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Influence of Tunnel Excavation on Mechanical Properties of Buried Pipeline

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Abstract

Tunnel excavation is one of the most important projects that threaten the safe operations of buried pipeline. The mechanical properties of buried pipeline after tunnel excavation were studied by using the finite element method in this paper. The effect of excavation length, pipeline parameters and tunnel parameters on pipeline were discussed. The results show that after tunnel excavation, the high stress area concentrates in the middle of the pipeline, the maximum von Mises stress appears on the upper surface of pipeline. In the process of excavation, with the increasing of the excavation length, the stress of pipeline increases, while the horizontal displacement of pipeline decreases, but the vertical displacement of pipeline increases. The maximum von Mises stress and deformation of pipeline increase with the increasing of the radius-thickness ratio, buried depth and diameter of tunnel, but decrease with the increasing of the internal pressure and lining thickness.

Keywords

buried steel pipeline; tunnel excavation; numerical simulation; von Mises stress; displacement.

1. Introduction

As an economical and reliable means of transmission, the structural safety and reliability of the pipeline are becoming increasingly prominent and widely concerned. Buried pipelines because of its economic and security advantages has become the main pipeline laying method [1]. The buried pipeline is contacted with rock and soil, so it is greatly affected by stratum. Especially in recent years, more and more underground engineering constructions will cause the irregular disturbance of surrounding stratum. One of the most common is the effect of underground tunnel excavation on the pipeline. Tunnel excavation leads to the release of geostatic stress, resulting in the displacement of the soil in the upper part of the excavation area. It will cause the uneven settlement of the buried pipeline, seriously even affect the normal use of the pipeline. Therefore, studying on the effects of tunnel excavation on mechanical properties of buried pipelines has very important practical significance.

Nowadays, many scholars have researched the effect of tunnel excavation on buried pipeline. For example, Liu [2] studied the influence of tunnel construction on adjacent pipeline based on 2-D FEM. Zhang [3] suggests a continuous elastic method of evaluating adjacent tunnelling effects on existing pipelines in multi-layered soils. Klar [4] analyzed the problem of tunnelling effect on existing pipeline by two different theories to represent the pipeline: The Euler-Bernoulli simple beam theory and shell element theory. Zhang [5] presented a simplified displacement controlled two-stage method and stress-controlled two-stage method using Winkler foundation model for determining the mechanical behavior of buried pipelines induced by underground excavation in soft clays. Bi [6] established the three-dimensional to simulate the effect of tunnel excavation on underground pipeline by using FEM software

ABAQUS, and different buried depths, material properties, and stiffnesses of subjacent bed were considered.

But most of them did not consider the deformation regulation of pipeline in the process of tunnel excavation. Meanwhile, the pipeline was treated as a beam, and assumed that the pipeline is in close contact with the soil. This is different with the actual project. In fact, the difference between the stiffness of the pipeline and the soil is large, some separation will occur during the process of deformation. In addition, pipeline is a thin shell structure, and there may be residual stress and stress concentration during the excavation [7]. So, the finite element model is more suitable than the analytical model. Therefore, a coupling finite element model of pipeline and soil were built to study the mechanical properties of the buried pipeline affected by tunnel excavation. Moreover, effects of the parameters of pipeline and the parameters of tunnel were also discussed. The result of the research can provide a reliable reference for buried pipeline and tunnel.

2. Numerical Simulation Model

In order to analyze the mechanical properties of the buried pipeline, a soil-pipeline coupling model was established based on finite element model. The model consists of tunnel, pipeline, lining and surrounding soil.

The whole is much bigger than the tunnel because the end-effect needs to be eliminated. The size of the whole model is 50m×20m×30m. The tunnel section is circular, the diameter of tunnel D=7m, the axis of tunnel is 15m from the surface. The diameter of pipeline d=660mm, the thickness of pipeline t=8mm, and the buried depth H=4m. The pipeline is perpendicular to the excavation direction of the tunnel. The thickness of lining r=0.2m. Eight-node reduced-integration elements are used for modelling the soil and pipeline. In order to improve the accuracy of the calculation, the areas near the buried pipeline have to be refined. The model is shown in Fig.1. The x direction is the axis of the pipeline, the y direction is horizontal, the z direction is vertical.

