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Technical Note

Mechanical Behavior of Parallel Pipelines Under Foundation Pit Excavation

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In order to study the effect of foundation pit excavation on mechanics of parallel pipeline, a pipeline-soil interaction model was established based on the finite element principle. The deformation of the pipeline by the foundation pit excavation were analyzed. Effect regulations of parallel distance, pipeline parameters and foundation pit parameters on the deformation of the pipeline were studied. The results show that there are two maximum stress areas in pipeline under the action of excavation. The upper and lower surfaces of the pipeline also appear the large stress area. The pipeline has horizontal and vertical displacements. With the increasing of the parallel distance, the deformation of the nearest pipeline increases, but the deformation of the farthest pipeline decreases. With the increasing of the radius-thickness ratio and distance between the foundation pit and the nearest pipeline, the deformation of the pipeline decreases. With the decreasing of the foundation pit width, the deformation of the pipeline decreases. Effect of the foundation pit's length on the pipeline is not obvious.

Key words: parallel pipeline; foundation pit; numerical simulation; axial strain; displacement.

1. Introduction

In order to save land, improve the underground space utilization and avoid the damages to the pipeline by unpredictable factors. Buried pipeline have been widely used in pipeline construction project [1]. Therefore, the pipeline will be affected by a variety of underground constructions. The excavation of the foundation pit will cause soil disturbance around the pipeline, and the pipeline will bear additional load. It causes the pipeline to be displaced, and the excessive deformation will destroy the pipeline. And then lead to oil leaks, fires, explosions and other accidents [2]. Therefore, it is great for social and economic significance to study the effect of foundation pit excavation on pipelines.

Some scholars have studied the effect of the pipeline under foundation pit excavation. Wang [3] set up a 3D finite element model for simulating the interaction of soil-pipeline during foundation pit excavation by using the software Plaxis 3D Tunnel. Cai [4] proposes the DCFEM method to analyze the influence of deep excavation on adjacent underground pipelines by the statistical deformation curve of excavation. Jiang [5] derive the deformation and internal force of the pipeline by using the elastic foundation beam method. Du [6] study the evaluation method of influence of deep excavation on adjacent buried utilities and the influence of excavation on adjacent pipelines with varied diameters is analyzed by FLAC^{3D}. Yang [7] used software ANASYS to set up the 3D finite element model, the effect of size of excavation, pipeline's material, pipeline's depth, the distance between the excavation and soil mass are studied. Lv [8] used numerical calculation method to study the displacement of pipeline with inner pressure. Hu [9] used numerical software to study the influence of deep foundation pit excavation on pipeline in sand and gravel area, and effect of different parameters were analyzed. At present, the research has been focused on single pipeline, and the research for parallel pipeline is less. Therefore, this paper considers the soil-pipeline interaction, and the numerical model of the parallel pipeline is established. It is used to analyze the stress, strain and displacement of pipeline under the action of excavation and the effect of pipeline parameters and foundation pit parameters.

2. Numerical model

The buried pipeline under the stress by the action of excavation is complex. It involves material nonlinear and contact nonlinear, routine theoretical method is difficult to analyze stress and deformation of the pipeline. Furthermore, the soil-pipeline interaction has obvious effect on the mechanics of the pipeline. Therefore, the numerical simulation can be used to solve the problem of buried pipeline by using ABAQUS.

The numerical results are analyzed for X65 steel pipelines. It is a common steel material for gas and oil pipeline applications [2]. The density $\rho =$ 7800 kg/m^3, the Young's modulus of steel material is 210 GPa, Poisson's ratio is 0.3, the yield stress is 448.5 MPa, the pipeline diameter $D = 660$ mm, the pipeline wall thickness $t = 8$ mm [1], the buried depth of pipeline is 2 m, the distance between pipeline and foundation pit is 4 m [10]. The mechanical behavior of soil material is described through an elastic-perfectly plastic Mohr-Coulomb constitutive model [11], the density of soil $\rho = 1980$ kg/m^3, the elastic modulus $E = 25$ MPa, the Poisson's ratio $\mu = 0.3$, the cohesion $c = 22$ kPa, the frictional angle $\phi = 15°$ [10].The interface between the pipeline and the soil are simulated with a contact algorithm, which allows separation of the pipeline and soil, and the friction coefficient is 0.3 [13]. Eight-node reduced-integration elements are used to simulate the soil, and mesh of pipeline's location region is refined. The shape of the foundation pit is square, and the size of foundation pit is $30 \times 30 \times 8$ m. The results of previous research show that effect of width is about 3 to 4 times of excavation depth of foundation pit, the effect of the depth is about 2 to 4 times of excavation depth of foundation pit [3]. For the aim of simplifying the calculation, it takes the 1/2 model according to its symmetry [12]. Therefore, the size of entire geometric model is $100 \times 50 \times 40$ m. The entire model is shown in Fig. 1.

