NUMERICAL INVESTIGATION OF THE INFLUENCE OF SPATIAL EFFECTS AND SUPPORTING STRUCTURES DURING PIT EXCAVATION

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Abstract

This paper reports on a field test in Nanjing, China, performed to investigate the effects of excavation on shallow-buried pipelines by monitoring and analyzing the displacements of these pipelines. A parametric study is also carried out using the finite-element program ABAQUS to investigate the influence of the spatial effects of the pit excavation and the supporting-structure combination forms. The numerical simulations are verified by the field test. The results show that the first excavating area, which is farther from the existing buried pipeline, causes smaller displacements of the pipeline. When the slope angle of the existing bored piles increases from 0° to 15°, the maximum horizontal and vertical displacements decrease by 4.92 mm and 2.49 mm, respectively. Both the maximum horizontal and vertical displacements decrease by over 20% when the front row pile length is increased by 50%. An increase in the slope angle or the front row

Keywords

pit excavation; spatial effect; supporting structure combination; field test; pipeline displacement monitoring

Izvleček

V članku je podano poročilo o terenskem preizkusu v Nanjingu na Kitajskem, ki je bil opravljen z namenom raziskovanja učinkov izkopavanja na plitveje vkopane plinovodih s spremljanjem in analiziranjem premikov teh cevovodov. Izvedena je bila tudi parametrična študija z uporabo programa na osnovi končnih elementov ABAQUS. Raziskovani so vplivi prostorskih učinkov izkopa gradbene jame in modelov sestavljena podporna konstrukcija, terenski preizkus, spremljanje premikov cevovodov

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Ključne besede

izkop gradbene jame, prostorski vpliv, sestavljena podporna konstrukcija, terenski preizkus, spremljanje premikov cevovodov

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pilot length helps to reduce the pipeline displacements due to the increase in the effective weight and bottom width of the trapezoidal gravity retaining wall that is equivalent to the double row of piles. This research has important theoretical significance and practical value for the design and construction of foundation pit engineering.

1 INTRODUCTION

Currently, underground space has been widely developed worldwide for all kinds of uses, resulting in a large number of excavations. It is well known that the significant changes in the surrounding soil stress [1] and strain field caused by deep excavation can change the static and dynamic response of existing structures [2]. Sharma and Hefny [3] found that the lining stiffness [4] of a tunnel has a significant impact on the displacement and deformation of the tunnel, caused by adjacent excavation. The stiffer lining sustains less displacement and deformation, but is likely to experience greater bending moments. Chen et al. [5] investigated the development of the bending moment and displacement of a tunnel during different construction stages of a nearby excavation. Chen also suggested that the bending moment and displacement of the tunnel are strongly related to the unloading effects [6] and displacement of the surrounding soils, which can be alleviated by means of a proper improvement of the excavation sequence.

Liyanapathirana and Nishanthan [7] simulated the excavation process of the foundation pit, and a finite-element method was used to analyze the stress behavior of a single pile [8] under the action of surface movement [9] caused by the excavation. The stiffness and spacing of the wall-support system significantly influence the pile behavior adjacent to the excavation. Therefore, considerable effort has been invested to study the various factors that can influence the stress behavior and displacements in a pit excavation. The method of estimating the water and earth pressures [10] on supporting structures separately and together, which has become a focus of attention and discussion in the field of geotechnical engineering, is analyzed. It is indicated that the method of estimating water and earth pressures together is inconsistent with the principal of effective stress. However, the protection of shallow-buried pipelines and constructions has gradually become the dominant control factor for design and construction in foundation-pit engineering. Despite many studies on foundation-pit engineering, at present there are some subjects that still lack consideration: (1) an improper form of support can cause pit-excavation accidents, resulting in the destruction of the pipes; (2) for foundation-pit engineering in soft soil in the riverside of the Yangtze River, the influence of excavation on the surrounding existing structures is less-well studied; and (3) the influence of spatial effects during excavation and different combination forms of supporting structures of foundation-pit excavation are seldom considered.

