8mm five years after completion of hydraulic reclamation, while pile of tip horizontal displacement is 1.3mm.

2. Five years after the completion of hydraulic reclamation, the horizontal displacement of the typical pile is reduced compared with that after completion of hydraulic reclamation. This is mainly due to the excess pore pressure dissipates less after completion of hydraulic reclamation. The deformation of soil is mainly shape rather than consolidation. While five years after the completion of hydraulic reclamation, the deformation of soil is mainly consolidation with the dissipation of the excess pore water pressure. As a result, the horizontal displacement of the pile decreases.

The horizontal displacement and maximum axial force of typical pile is shown in table 5.
Table 5 the influence of distance between the bridge and Seawall on the internal force and deformation of typical pile

| distance L/m | completion of Seawall | completion of hydraulic reclamation | Five years after the completion of hydraulic reclamation |
|--------------|-----------------------|------------------------------------|-------------------------------------------------------|
|              | top horizontal displacement /mm | tip horizontal displacement /mm | top vertical displacement /mm | Maximal bending moment/ kN•m | top horizontal displacement /mm | tip horizontal displacement /mm | top vertical displacement /mm | Maximal bending moment/ kN•m | top horizontal displacement /mm | tip horizontal displacement /mm | top vertical displacement /mm | Maximal bending moment/ kN•m |
| 200          | 11                    | 5.3                               | -0.8                              | 80.9                        | 18.4                           | 8.5                           | -1.2                              | 116.3                        | 9.4                           | 6                             | -2                             | 88.4                        |
| 250          | 8.8                   | 2.9                               | 0                                | 64.9                        | 13.6                           | 4.5                           | 0.1                                | 69.6                        | 5.7                           | 2.5                           | -0.6                           | 73.4                        |
| 300          | 6.4                   | 1.8                               | 0.2                              | 86.5                        | 9.5                            | 2.8                           | 0.4                                | 85                          | 3.8                           | 1.3                           | -0.2                           | 89                          |
| 350          | 4.2                   | 1.2                               | 0.3                              | 75.6                        | 6.6                            | 1.8                           | 0.5                                | 81.1                        | 2.5                           | 0.8                           | 0.1                            | 79.4                        |

As can be seen from the table 5:

1. When the distance between Seawall and bridge from 200m to 350m, after completion of Seawall, the top horizontal displacement of the typical pile is from 11mm to 4.2mm, and the top vertical displacement is from -0.8mm to 0.3mm. The maximum bending moment is respectively 80.9 kN•m, 64.9 kN•m, 86.5 kN•m and 75.6 kN•m; After completion of hydraulic reclamation, the top horizontal displacement of the typical pile is from 18.4mm to 6.6mm, and the top vertical displacement is from -1.2mm to 0.5mm. The maximum bending moment is respectively 116.3kN•m, 69.6 kN•m, 85 kN•m and 81.1 kN•m; Five years after the completion of hydraulic reclamation, the top horizontal displacement of the typical pile is from 9.4mm to 2.5mm, and the top vertical displacement is from -2.0mm to 0.1mm. The maximum bending moment is respectively 88.4 kN•m, 73.4 kN•m, 89 kN•m and 79.4 kN•m.

2. When the distance between Seawall and bridge from 200m to 350m, after completion of Seawall and hydraulic reclamation, the top horizontal displacement of the typical pile varies from -2.0mm to 0.5mm, from this the top vertical displacement of the typical pile is very small and the change is not obvious; The maximum bending moment of typical pile varies from 64.9 kN•m to 116.3kN•m, and the maximum tensile and compressive stress varies from 0.2MPa ~ 0.35MPa. What is more, the stress generated by this is far smaller than that generated by the upper load. Therefore, the influence on internal force and deformation of typical pile by newly Seawall with inner epeirogenic through blowpipe is minor; The top horizontal displacement of the typical pile is 18.4mm ~ 2.5mm. According to the design requirements of the bridge pile foundation, the limit of top horizontal displacement of pile foundation is 6mm. Therefore, the top horizontal displacement of the pile is the main factor affecting the safety of the bridge.

3. From the safety angle of bridge pile foundation, when the distance is 300m between Seawall and bridge, the maximum top displacement of pile is 6.4mm, 9.5mm and 3.8mm respectively after completion of Seawall, hydraulic reclamation and five years later.

After completion of Seawall, the top horizontal displacement of pile meets the design requirements, in the process of hydraulic reclamation, the top horizontal displacement of pile also meets the design requirements only if reasonable loading rate and strengthening pile foundation monitoring.

In this paper, the height of the dredger fill take 6m, which considering the settlement by the dredger fill, the height of the dredger fill is greater than the design. The calculated result is more secure.

6. Conclusion
Using Plaxis3D software in this paper, the subsoil is used by the Hardening Soil model. Analysis the mechanism of the influence of bridge pile foundation by the newly built Seawall with the inner
epirogenic through blowpipe when the distance between Seawall and bridge is changed from 200m to 250m, 300m, and 350m. Conclusions are as follows:

1 In the process of hydraulic reclamation, the loading rate has an effect on the top horizontal displacement of pile foundation. Five years after the completion of hydraulic reclamation, the horizontal displacement of the typical pile is reduced compared with that after completion of hydraulic reclamation.

2 The construction of newly Seawall with inner epirogenic through blowpipe have little effect on the bearing capacity of bridge pile foundation and have great effect on the horizontal deformation of bridge pile foundation, which is main factor affecting the safety of bridge.

3 When the distance between Seawall and bridge is 300m, in the process of hydraulic reclamation, the top horizontal displacement of pile meets the design requirements. The bridge is in safe condition.

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