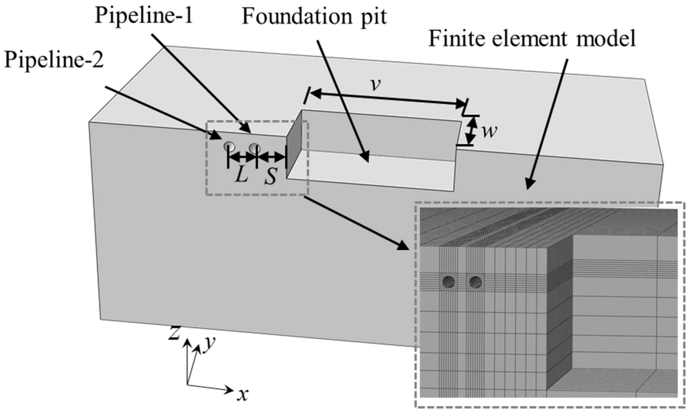

FIG. 1. Schematic diagram of foundation pit.

3. Results analysis

As shown in Fig. 1, the L defined as the parallel distance between pipeline-1 and pipeline-2. When $D/t = 83$, the stress of the pipeline under different parallel distances are shown in Fig. 2. There are two maximum stress areas in pipeline. It is located in the symmetry plane and the edge of the pit. High stress area lies on the upper and lower surfaces of the pipeline. After excavation, the horizontal displacement and the vertical displacement of the pipeline are generated under addition load. The horizontal displacement moves to the internal of the pit, and the vertical displacement moves to the bottom of the pit. The stress of the pipeline-1 and the pipeline-2 change with different parallel distances. With the increasing of the parallel distance, the stress of the pipeline-1 increases, but the stress of the pipeline-2 decreases. This is because when the parallel distance is small, the pipeline-2 will bear part of the additional load of the soil to prevent the soil moving from outside the pipeline to the pit. When the parallel distance

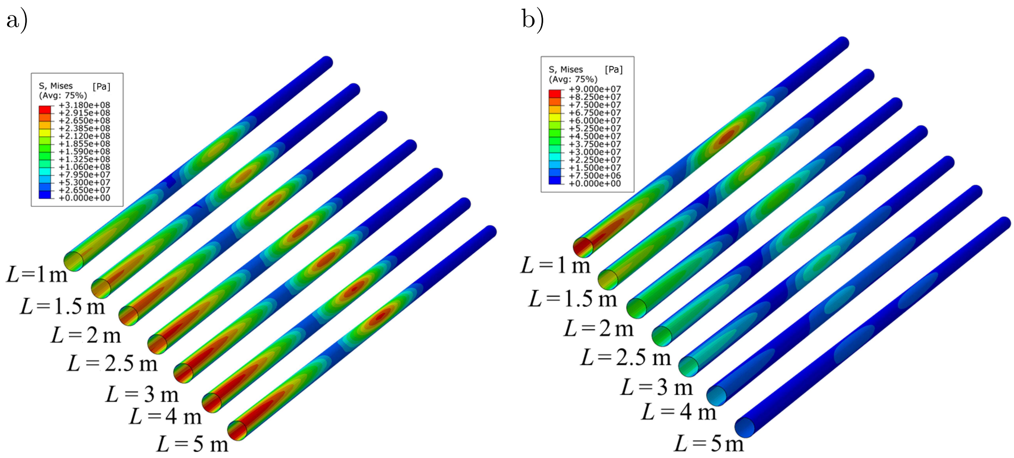

Fig. 2. Stress of the pipeline under different parallel distances: a) pipeline-1, b) pipeline-2.

increases, the pipeline-2 bears small additional load while most is subject to the pipeline-1. Therefore, the pipeline-1 bears major load.

When the parallel distance is 3 m, the difference between parallel pipeline and single pipeline is shown in Fig. 3. When there is only pipeline-1 or pipeline-2, the stress is bigger than the occasion of parallel pipeline. It further indicates that the parallel pipeline can reduce stress of the pipeline.