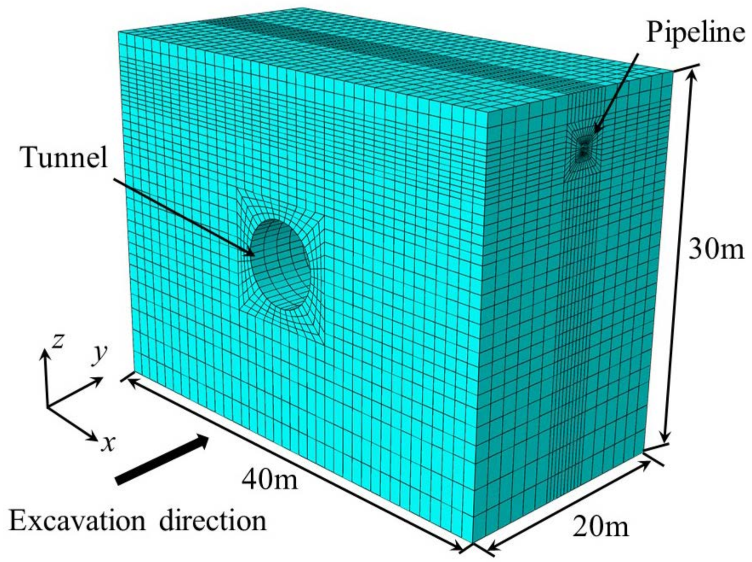

Fig.1 Finite element model

Take X65 pipeline as an example to analyze the mechanical properties, which is widely used in gas transmission. The density of pipeline ρ=7800kg/m^3, the elastic modulus of steel material E=210GPa, the Poisson's ratio μ=0.3, and the yield strength is 448MPa. With the development of civil engineering research, there are many constitutive models for

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geotechnical soils, in this paper, the mechanical behaviour of the soil material chosen by elastic-perfectly plastic Mohr-Coulomb constitutive model, so the yield criterion:

$$(\sigma_1-\sigma_3)=2c\cos\phi-(\sigma_1+\sigma_3)\sin\phi$$

Where σ_1 is the maximum principal stress; σ_3 is the minimum stress; c is the cohesion of soil; ϕ is the internal friction angel of soil [8]. The material of lining is the concrete, the density ρ=2500kg/m^3, the elastic modulus E=28GPa, and the Poisson's ratio μ=0.2. The physical parameters of the soil are shown in Table 1.

Table 1: Physical parameters of the soil [9].

Soil	ρ(kg/m^3)	E(MPa)	μ	c(kPa)	ϕ(°)	Thickness(m)
1	1860	15	0.35	12	15	6
2	1930	25	0.3	20	22	18
3	2060	60	0.24	40	26	6

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. Every surface of the whole model is the normal constraint except the top surface. Because the working conditions and interaction between the pipeline and the soil are very complex, it is necessary to make the following assumptions for the whole model: The pipeline is straight and does not take into account the effects of the joints; The soil is isotropic, homogeneous and continuous which not mixed with sand and gravel, regardless of the impact of groundwater.

3. Results and Analysis

When the buried depth of pipeline is 2m, and the wall thickness of pipeline is 8mm, the von Mises stress distributions of pipeline during tunnel excavation are shown in Fig.2. In the process of excavation, the maximum von Mises stress appears on the upper surface of pipeline. The high stress area in the process of pipeline deformation is mainly concentrated in the middle of the pipeline, that is, the position of x = 20m. At the same time, there are high stress areas on both sides of the pipeline, but it much less than the stress in the middle of the pipeline. The maximum von Mises stress increases with the increasing of the excavation length, and the high stress area extends along the pipeline's axial direction. When the excavation length is 16m and 20m, the stress of pipeline is basically unchanged, it indicating that the deformation of pipeline has ended.