This paper reports on a field test to study the deformation of existing pipelines during excavation at the riverside of the Yangtze River. According to the on-site engineering background, the numerical simulation is carried out using the three-dimensional finite-element software ABAQUS [11]. The numerical results are verified by the on-site monitoring data. Then, a parametric study is undertaken to investigate the influence of the spatial effects and the forms of supporting structures during foundation-pit engineering. This investigation is undertaken by comparing the displacements of the shallow-buried pipeline beside the pit. Finally, construction measures that can effectively reduce the influence of the foundation-pit excavation are put forward to provide a reference for similar projects in the future.

2 FIELD TEST

2.1 Background of the field test

The pit project is located in the Yangtze River diffuse beach landform unit in Nanjing, and there is a DN600 rainwater pipeline 5 m away from the boundary of the pit, which is buried 2 m below the surface. The DN600 pipeline is of the pre-stressed concrete cylinder pipe. The external diameter of the rainwater pipelines is 630 mm. The elastic and bending moduli of the material are 960MPa and 24MPa, respectively. The pit site profile and the pipeline distribution are shown in Figure 1. The total length of the foundation pit is approximately 628 m, the total area is approximately 27049 m², and the soil-excavation depth is approximately 5.85 m. According to the exploration data of the stratum structure, the soil profile of the site is mainly composed of clay and silt, and the soil's physical-property parameters are shown in Table 1.
Table 1. Physical and mechanical parameters of soil parameters.

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Soil</th>
<th>Thickness (m)</th>
<th>$\gamma$ (kN/m$^3$)</th>
<th>$E_s$ (MPa)</th>
<th>$\varepsilon$</th>
<th>$c$ (kPa)</th>
<th>$\phi$ (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>①</td>
<td>Plain fill</td>
<td>4.00</td>
<td>18.00</td>
<td>4.10</td>
<td>0.33</td>
<td>12.00</td>
<td>11.00</td>
</tr>
<tr>
<td>②$\overset{1}{2}$</td>
<td>Silty clay</td>
<td>8.50</td>
<td>18.10</td>
<td>11.40</td>
<td>0.33</td>
<td>12.90</td>
<td>11.00</td>
</tr>
<tr>
<td>②$\overset{2}{2}$</td>
<td>Clayey silt</td>
<td>5.00</td>
<td>19.30</td>
<td>10.09</td>
<td>0.33</td>
<td>3.60</td>
<td>32.90</td>
</tr>
<tr>
<td>②$\overset{3}{2}$</td>
<td>Silt</td>
<td>4.00</td>
<td>19.40</td>
<td>11.20</td>
<td>0.30</td>
<td>5.00</td>
<td>30.20</td>
</tr>
<tr>
<td>③$\overset{2}{2}$</td>
<td>Fine sand</td>
<td>8.50</td>
<td>19.60</td>
<td>11.15</td>
<td>0.30</td>
<td>4.70</td>
<td>31.10</td>
</tr>
</tbody>
</table>

NOTES: All the data were obtained from the laboratory tests.  
$\gamma$ = the unit weight  
$E_s$ = the compression modulus  
$\varepsilon$ = the Poisson's ratio  
$c$ = the cohesion of the soil  
$\phi$ = the friction angle of the soil

Soil layer ① is mainly distributed in the north and west of the study area, while soil layers ②$\overset{1}{2}$, ②$\overset{2}{2}$ and ②$\overset{3}{2}$ are unevenly distributed across the whole field and are saturated. The low density of soil layer ① leads to the existence of large pores between the soil particles, providing space for the storage of groundwater. This type of soil structure has a better connectivity and permeability than those of soil layers ②$\overset{1}{2}$, ②$\overset{2}{2}$ and ②$\overset{3}{2}$, which have poor water permeability and supply capacities. The initial position of the shallow phreatic water is 0.1–1.5 m from the ground.

2.2. Construction technology and procedure

The zoning situation of the foundation pit is shown in Figure 1. The order of excavation in the construction of the pit in this project is as follows: first, divide the pit into two layers of excavation and then dig A $\rightarrow$ B $\rightarrow$ C $\rightarrow$ D $\rightarrow$ E $\rightarrow$ F $\rightarrow$ G. The supporting structures in the pit engineering are divided into three segments, as shown in Figure 2.