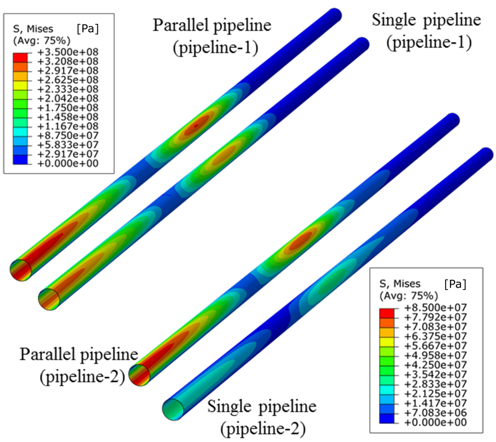

Fig. 3. Difference between parallel pipeline and single pipeline.

Figure 4 shows the axial strain of the pipeline under different parallel distances. The axial strain distribution of the pipeline is the same as the stress of the pipeline. The pipeline has a maximum axial strain at the symmetry plane and at the edge of the foundation pit. And the upper and lower surfaces of the

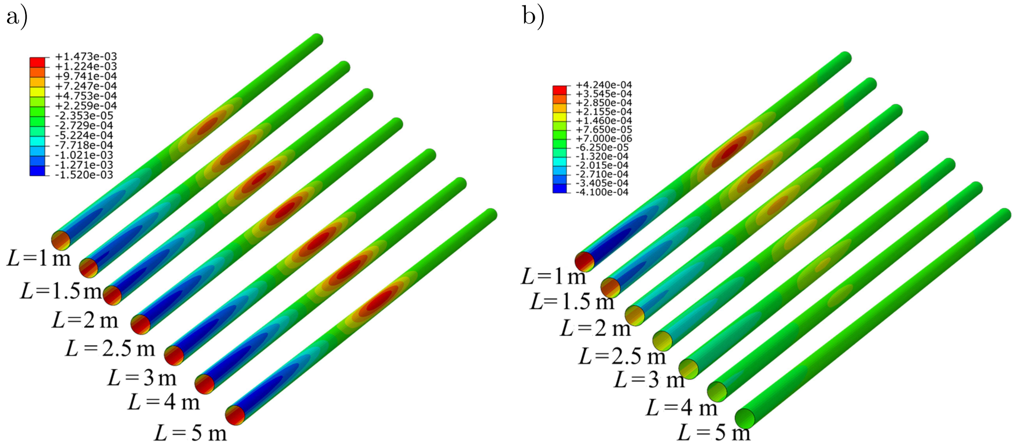

FIG. 4. Axial strain of the pipeline under different parallel distances: a) pipeline-1, b) pipeline-2.

pipeline also have the maximum axial strain. After the excavation of the foundation pit, deformation of the pipeline-1 is more serious than the pipeline-2.

The axial strain curves of the upper surface under different parallel distances are shown in Fig. 5. For both pipeline-1 and pipeline-2, the change rules of curves are the same. The pipeline in the symmetry plane is the negative strain, and the pipeline at the edge of the pit is the positive strain. It shows that the symmetry plane of the pipeline is compressive and at the edge of the pit is in tension. But it is opposite in lower surface. The deformation of the pipeline-1 increases with the increasing of the parallel distance, but the change rate decreases. The change rule of the pipeline-2 is the opposite.

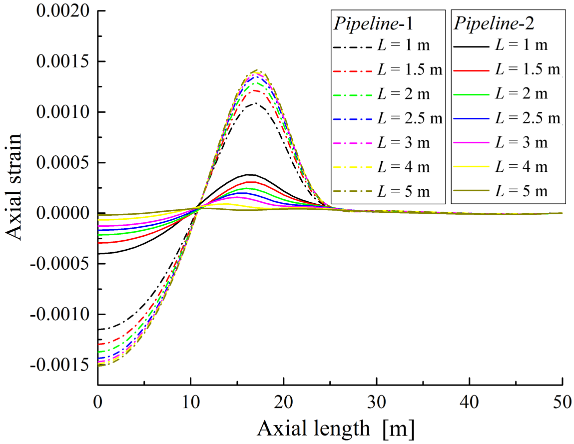

FIG. 5. Axial strain curves of the upper surface under different parallel distances.