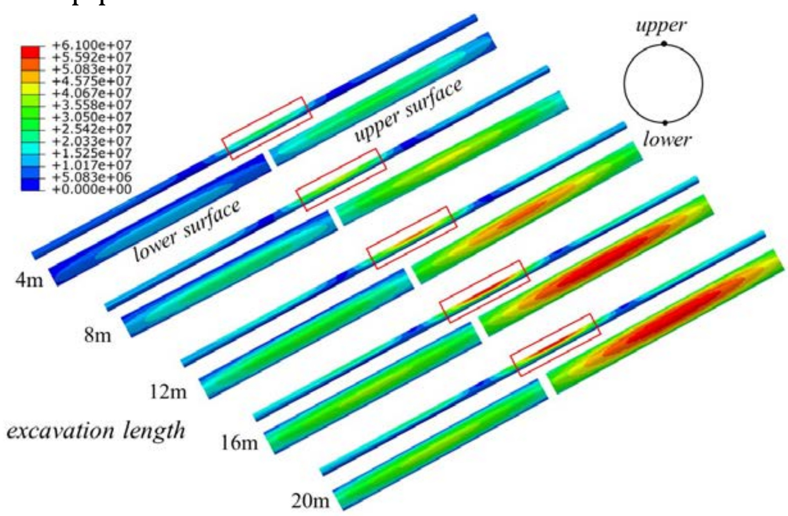
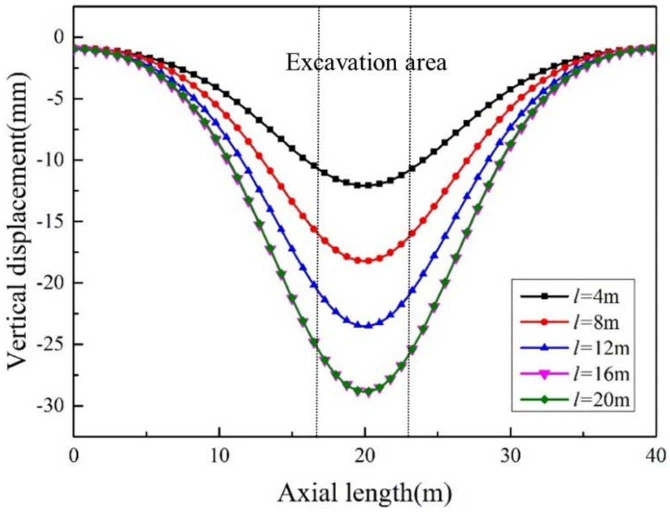


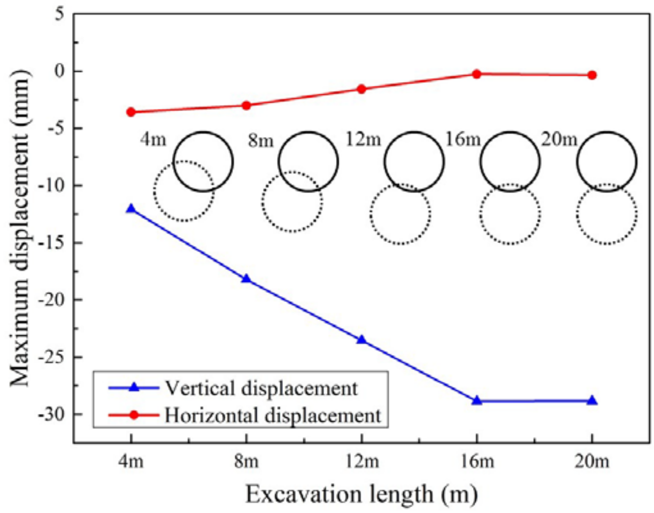
Fig.2 Von Mises stress distribution of pipeline after tunnel excavation

Fig.3 shows the displacement curves of pipeline with different excavation lengths. As shown in Fig.3(a), when the excavation length is 4m, pipeline already has vertical displacement. Then the vertical displacement gradually increases. The maximum vertical displacement is in the middle of pipeline, it corresponds to maximum stress. When the excavation length is 16m and 20m, the displacement curves of the pipeline is basically coincident.