(1) From part a to part b and part b to part c, $B=5.2$ m ($W_1=3.7$ m, $W_2=1.5$ m).
(2) From part c to part d, $B=6.7$ m ($W_1=3.7$ m, $W_2=3.0$ m).
(3) From part d to part a, $B=6.2$ m ($W_1=3.7$ m, $W_2=2.5$ m).

$B$ is the width of the cement retaining wall. $W_1$ and $W_2$ are the widths of the slabs of the cement retaining wall. A wide cement retaining wall and the double row of $\Phi 800$ cast-in-place bored piles are used as the supporting structures.
2.3 On-Site Monitoring Design

Considering the engineering monitoring projects and geological conditions, the monitoring settings are shown in Table 2.

The support structures of this foundation engineering and the shallow-buried pipeline monitoring point plane layout are shown in Figure 1. Twenty-five monitoring points are arranged on the support structures, 12 monitoring points are arranged along the enclosure structure and 6 monitoring points are arranged along the shallow-buried pipeline to monitor the horizontal and vertical displacements so that we can evaluate the impact of the pit excavation on the surrounding existing structures. The layout principles and the numbers of test points are shown in Table 3.

![Figure 3](image-url)  
(a) On-site monitoring horizontal displacements. (b) On-site monitoring vertical displacements.

### Table 2. Monitoring projects.

<table>
<thead>
<tr>
<th>Monitoring projects</th>
<th>Design value</th>
<th>Warning value</th>
<th>Alarm value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ultimate displacements value (mm)</td>
<td>Rate of change (mm/d)</td>
<td>Cumulative change value (mm)</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------</td>
<td>------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Horizontal and vertical displacements of the supporting structures</td>
<td>A~G 35.00</td>
<td>2.00</td>
<td>21.00</td>
</tr>
<tr>
<td>Others</td>
<td>30.00</td>
<td>2.00</td>
<td>18.00</td>
</tr>
<tr>
<td>Deep horizontal displacements</td>
<td>A~G 35.00</td>
<td>2.00</td>
<td>21.00</td>
</tr>
<tr>
<td>Others</td>
<td>30.00</td>
<td>2.00</td>
<td>18.00</td>
</tr>
<tr>
<td>Pipeline displacements</td>
<td>Rigidity /</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Flexibility</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
</tbody>
</table>

### Table 3. Monitoring station layout numbers and principles.

<table>
<thead>
<tr>
<th>Numbering</th>
<th>Monitoring projects</th>
<th>Quantity</th>
<th>Layout principle</th>
<th>Monitoring point number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Horizontal and vertical displacements of the supporting structures</td>
<td>25</td>
<td>Set one monitoring point along the top of the pile at 20-25m</td>
<td>QL1~QL25</td>
</tr>
<tr>
<td>2</td>
<td>Deep horizontal displacements</td>
<td>12</td>
<td>Set one monitoring point along the perimeter of the enclosure structures at 25-30m</td>
<td>CX1~CX12</td>
</tr>
<tr>
<td>3</td>
<td>Pipeline displacements</td>
<td>6</td>
<td>Set one monitoring point along the buried pipeline at 20-25m</td>
<td>G1~G6</td>
</tr>
</tbody>
</table>
The results of the on-site monitoring are shown in Figure 3. Both the horizontal and vertical displacements of the pipeline are compatible with the construction conditions of the foundation pit and show a synchronous trend. With the excavation of the pit, the horizontal and vertical displacements of the pipeline monitoring points gradually increase with the excavation depth. Then, the horizontal and vertical displacements of each monitoring point gradually decrease and eventually stabilize. The maximum value of the cumulative amount of horizontal displacement reaches 5.43 mm; the maximum value of the vertical displacement reaches 5.19 mm; both of which are far below the alarm value of the cumulative displacement of 20 mm. In addition, a displacement singularity occurs for the horizontal displacement of the monitoring point G6. This singularity can be caused by temporary loading on the ground and measurement errors when monitoring at this point.