4. Analysis of pipeline parameters

4.1. Radius-thickness ratio effect

The radius-thickness ratio of the pipeline affects the stiffness of the pipeline, and affects the stability of the pipeline. When the diameter of the pipeline $D = 660$ mm, and the distance between pipeline-1 and pipeline-2 is 1.5 m, the axial strain of the pipeline under different radius-thickness ratios is shown in Fig. 6. In pipeline-1, the axial strain decreases with the decreasing of the radius-thickness ratio, and the pipeline is more stable. With the increasing of the radius-thickness ratio, the high strain area of the pipeline is spread along the axial direction. The maximum strain of the pipeline-2 is smaller than the pipeline-1, which makes up approximately a quarter of the pipeline-1. And the axial strain decreases with the decreasing of the radius-thickness ratio.

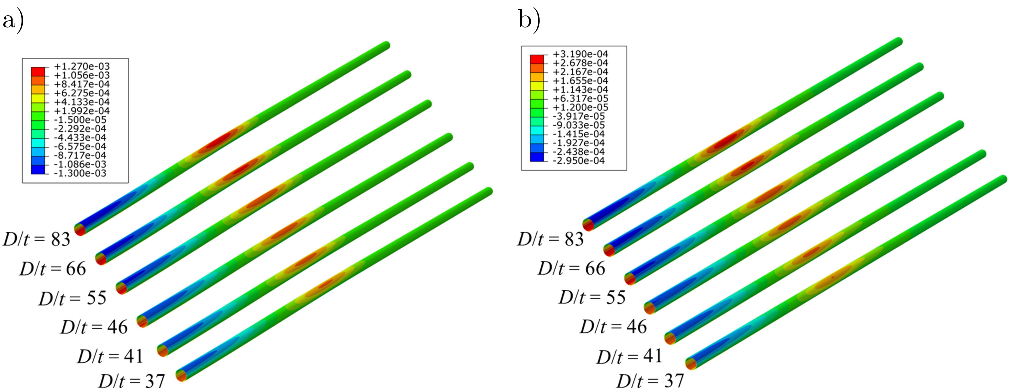

Fig. 6. Axial strain of the pipeline under different radius-thickness ratios: a) pipeline-1, b) pipeline-2.

Figure 7 shows the axial strain curves of the upper surface. With the decreasing of the radius-thickness ratio, the maximum strain of the pipeline-1 decreases, but the change of the maximum strain of the pipeline-2 is small. And the change of the pipeline-1 is more obvious than the pipeline-2.

The displacement of the pipeline under different radius-thickness ratios is shown in Fig. 8. With the decreasing of the radius-thickness ratio, both the horizontal and the vertical displacement of the pipeline increase. And the change of the pipeline-1 is more obvious than the pipeline-2. There is about 10 mm difference between the maximum and the minimum displacement of the pipeline-2. For both pipeline-1 and pipeline-2, the vertical displacement of the pipeline is bigger than the horizontal displacement.

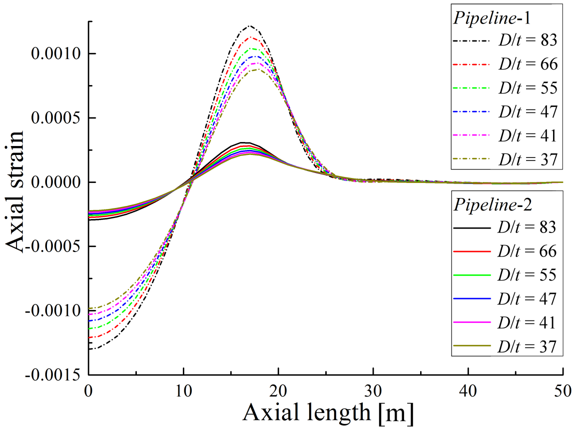

FIG. 7. Axial strain curves of the upper surface under different radius-thickness ratios.