In Fig.3(b), The pipeline has horizontal displacement and vertical displacement during excavation, and the vertical displacement is much larger than the horizontal displacement. When the excavation length is 4m, the pipeline has produced horizontal and vertical displacement. With the increasing of the excavation length, the horizontal displacement decreases, but the vertical displacement increases, both are approximately linearly changed. When the excavation length is greater than 16m, the pipeline is basically no longer deformed.



(a) Vertical displacement



(b) Maximum displacement

Fig.3 Displacement of pipeline after tunnel excavation

4. Effect of the Tunnel Parameters

4.1. Diameter of Tunnel

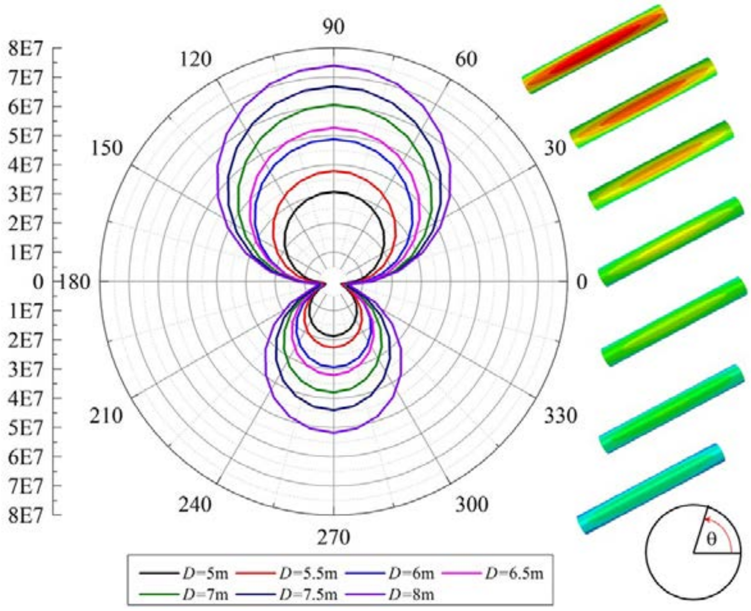
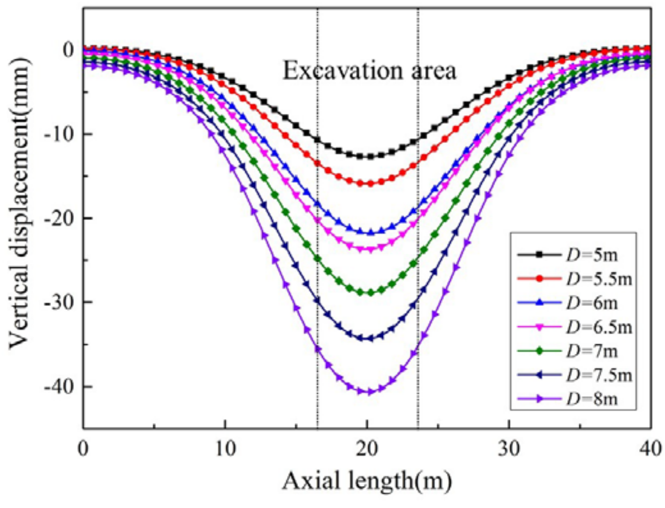
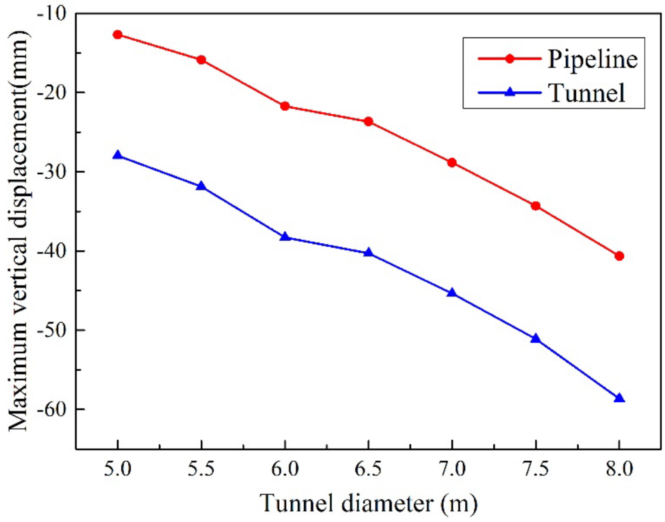