3 NUMERICAL ANALYSIS OF THE PIT EXCAVATION

3.1 Geometric models

A three-dimensional numerical analysis using ABAQUS is performed. Because of the asymmetry of the foundation pit model and pipeline position and the asymmetry of the pit excavation, it is necessary to carry out a comprehensive three-dimensional modeling of the project. According to the engineering background, the long east edge of the pit is 170 m, the southwest length of the Stone Bridge Waterway is 150 m, and the depth of the pit excavation is 5.85 m. The back boundary of the supporting structure is five times the depth of the excavation, as is the bottom boundary. Additionally, the scope of influence is 20 m outside of the pipeline. As a result, the total length of the final model is 240 m, the total width is 225 m, and the total depth is 30 m.

3.2 Soil properties and constitutive models

In the three-dimensional numerical simulation calculation, the Mohr-Coulomb model is selected as the soil model. The bored pile, cement retaining wall and pipelines are all selected as isotropic elastic models. The thickness, compressive modulus, cohesive force and internal friction angle of the different soil layers in the model are evaluated according to the geological survey data measured at the beginning of the project. The physical parameters are shown in Table 1. The physical and mechanical parameters corresponding to each structural material are shown in Table 4. In the pit-supporting structure system of this project, the water curtain of the cement mixing pile and the cement retaining wall with a variable section width are soil-cement materials, while the double row of cast-in-place bored piles are C30 concrete.

3.3 Finite-element meshes and boundary-condition settings

The total number of grid divisions in the model is 84205 units, of which the number of soil units is 72377 and the number of nodes is 83776. The number of units in the pipeline is 1136, and the corresponding number of nodes is 1728. The number of support structure units is 10692, and the corresponding number of nodes is 14652. Each material in the model uses a C3D8 hexahedral solid element. The boundary conditions are set in the analysis step to limit the horizontal and vertical displacements of the bottom surface of the geometric model (horizontal displacement equals 0, vertical displacement equals 0). While limiting the horizontal displacements around the soil model (x-direction displacement equals 0 or z-direction displacement equals 0), the vertical displacements can be changed freely. The grid division and boundary-limit displacements are shown in Figure 4.

<table>
<thead>
<tr>
<th>Supporting structure</th>
<th>$y$ (kN/m$^3$)</th>
<th>$E$ (GPa)</th>
<th>$\epsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast-in-situ bored pile</td>
<td>24.50</td>
<td>30.00</td>
<td>0.20</td>
</tr>
<tr>
<td>Concrete retaining wall</td>
<td>18.30</td>
<td>0.20</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Table 4. Physical and mechanical parameters of soil parameters.

NOTES: All the data were obtained from the laboratory tests. $y$ = the unit weight; $E$ = the elastic modulus; $\epsilon$ = the Poisson’s ratio

Figure 4. Meshing and boundary limit diagram.
4 RESULTS AND COMPARISONS

4.1 Verification

To verify the numerical simulation, the data obtained using the simulation are compared with the on-site monitoring data. The analysis of Figure 5 shows that the simulated values of the maximum horizontal displacements appear in the middle of the pipelines and are distributed symmetrically to both sides during different excavation stages. The measured values at the middle of the pit edge, which is parallel to the pipelines, are the largest and present a symmetrical distribution state. The change law of the simulated result is consistent with the measured one. With the increase in the excavation depth of the first layer of soil, the displacements of the existing pipelines are small, but increase slowly. By analyzing the Figure 6, as the excavation progresses, the displacements of the pipeline tend to increase gradually.

When excavating the second layer of soil, the displacements of the pipeline increase greatly with the depth of the excavation and finally tend to be stable. The measured value of the horizontal displacement of the pipeline is 5.43 mm, and the simulated value is 6.27 mm, a difference of 0.84 mm. Additionally, the measured value of the vertical displacement of the pipeline is 5.19 mm, and the simulated value is 4.87 mm, a difference of 0.32 mm. However, the measured and simulated displacement trends are slightly different in the bottom corner of the studied area because a series of idealized simplifications are carried out in the numerical simulation calculation, i.e., the bored pile, cement retaining wall and pipelines are all selected as isotropic elastic models to simplify the model and expedite the computation process. At the same time, a series of factors, such as precipitation, vehicle load and construction, which are related to the actual engineering, can also cause differences in the result.

However, as shown in Figures 6 and 7, the numerical simulated results are similar to the on-site monitoring data. Some critical points have relatively small errors, and we can clearly see that the trend of the simulated results is consistent with the on-site data. Through these points, we can determine that the numerical simulation model corresponds to the field engineering project.