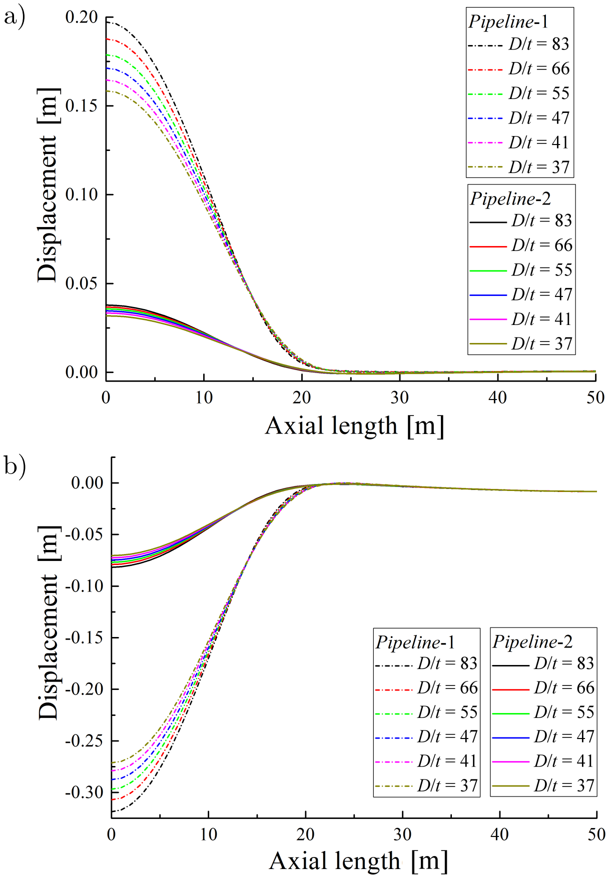

FIG. 8. Displacement of the pipeline under different radius-thickness ratios: a) horizontal displacement (x-direction), b) vertical displacement (z-direction).

4.2. Distance effect

The engineering results show that the excavation of the foundation pit has a certain effect on the surrounding environment. As shown in Fig. 1, the S defined as the distance between pipeline-1 and foundation pit. When the distance between the pipeline-1 and the pipeline-2 is 1.5 m, the radius-thickness ratio is 83, the axial strain of the pipeline under different distances between the pipeline-1 and the foundation pit are shown in Fig. 9. In pipeline-1, the axial strain decreases with the increasing of the distance. When the distance is 8 m, there is no high strain area in the pipeline. With the increasing of the distance, the high strain area is spread along the axial direction. Distribution of the pipeline-2 is basically the same as the pipeline-1.

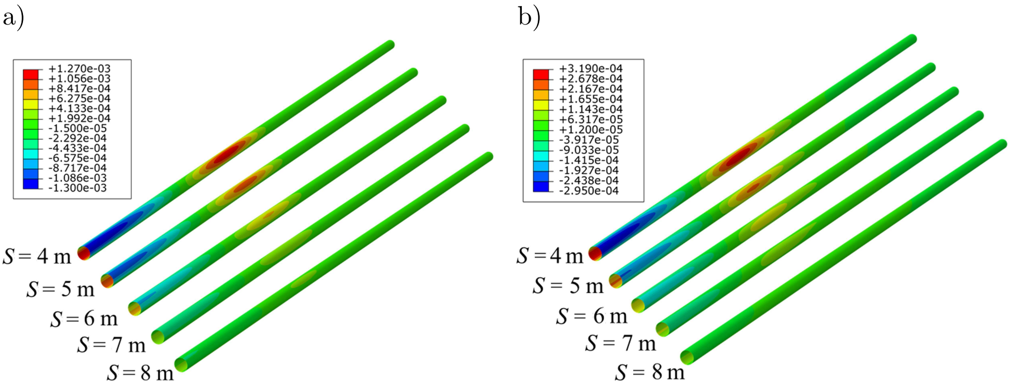

FIG. 9. Axial strain of the pipeline under different distances: a) pipeline-1, b) pipeline-2.

Figure 10 shows the axial strain curves of the upper surface of pipeline. With the increasing of the distance, the maximum strain of the pipeline decreases,

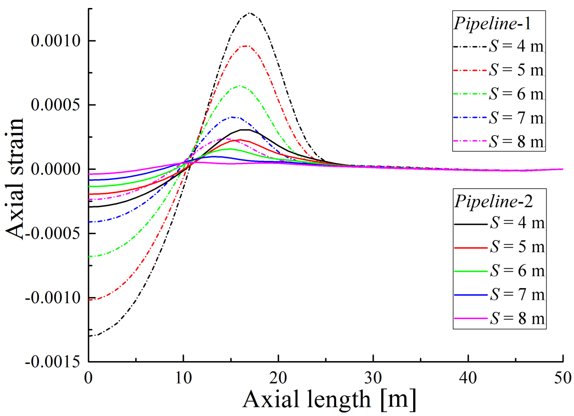

FIG. 10. Axial strain curves of the upper surface under different distances.

and the change rate of the pipeline-1 and the pipeline-2 decreases. When the distance is 8m, the axial strain of the pipeline-2 close to zero. It means that when the distance between the pipeline-1 and the foundation pit is very large, the foundation pit mainly affects the pipeline-1 while the pipelilne-2 is almost unaffected.