Fig.4 Von Mises stress of pipeline with different diameters of tunnel

In the actual project the tunnel will have different diameters, when the buried depth of pipeline is 4m, the axis of tunnel is 15m from the surface, the von Mises stress in the cross section of the middle of pipeline with different diameters of tunnel is shown in Fig9. With the increasing of the diameter of tunnel, the stress of upper surface and lower surface of pipeline increases. The change of stress on the upper surface of the pipeline is about 43MPa, but the change of stress on the lower surface is only 33MPa. Therefore, the actual size of the tunnel should be considered in order to avoid the effect on the pipeline.



(a) Vertical displacement



(b) Maximum vertical displacement

Fig.5 Displacement of pipeline with different diameters of tunnel

The displacement curves of pipeline with different diameters of tunnel are shown in Fig.5. In Fig.5(a), with the increasing of the diameter of tunnel, the vertical displacement of pipeline increases. and the displacement width is significantly increased. Because the diameter of tunnel will affect the deformation range of soil, and further affecting the deformation range of pipeline. In Fig.5(b), with the increasing of the diameters of tunnel, the maximum vertical displacement of pipeline increases, and the maximum vertical displacement of tunnel vault increases. The change rate of curves is getting bigger and bigger with diameter of tunnel.

4.2. Lining Thickness of Tunnel

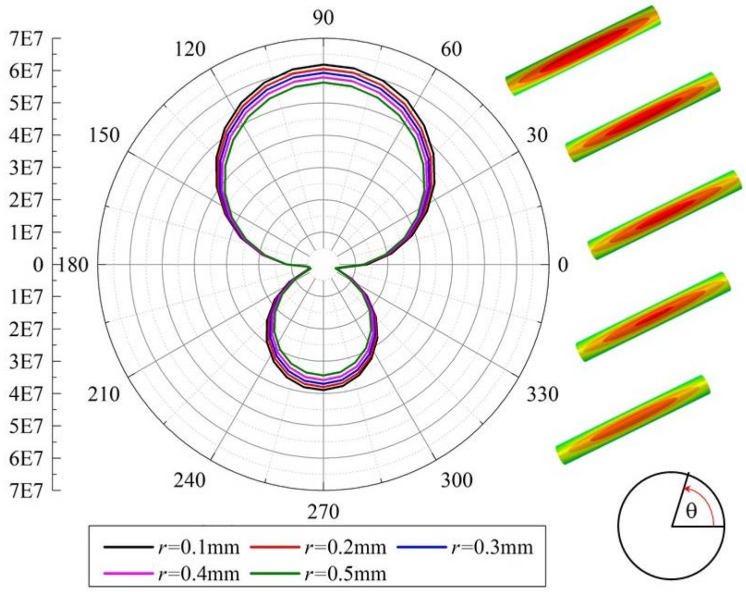
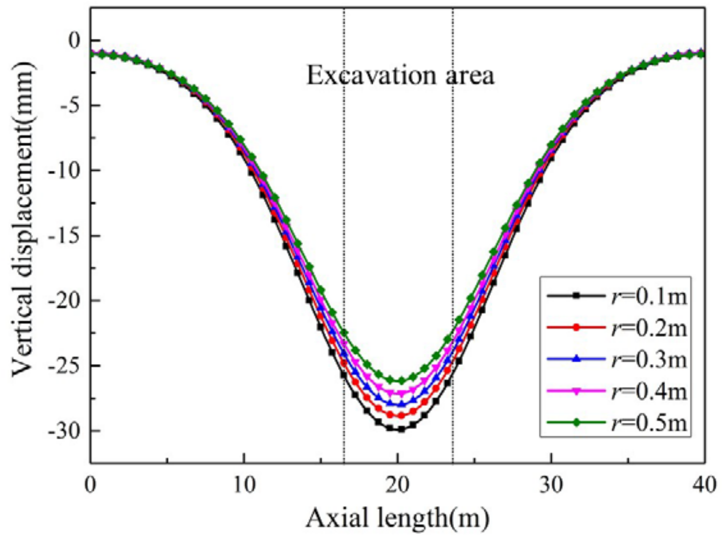
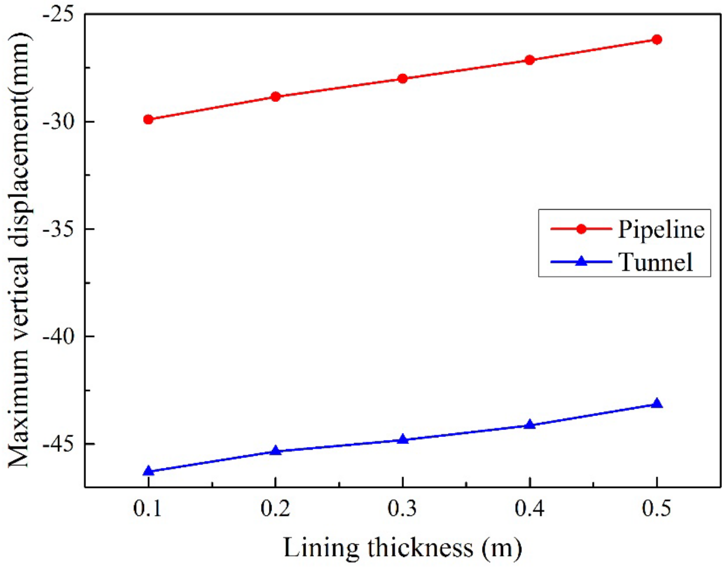


Fig.6 Von Mises stress of pipeline with different lining thickness of tunnel