4.2 Influence of space effect on the pipeline displacements

4.2.1 Influence of the sequence of pit excavation

Considering the distance from the excavation impact zone to the shallow-buried pipelines, along half of the
pipeline length, this section sets up two simulation working conditions to compare with the on-site working condition, and the influence of the pit excavation sequence on the shallow-buried pipeline is discussed. By analyzing Figure 7, which shows the results for different excavation block ordering, it is shown that the displacements of the pipeline at the pit corner are not very different from those of the on-site working condition, yet the difference increases at the central location of the pipeline. This might be because of the stress concentration at the corner of the foundation pit, which gradually disappears along the edge of the foundation pit, causing the displacement difference in the middle part to increase.

As shown in Figure 7, first excavating the areas which are far from the existing pipeline leads to the minimum displacements. The cause of this phenomenon is that the soil close to the pipeline is equivalent to the pressure and weight of one kind of supporting structure, which causes a reduction in the pipeline displacement when the area farther away from the pipeline is excavated first. In contrast, first excavating in the affected area near the pipeline results in larger displacements. The cause of this phenomenon is that the displacements generated by the nearer disturbance zone have a superposition effect on the displacements generated by any subsequent excavation in other areas.

4.2.2 Influence of the Number of Excavation Blocks

During the excavation, the block excavation can be divided into two types. One is that the block is not stratified for excavation, and the other is that the block is stratified for excavation. At present, the research on block excavation is still very vague. Some scholars mentioned that block excavation and backfilling can effectively reduce subsequent uplift displacement at the bottom of the foundation pit.

The way the case pit is used in this paper is a stratified block excavation. By keeping the number of excavation layers unchanged and changing the number of excavation blocks, this section sets up four simulation working conditions, shown in Table 5.

<table>
<thead>
<tr>
<th>Working Condition</th>
<th>Forms of block excavation</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-site Condition</td>
<td>Each layer is excavated in order of 7 blocks, A, B, C, D, E, F, G</td>
</tr>
<tr>
<td>Simulated Condition One</td>
<td>Each layer is excavated in one block</td>
</tr>
<tr>
<td>Simulated Condition Two</td>
<td>Each layer is excavated in order of 2 blocks, AEF and BCDG</td>
</tr>
<tr>
<td>Simulated Condition Three</td>
<td>Each layer is excavated in order of 4 blocks, A, DE, BF and CG</td>
</tr>
</tbody>
</table>

With changes in the number of excavation blocks, the results shown in Figure 8 indicate that the displacement value of the pipeline increases along the long edge of the pit, from the two corners to the middle. The displacement value reaches the maximum in the middle of the pipeline. By analyzing the horizontal and vertical displacements under the four working conditions, the more blocks there are, the smaller is the displacement value of the pipeline under the same number of excavation layers. During the excavation and unloading process of the foundation pit, with the removal of the overlying soil mass, the rock and soil mass at the bottom of the foundation pit will uplift and spring back due to
the stress redistribution, and the lateral deformation will also occur due to the stress redistribution of the soil mass at the side wall of the foundation pit. Although the total amount of unloading caused by the multi-block excavation and the whole-block excavation is the same, the larger the number of blocks, the less the amount of unloading every time, the smaller the stress change rate of soil, the smaller the damage degree\[12\] of soil, and the smaller the displacement caused.

4.3 Influence of the supporting structure on the pipeline displacements

4.3.1 Influence of the slope angle of the front pile

In the process of pit excavation, the supporting piles play a role in restraining the displacements, and mostly conventional engineering piles are used in the vertical direction. However, often in engineering practice, the supporting piles can effectively reduce the displacement of the soil around the pit when the piles are inclined at a certain angle, thereby reducing the influence on the displacement of the existing buried pipelines. Based on the ABAQUS model established in this pit project, this section sets up four simulation working conditions. The angle of the front pile is designed to be 0°, 5°, 10°, 15°, as shown in Figure 9. The influence of the inclined angle of the front pile on the displacements of the shallow-buried pipelines will be analyzed and discussed. The numerical simulation results of the existing pipeline displacements are shown in Table 6.