The displacement of the pipeline under different distances is shown in Fig. 11. With the increasing of the distance, both the horizontal and the vertical displacement of the pipeline decrease. In pipeline-2, when the distance is 8 m, the horizontal and the vertical displacement of the pipeline is only about 10 mm. The difference between the pipeline-1 and the pipeline-2 is big while the distance is 8 m, but it is small while the distance is 4 m. The results show that the deformation of the buried pipeline with small distance is more serious. Therefore, the construction of the foundation pit should be considered with the nearest distance of the pipeline, so as not to affect the pipeline.

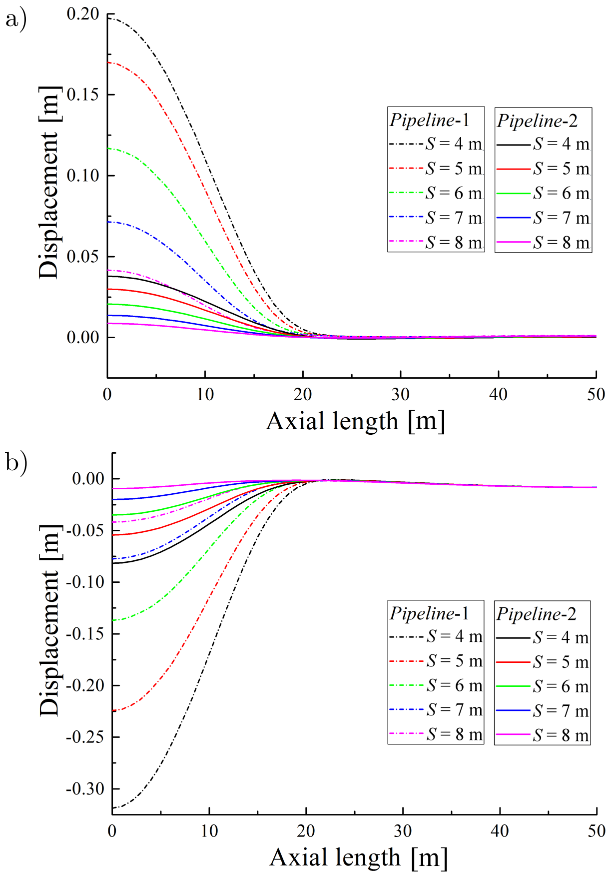

FIG. 11. Displacement of the pipeline under different distances: a) horizontal displacement (x-direction), b) vertical displacement (z-direction).

5. Analysis of pit parameters

5.1. *Pit width effect*

In analytical results, the effect of the foundation pit size on pipeline is also obvious [7]. As shown in Fig. 1, the w defined as the width of the foundation pit. When the length of the foundation pit is 30 m, the axial strain of the pipeline under different widths of the foundation pit are shown in Fig. 12. With the decreasing of the width, the axial strain of the pipeline decreases. The high strain area of the pipeline at the edge of the pit is gradually decreased, and it moves to the symmetry plane of the pipeline at the same time. When the width of the foundation pit is 10 m, both the pipeline-1 and the pipeline-2 have very small axial strain.

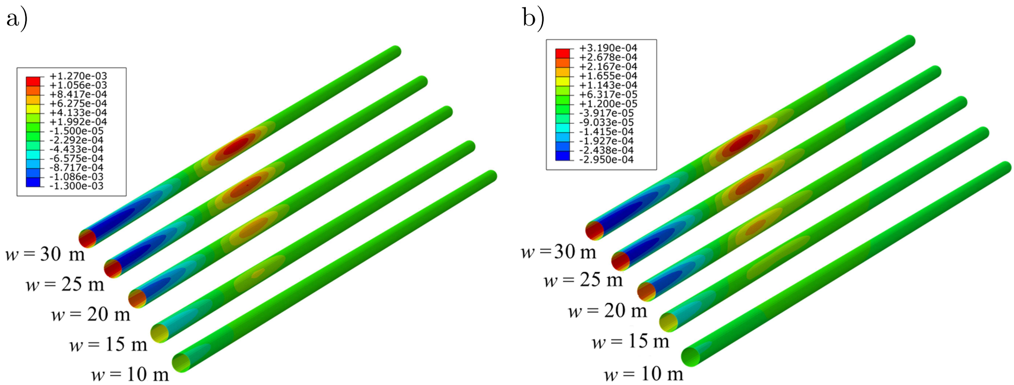

Fig. 12. Axial strain of the pipeline under different widths: a) pipeline-1, b) pipeline-2.