When the diameter of tunnel is 7m, the von Mises stress in the cross section of the middle of pipeline with different lining thickness of tunnel is shown in Fig6. With the increasing of the lining thickness, the stress of upper surface and lower surface of pipeline decreases. The change of stress on the upper surface and lower surface of pipeline is about 5MPa. It can be seen that thick lining can protect the pipeline to some extent.



(a) Vertical displacement



(b) Maximum vertical displacement

Fig.7 Displacement of pipeline with different lining thickness of tunnel

The displacement curves of pipeline with different lining thickness of tunnel are shown in Fig.7. In Fig.7(a), with the increasing of lining thickness of tunnel, the vertical displacement of pipeline decreases. and the displacement width is decreased. In Fig.7(b), with the increasing of lining thickness of tunnel, the maximum vertical displacement of pipeline decreases gradually, and the maximum vertical displacement of tunnel vault decreases, and the change rate is basically the same.

5. Conclusion

Mechanical properties of buried pipeline under tunnel excavation were investigated. Effect of excavation length, pipeline parameters and tunnel parameters on the buried pipeline were discussed which led to the following conclusions:

(1) After excavation, the high stress area is concentrated in the middle of the pipeline, the maximum von Mises stress appears on the upper surface of pipeline.

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(2) In the process of excavation, with the increasing of the excavation length, the stress of pipeline increases, the horizontal displacement of pipeline decreases and the vertical displacement of pipeline increases.

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