<table>
<thead>
<tr>
<th>Angle of slope of the front pile (°)</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>The maximum horizontal displacement (mm)</td>
<td>17.19</td>
<td>15.86</td>
<td>14.26</td>
<td>12.27</td>
</tr>
<tr>
<td>The maximum vertical displacement (mm)</td>
<td>10.28</td>
<td>9.91</td>
<td>9.03</td>
<td>7.79</td>
</tr>
</tbody>
</table>

The displacement of the pipeline decreases when the angle of the front-row pile increases. Keeping the rear-support pile vertical, the front-support pile inclined at a certain angle can effectively reduce the displacements of the existing buried pipeline. Moreover, with the increase in the slope angle, the effects of controlling the pipeline displacement become more obvious. When the current row pile is inclined, it is equivalent to forming a trapezoidal gravity retaining wall combined with the back-row pile, thus increasing its effective weight and bottom width. In the numerical simulation, the ability to reduce the deformation of the pit of the equivalent retaining wall is clearly shown.
However, the range of angles discussed in this paper is only 0° to 15°, and for larger angles, considering the increase in the difficulty in pit-supporting construction and the cost, the practical significance of the research is not considerable.

4.3.2 Influence of the length of the front pile

In the design of the foundation-pit support, for the convenience of the design and construction, when designing a double row of pile support, the lengths of the front piles are usually equal. However, for the support schemes of unequal length piles, there are few studies on the influence of the pit displacements. This section sets up five simulation working conditions, as shown in Table 7. The simulation results of the buried pipeline displacements under the different lengths of the front-support piles are shown in Table 8.

Table 7. Simulated conditions of the length of the front piles.

<table>
<thead>
<tr>
<th>Working Condition</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the front piles (m)</td>
<td>16</td>
<td>18</td>
<td>20</td>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>Length of the back piles (m)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 8. Maximum displacements with the length of the front pile.

<table>
<thead>
<tr>
<th>Length of the front pile (°)</th>
<th>16</th>
<th>18</th>
<th>20</th>
<th>22</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum horizontal displacement (mm)</td>
<td>20.20</td>
<td>18.26</td>
<td>17.19</td>
<td>16.78</td>
<td>16.70</td>
</tr>
<tr>
<td>Maximum vertical displacement (mm)</td>
<td>12.50</td>
<td>11.13</td>
<td>10.28</td>
<td>9.82</td>
<td>9.74</td>
</tr>
</tbody>
</table>

We can see that the maximum horizontal and vertical displacements decrease with the increasing pile length in the front row. The laws of the variation in the curves for the maximum horizontal and vertical displacements are the same. The cause of this phenomenon is the same as that for the equivalent retaining wall mentioned above. And it is easy to understand that the higher and heavier the retaining wall is, the less the displacements will be. This method reduces the displacement of the foundation pit by increasing its effective weight. Nevertheless, the sensitivity to the displacements of the pipelines decreases with the increasing length of the front-row pile. This is because the effective weight of the retaining wall formed by the rear pile does not increase after the front pile increases to a certain extent because the length of the rear pile does not lengthen.

5 CONCLUSIONS AND DISCUSSIONS

Based on previous research, this paper combines the on-site monitoring data of existing pipelines in the context of a soft soil foundation-pit project in Nanjing with an ABAQUS three-dimensional numerical simulation. By comparing the results of the simulation with the field test data, the displacements of the pipeline are studied by analyzing the spatial effects of the pit's excavation and the combination of piles in the supporting structure.

The main conclusions are as follows:

1. In the foundation-pit engineering of the Yangtze River plain, the horizontal and vertical displacements of the shallow-buried pipeline increase with the depth of the excavation. The displacements increase from the two external corners to the middle, which is a symmetrically distribution.

2. The space effect of the pit's excavation is significantly present. The soil in the area far from the pipeline should be excavated first, which can effectively restrain the displacements of the buried pipeline. In addition, it is more helpful to restrain the displacements of the pipeline by using as many layers and blocks as possible in the excavation design.

3. When a double-row pile support is used, the front pile is inclined at a certain angle within a certain range, which can effectively suppress the displacements of the existing buried pipeline. At the same time, the longer the front pile is, the smaller are the displacements of the pipeline.

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Disclosure statement

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