Figure 13 shows the axial strain curves of the upper surface. The axial strain of the pipeline-1 at the width of 10 m is less than the axial strain of the pipeline-2

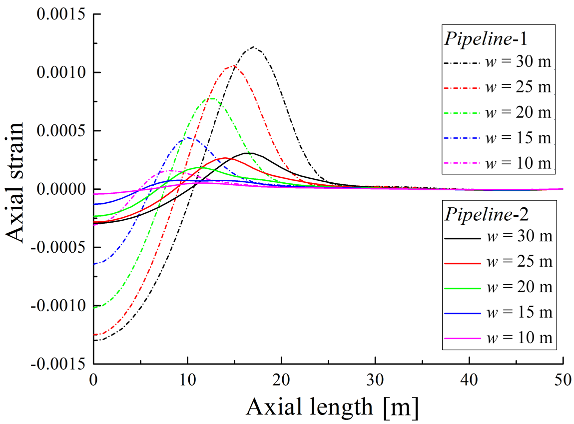

Fig. 13. Axial strain curves of the upper surface under different widths.

at the width of 30 m. And when the width of the foundation pit is 10 m, the axial strain of the pipeline-2 close to zero. It indicates that the width of the foundation pit mainly affects the pipeline-1.

The displacement of the pipeline under different widths is shown in Fig. 14. With the decreasing of the width, the horizontal and the vertical displacement of the pipeline decrease, and the change rate of the pipeline decrease. The position where the pipeline deforms gradually moves to the symmetry plane of the pipeline. When the width of the foundation pit is 10 m, the horizontal and the vertical displacement of the pipeline-1 is less than 20 mm, and the horizontal and the vertical displacement of the pipeline-2 is less than 10 mm. It indicates that small width of the foundation pit has a little effect on the pipeline. The results show that the deformation of the pipeline increases as the width of the foundation pit increases.

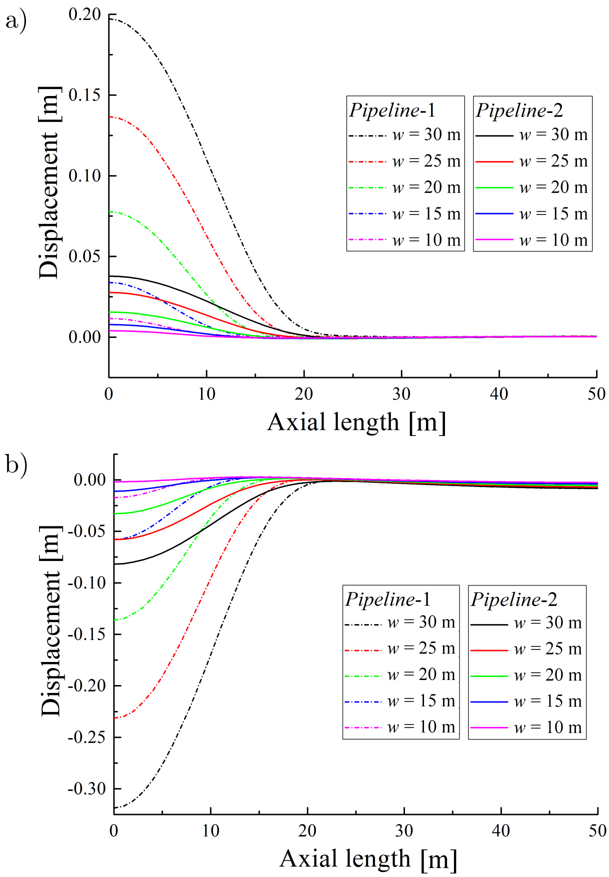

FIG. 14. Displacement of the pipeline under different widths: a) horizontal displacement (x-direction), b) vertical displacement (z-direction).

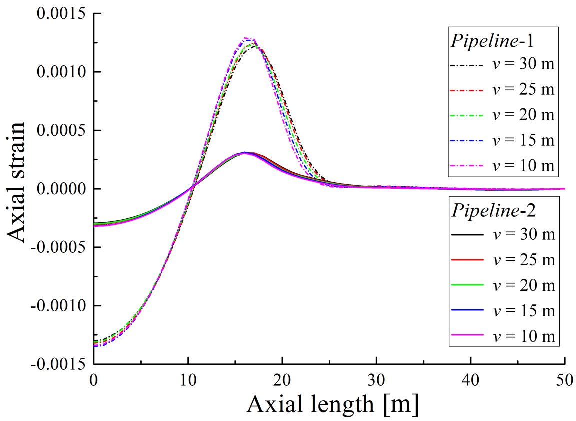

FIG. 15. Axial strain curves of the upper surface under different lengths.

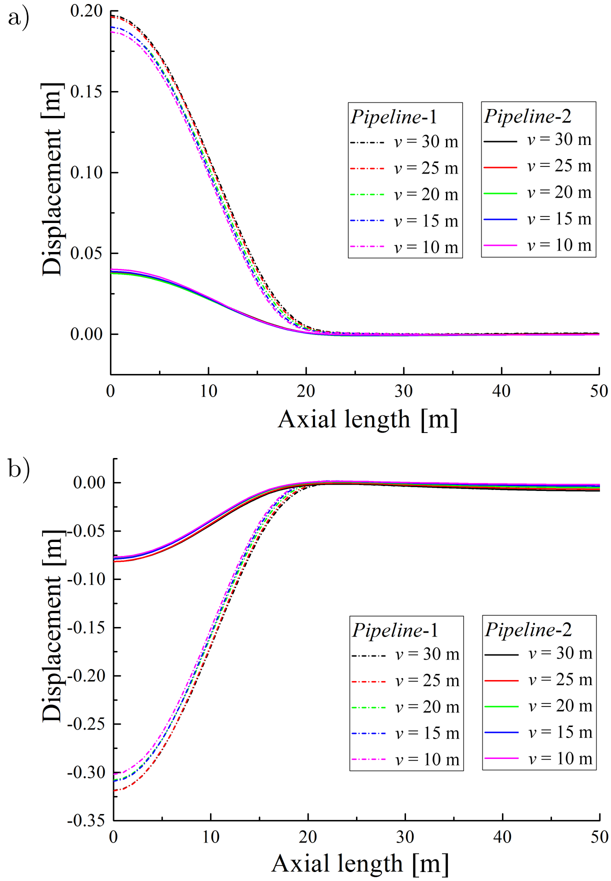

FIG. 16. Displacement under different lengths: a) horizontal displacement (x-direction), b) vertical displacement (z-direction).

5.2. Pit length effect

As shown in Fig. 1, the v defined as the length of the foundation pit. When the width of the foundation pit is 30 m, the axial strain curves of the upper surface under different lengths are shown in Fig. 15. With the decreasing of the length, the change of axial strain of the pipeline is very small. The overall deformation of the pipeline is not obvious.

Figure 16 shows the displacement of the pipeline under different lengths. Likewise, the change of displacement of the pipeline is small. For both pipeline-1 and pipeline-2, the effect of length of the foundation pit on pipeline is not obvious within the range of 10 m to 30 m.

6. Conclusions

Mechanical behavior of the buried parallel pipeline under foundation pit excavation was investigated by the finite element method. Effect of pipeline parameters and foundation pit parameters on the pipeline were discussed which led to following conclusions.

There are two maximum stress areas in pipeline after excavation which located in the symmetry plane and at the edge of the pit. High stress area appears on the upper and lower surfaces of the pipeline. Excavation cause the pipeline's negative strain on the symmetry plane of the upper surface, positive strain on the upper surface at the edge of the pit while the opposite result in lower surface. The horizontal displacement of the pipeline moves to the internal of the pit, and the vertical displacement moves to the bottom of the pit.

With the increasing of the parallel distance, the deformation of the pipeline-1 increases, but the deformation of the pipeline-2 decreases. The pipeline-2 will help the pipeline-1 to bear a partial load. And the stress of parallel pipeline is less than single pipeline.

The deformation of the pipeline decrease as the radius-thickness ratio and distance between the foundation pit and pipeline increase. With the increasing of the width, the deformation of the pipeline increase. But the effect of length of the foundation pit on pipeline is not obvious.

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